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Baseline Investigations into the Groundwater Resources of the Athabasca Oil Sands (In Situ) Area, Northeast Alberta

Alberta Energy and Utilities Board
Alberta Geological Survey

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Special Report 98

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Foreword

This Special Report is a compilation of the results and interpretations of the geological and hydrogeological setting of the Athabasca Oil Sands Area, as submitted to the Federal Ministry of Western Economic Diversification (WED) in 2002. The study was undertaken by the Alberta Geological Survey in 1999–2002 and was funded through the joint Western Economic Partnership Agreement (WEPA) between the Province of Alberta and the Ministry of Western Economic Diversification.

Much of the content of this report has been published previously in a series of Alberta Geological Survey reports that include the following:

1) **Earth Sciences Report 2002-03**: Quaternary Geological Setting of the Athabasca Oil Sands (In Situ) Area, Northeast Alberta http://www.ags.gov.ab.ca/publications/abstracts/ESR_2002_03.html
2) **Geo-Note 2002-01**: Observations of Naturally Occurring Hydrocarbons (Bitumen) in Quaternary Sediments, Athabasca Oil Sands Area and Areas West, Alberta http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_01.html
3) **Geo-Note 2002-02**: Geochemical and Isotope Data for Formation Water from Selected Wells, Cretaceous to Quaternary Succession, Athabasca Oil Sands (In Situ) Area, Alberta http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_02.html
4) **Geo-Note 2002-03**: Carbon-14 Dating of Groundwater from Selected Wells in Quaternary and Quaternary-Tertiary Sediments, Athabasca Oil Sands (In Situ) Area, Alberta http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_03.html
5) **Geo-Note 2002-04**: Arsenic Concentrations in Quaternary Drift and Quaternary-Tertiary Buried Channel Aquifers in the Athabasca Oil Sands (In Situ) Area, Alberta http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_04.html
6) **Geo-Note 2002-06**: Baseline Discharge and Geochemistry of the Wiau Channel Springs, 1999 - 2001, Athabasca Oil Sands (in situ) Area, Alberta http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_06.html
7) **Geo-Note 2002-08**: Static Water Levels and Completion Details of Nested Piezometers in the Quaternary-Tertiary(?) Succession, Athabasca Oil Sands (In Situ) Area, Alberta http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_08.html
8) **Geo-Note 2002-09**: Sampling of Surface Water and Spring Water in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 - A Compilation of Protocols and Methods http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_09.html
9) **Geo-Note 2002-10**: Sampling of Groundwater from Wells in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 - A Compilation of Protocols and Methods http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_10.html
10) **Geo-Note 2002-11**: Sampling of Formation Water from Wells in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 - A Compilation of Protocols and Methods http://www.ags.gov.ab.ca/publications/abstracts/GEO_2002_11.html

The purposes of this report are as follows:

1) To provide a regional assessment of the geology and hydrogeology of groundwater resources in the Athabasca Oil Sands (In Situ) Area to assist regulators and operators in addressing challenges pertaining to groundwater supply, groundwater protection, and waste disposal in the oil sands industry. In part, this report updates previous work reported on by Hackbarth and Nastasa (1979), which focused mainly on the surface-mineable areas north of Fort McMurray, and the report of Bachu et al. (1993), which considered the area only as a small component of the basin-scale hydrogeological study. It also marks an effort to update the regional hydrogeology reconnaissance report of Ozaray (1974), reflecting the substantial changes in both geological and hydrogeological concepts since then.

2) To document baseline hydrogeological and hydrogeochemical conditions at selected locations and in selected geological formations in advance of large-scale oil-sands industrial expansion. Because of the size of the area and its geological complexity, a comprehensive record of representative baseline conditions everywhere would be impossible to do. The locations selected for baseline observations were chosen on the basis of access as well as regional geological and hydrogeological significance. Areas where oil-sands operations are expected to develop in the near future were not targeted because the baseline conditions in these areas are the subject of an environmental impact assessment (EIA). EIAs are commonly submitted to regulators in support of approvals for industrial development.

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- Louise Leslie of Geo-Environmental Ltd. interpreted the aerial photographs for the preparation of the terrain analysis maps.
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- Ilona Ranger interpreted the petrophysical logs for the construction of the bedrock topography maps and drift stratigraphy, as well as developed a stratigraphic database.
- McAuley Drilling conducted the drilling and coring of the Quaternary drift.
- Layne Christensen Canada Limited provided drilling and coring services, and down-hole petrophysical logs.
- David Sim of Electrolog Services Inc. conducted the downhole petrophysical logs in core holes.
- Elk Point Drilling conducted the drilling and installation of the water-well piezometers.
- Becquerel Laboratories Inc. performed the geochemical analyses of the Quaternary sediment samples.

- Norwest Labs conducted the standard chemical analyses on water samples as well as hydrocarbon analysis on Quaternary sediments
- The University of Calgary‘s stable isotope laboratory performed the isotope analyses of O, H, C and S.
- Dr. M. Wieser of the University of Calgary did the stable isotope analyses of B.
- Dr J. Duke of the University of Alberta’s SLOWPOKE Nuclear Reactor Facility performed the NAA for I, B, Cl and did the radionuclide analyses.
- The University of Saskatchewan’s isotope laboratory did the isotope analyses of Sr.
- The University of Waterloo did the preparatory work for the C-14 analyses and did the C-13 analyses of those 5 samples.
- The University of Toronto's IsoTrace laboratory performed C-14 analyses.
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Abstract

This technical report summarizes the work done by the Alberta Geological Survey on the WEPA-funded project (# APEZ00011) to conduct baseline investigations into the groundwater resources of the Athabasca Oil Sands (In Situ) Area of northeast Alberta. The report consists of two parts: Volume 1, which comprises 10 chapters of interpretations and results, and Volume 2, which consists of 8 appendices of data and other types of background information.

Chapter 1 of Volume 1 discusses the important role that groundwater plays in the development of oil sands in northern Alberta. It addresses water and waste balances in steam-enhanced recovery methods such as SAGD, and discusses the challenges that the industry faces pertaining to groundwater availability, groundwater protection, and wastewater and solid waste disposal.

Chapter 2 presents a conceptual framework for groundwater resource assessments. It provides the reader with a basic understanding of groundwater flow, both at the local scale of a well and at a regional scale, and discusses the concepts of sustainability and resource development, groundwater as a non-renewable resource, waste-water injection and storage capacity of groundwater basins.

Chapter 3 sets the physical stage for the study by discussing the major topographic and physiographic features that influence groundwater recharge and discharge in the region.

Chapter 4 discusses the approaches used to evaluate the inputs (recharge) and outputs (discharge) of groundwater flow. It discusses the general hydrological setting of the study area, the application of remote sensing such as RADARSAT to map recharge and discharge, differences in baseline chemistry and discharge from groundwater springs, and the behaviour of recharge as determined from water-table fluctuations in monitoring wells.

Chapter 5 presents the results of a terrain analysis of the surficial geology, as determined by an aerial photograph interpretation of the landscape. It looks at the nature and distribution of the surficial geological materials, relief of landforms, and particularly the distribution of wetlands (organic deposits) as potential indicators of groundwater recharge and discharge.

Chapters 6 and 7 discuss the bedrock topography and geology of the unconsolidated drift (Quaternary sediments) that lies above the bedrock surface in the study area. Chapter 6 highlights the occurrence, distribution and properties of buried bedrock channels that contain thick deposits of coarse fluvial sediment. Chapter 7 discusses the methods used to construct the Quaternary stratigraphy, and presents the results of 7 test holes that cored the drift sediments. A series of structure contour and isopach maps are provided to illustrate the subsurface distribution of major Tertiary/Quaternary sand and gravel deposits that constitute one of the largest drift aquifers in the Western Canadian Sedimentary Basin. Chapter 7 concludes with a discussion of the role that buried channels and channel aquifers play in the development of oil sands.

Chapter 8 presents the results of the investigation into the groundwater of the drift (Quaternary) succession. It includes a discussion of the results from AGS' well installations, the geochemistry and isotope characteristics of drift waters, and a characterization of groundwater resources according to subsurface geographic domains.

Chapter 9 presents the results of the investigation into deeper hydrostratigraphic horizons, specifically the water within the Upper Mannville Group. The chapter begins with a discussion of the stratigraphic framework of the Upper Mannville Group, developed through the concept of sequence stratigraphy. It portrays the results of the permeable units through a moment-statistic analysis, and a series of slice

maps that delineate the Upper Mannville aquifers. Lastly, the chapter concludes with a discussion of the geochemistry of the formation water.

Chapter 10 is a brief discussion of the groundwater issues specific to the major oil sands unit in the study area, the McMurray Formation.

Volume II incorporates geological and hydrogeological data, methods, procedures and protocols, and other supplementary reports within 8 appendices.

1 Introduction

1.1 Opening Remarks

The Athabasca and Cold Lake oil-sand deposits are located in northeast Alberta, Canada (Figure 1.1). Oil sands are naturally occurring deposits of bitumen, defined as a viscous mixture consisting mainly of hydrocarbons of atomic weight greater than pentane, and which in its naturally occurring viscous state will not flow to a well. The bitumen is hosted in semi-consolidated sands of Cretaceous age as well as in underlying karsted limestones of Devonian age. Table 1.1 shows conservative estimates of recoverable bitumen volumes in place by area and compares their size to other world-class hydrocarbon deposits.

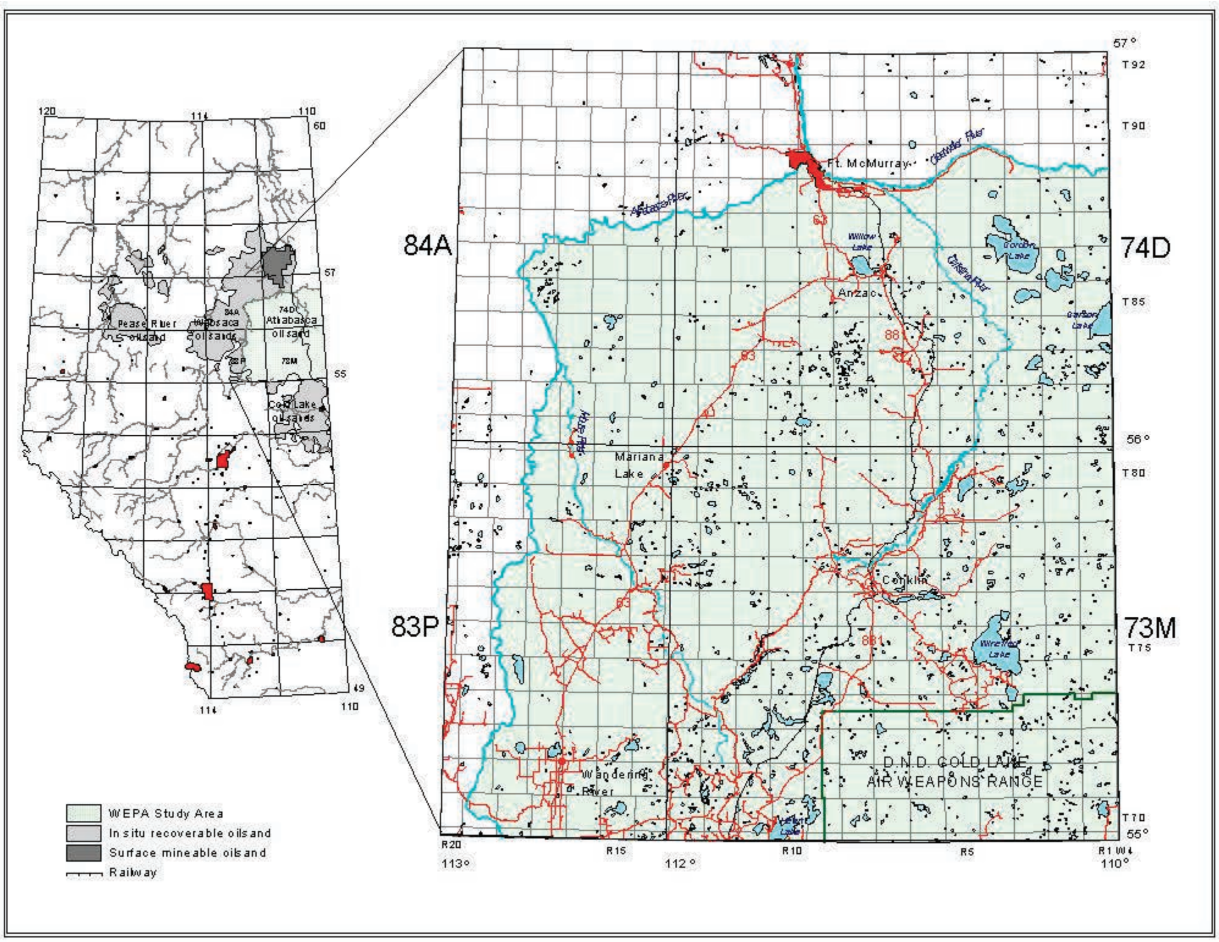

Figure 1.1. Location of study area.

Commercial development of the oil sands began in the 1940s and accelerated after the 1960s. Initial commercial development focused on extraction of bitumen from surface mineable deposits, leading to the construction of the Syncrude and Suncor mines north of Fort McMurray, Alberta. Commercial application of in-situ recovery techniques using injected steam began in the Cold Lake area the 1970s, most notably at the Imperial Oil Cold Lake Project. Breakthroughs in horizontal well technology and changes in the provincial royalty regime during the 1990s brought more of the in-situ deposits into the realm of commercially viable extraction. At the present time, there are over 60 approved in-situ schemes and single-well pilots in the Cold Lake Oil Sands area and at least 6 major in-situ projects in the Athabasca Oil Sands Area either under construction or in the regulatory approval process. Butler (2001) provides an overview of several of the major projects. Hein (2000) provides a historical perspective on oil sands development.

Table 1.1. Comparison of EUB-generated reserve estimates for Alberta's oil sands and conventional crude oil in comparison with reported reserves Saudi Arabia and Venezuela.

Deposit	Initial Reserves in Place (10^6 m^3)
Athabasca Area oil sands, northeast Alberta	21 300 (Resource: 206,700)
Cold Lake Area oil sands, northeast Alberta	5 300 (Resource: 32 000)
Peace River Area oil sands, northwest Alberta	1 700
Alberta conventional crude oil	2 500
Saudi Arabia light crude oil only	41 900
Venezuala heavy and extra-heavy oil	11 500

Source: EUB (1996), EUB (2000), and unpublished internal EUB reports

1.2 Water and Waste Balances in SAGD Projects

The key to in-situ extraction of bitumen is the delivery of heat to the bitumen to reduce its viscosity so that it flows to wells. The heating agent employed in most schemes is steam. Presently, the most favoured in-situ technology is steam-assisted gravity drainage, or SAGD. In SAGD, vertically parallel pairs of horizontal wells are completed in a bitumen reservoir. The wells are vertically offset by about 5 m. At start-up, steam generated in a surface plant is injected continuously into both wells creating an ever-expanding envelope of steam called the steam chamber. Once pressure communication is established between the wells, the lower well is converted to a production well, drawing out bitumen and water that drain down from the steam chamber under gravity. On the outside surface of the steam chamber, the steam encounters cold bitumen and condenses. Some of the latent heat is transferred to the bitumen, reducing its viscosity to the point where it can flow under gravity. Production is maintained by the continual expansion of the steam chamber into untapped, cold parts of the reservoir.

1.2.1 Water Inputs and Consumptive Losses

Water is both a key input and a key output in SAGD operations. Consequently, water management is a considerable part of any SAGD project and by extension, regulation of the in-situ oil sands industry. Butler (2001) states

> "commercial operations are extremely sensitive to water balances".

The biggest factor determining water requirements in a SAGD operation lies in the choice of water recycling technology and the chemical quality of the produced water (M. Dmytriw, pers. comm). The economics of a SAGD operation depend in large part upon the quality of the steam injected into the reservoir. The higher the quality of steam, the greater its latent heat content and the more heat that can be delivered to the bitumen. High quality steam requires high quality boiler feed (e.g., Table 1.2). If the

Table 1.2. An example of preferred chemical composition of boiler feedstock water.

Chemical Constituent	Preferred Maximum Concentration
Total Dissolved Solids	< 8000
Hardness	< 1 mg/l
Iron	<0.25 mg/l
Extractable silica	< 30 mg/l
Manganese	negligible
Barium	negligible
Sulfur	negligible
Dissolved oxygen	negligible
Chloride	negligible
Oil	< 0.5 mg/l
PH	7.5 - 9.0

Source: M. Dmytriw, pers.comm.

boiler feed is to include recycled produced water, then treatment will be required to bring its chemical quality in line with the steam-plant specifications. Under most treatment schemes, fresher make-up water will be needed to meet steam requirements. The fresher make-up water can be surface water, fresh groundwater or brackish groundwater – the regulatory boundary between the latter two being defined as a TDS content of 4,000 mg/l. In existing and proposed operations, most of the make-up water will be groundwater and not surface water. Treatment-related water consumption, loss, and disposal are large variables in SAGD water balances.

The EUB supports the use of produced water recycling and the use of brackish water in all in-situ operations. Two of the key ratios considered in regulatory review of in-situ operations are the recycle rate and the water-management ratio (Table 1.3).

In the ideal case, the produced water recycle ratio should approach unity and the water-management ratio should be as high as possible. If brackish water is available, the formulations are altered to give credit for its use over the use of fresh groundwater. Inputs for these calculations are found in applications for thermal projects submitted to the EUB and tracked through the production accounting system under EUB Guide S-18 (EUB, 1989).

As the water-management ratio increases, less make-up water is required and less produced water requires disposal.

The second biggest factor in determining water consumption in a SAGD operation lies in the steaming schedule and water-management strategy. In a simple SAGD operation employing a single well pair, once the start-up phase is complete, the amount of make-up water will decline as more produced water is recycled. Steaming will be relatively continuous except for plant shut-downs, work-overs, etc. In

Table 1.3. Key water-balance ratios used by EUB to assess in-situ plants.

Key Ratio	Formulation without brackish make-up water use	Formulation with credit for use of brackish make-up water
Produced Water Recycle Ratio	V_{ip} / V_p	$(V_i - V_{if})/V_p$
Water- Management Ratio	V_{ip}/V_i	$(V_i - V_{if})/V_i$
Symbology: V_p = total volume of produced water V_i = total volume of steam (as water) injected V_{ip} = total volume of produced water injected V_{if} = total volume of fresh make-up water injected		

Source: EUB (1989). Dmytriw, pers. comm.

this case, the management strategy is straightforward. But as lower quality reservoir is accessed, the simple SAGD program may have to be altered to include cyclic-steam stimulation (CSS) wells. In CSS, vertical, deviated, or horizontal wells are used to deliver steam under pressures above the least principal component of stress. The formation "fracs" and this allows steam to access parts of the reservoir unavailable to a steam chamber. After a "soak" period, the injector is turned into a producer, and so on in a cycle. In small projects, going to a CSS-type project poses water-management challenges because there are times when the steam is not needed but the boilers cannot be shut down, and times when water is produced in excess of steam requirements, meaning that produced waters must be stored or disposed of. In both cases there is potential for unproductive water consumption. As operations grow larger, there will be opportunities to balance water needs across different parts of the operation in different phases of production, reducing unproductive water consumption or disposal.

The third consumptive use of water in SAGD is formation loss. Formation loss includes voidage replacement within the reservoir. Voidage is defined as that volume of bitumen and produced water removed from the pore spaces that must be replaced by water so that the pore network does not become damaged under the increased effective stress. Unlike conventional waterfloods, where voidage replacement ratios can approach unity, voidage in bitumen recovery projects should be much less than unity. Formation loss also includes steam and heat lost to water-bearing "thief zones" or to surrounding aquifers (so-called "top water" and "bottom water). As lower grade deposits are accessed over time (the best parts of reservoirs always being exploited first), formation losses of the latter sort can be expected to increase.

Overall water consumption in a well-run SAGD operation is expected to be 2-3 m^3 of water (all sources including recycled produced water) for each m^3 of bitumen produced. With effective produced water recycling, it may be possible to reach ratios of less than 1 m^3 of make-up water for each m^3 of bitumen produced, depending on formation loss and other plant losses, including waste-stream requirements. These numbers are very preliminary as there is no history of these operations yet outside of Cold Lake. Of that volume of make-up water required, the EUB supports industry in their efforts to incorporate as much brackish water as possible. Future adoption of novel, solvent-based in-situ techniques may also reduce ultimate water demand.

1.2.2 Water Outputs and Waste-Streams

Even with high-efficiency water recycling, SAGD projects create waste-waters and waste-solids that need disposal. These waste streams may include:

- Produced waters in excess of what can be economically recycled or in excess of steam requirements on any given production day.
- Blowdown, waste-waters, regenerant backwashes, etc. from boilers, treaters, and softeners.
- Lime sludges from treaters and boilers.
- Brine solids from crystallizers if zero-liquid discharge technology employed.
- Produced sand.
- Captured runoff from plant sites.

Almost all of the waste streams will contain hydrocarbons, dissolved solids, or salts at levels that rule out disposal as untreated surface discharges. Consequently, subsurface disposal options are needed. The challenge for each project will be to identify acceptable waste repositories that will minimize the wastes' long-term impacts on the regional environment.

1.3 Issues Relating to Groundwater Development in the Athabasca Oil Sands (In Situ) Areas

There are significant issues arising in the Athabasca Oil Sands (In Situ) Area pertaining to groundwater development for the in-situ projects. These can be generally grouped into three general themes: issues around groundwater availability, groundwater protection, and wastewater and solid-waste disposal. The following list identifies some of the significant hydrogeological challenges that have arisen during application reviews, hearings, and interventions affecting in-situ developments submitted to the Alberta Energy and Utilities Board.

1.3.1 Challenges Pertaining to Groundwater Availability

- For any given project, operators need to establish that aquifers of suitable yield and quality exist as mapped in order to properly design their projects. The locations and yields of the wells need to be known with a high degree of certainty. For regulators, it is equally important that these studies are done well to minimize time and effort in the regulatory approval process.
- For effective stewardship of their operations, oil sands operators need to ensure that the stratigraphic and hydraulic continuity between aquifers proposed for industrial development and aquifers under present or future use by domestic or municipal wells is reasonably well understood. For regulators, this means that predicted effects of industrial use of groundwater on other stakeholders have a reasonable chance of being correct. This knowledge, in turn, will minimize the number of future complaints and reduce the chance of corrective actions.
- For individual projects, operators and regulators need to be satisfied that the strength of any hydraulic coupling between the industrial aquifer and surface-water bodies (lakes, wetlands, streams) is reasonably well understood. In this way, any predicted effects of industrial groundwater use on surface water-bodies have a reasonable chance of being correct, and mitigative measures, if required, will have a reasonable chance of being successful.
- For the entire area, there will be ongoing needs to understand the cumulative effects of large-scale, industrial groundwater use, to ensure that any impacts on the regional water balance will be tolerable, and to ensure that all stakeholder needs are addressed.

- For all projects, it remains a challenge to design regional groundwater-monitoring programs that can distinguish changes in the groundwater system due to development, from those due to natural variation.

1.3.2 Challenges Pertaining to Groundwater Protection

- There is ongoing public concern that either thermal or geo-mechanical effects due to steaming and injection may be releasing naturally occurring contaminants like arsenic in shallow aquifers. Collection of good baseline data and fundamental research into the controls on distribution and mobility of naturally occurring contaminants is an ongoing priority for operators and regulators alike.
- There is an ongoing need for due diligence in the prevention and timely remediation of subsurface spills, leaks, etc. from industrial operations. There is also an ongoing need for careful baseline assessments of natural geochemical conditions at industrial facilities. The need for careful baseline assessments is all the more important in the Athabasca oil sands area because there are known instances of naturally occurring bitumen in shallow tills. It is conceivable that this bitumen exists naturally at some locations at concentrations above regulatory guidelines for industrial sites.
- Regional hydrogeological studies in support of regulatory and industrial expansion in the oil sands areas have noted that total dissolved solids in groundwater tends to increase with depth in southwestward dipping aquifer beds. The potential for redistribution of high-TDS fronts in chemically heterogeneous aquifers due to long-term groundwater pumping, if any, is not well understood. Likewise, the long-term potential, if any, for geochemical change due to leakance from tills or bedrock into aquifers is unknown.
- In high-pressure steam schemes like cyclic-steam stimulation (CSS) or high-pressure SAGD, steam is injected at pressures above the fracturing threshold of the host formations. The collateral triggering of micro-seismic events in non-reservoir units has given rise to public concerns over impacts on shallow aquifers.
- There is an ongoing interest in protecting shallow aquifers from annular flow around wells or poorly abandoned boreholes/wells. This concern has given rise to a variety of other industry and government initiatives in the remediation of casing vent flows and orphan-well sites.

1.3.3 Challenges Pertaining to Wastewater and Solid Waste Disposal

- Proper selection and design of surface waste-storage facilities and landfill sites is challenging in complex glaciated terrain, which includes glacially thrusted areas.
- It is an ongoing challenge to identify potential waste-water injection zones that have sufficient injectivity and storage capacity while simultaneously having little chance of connectivity to shallow subsurface or surface, especially in an area of complex geology that includes incisement by modern river valleys, deeply-scoured glacial channels, buried paleokarst, and salt-collapse features.

1.4 Purpose of this Report

The purposes of this report are:

1) To provide a regional assessment of the geology and hydrogeology of groundwater resources in the Athabasca Oil Sands (In Situ) Area to assist regulators and operators to address challenges pertaining to groundwater supply, groundwater protection, and waste disposal in the oil sands industry. In part, this report updates previous work reported on by Hackbarth and Nastasa (1979), which focused mainly on the surface-mineable areas north of Fort McMurray, and the report of Bachu et al. (1993), which considered the area only as a small component of basinal-scale hydrogeological study. It also marks an effort to update on the regional hydrogeology reconnaissance report of Ozaray (1974), reflecting the substantial changes in both geological and hydrogeological concepts since then.

2) To document baseline hydrogeological and hydrogeochemical conditions at selected locations and in selected geologic formations in advance of large-scale oil-sands industrial expansion. Because of the size of the area and its geological complexity, a comprehensive record of representative baseline conditions everywhere would be impossible to do. The locations selected for baseline observations were chosen on the basis of access as well as regional geological and hydrogeological significance. Areas where oil-sands operations are expected to develop in the near future were not targeted as the baseline conditions in these areas are the subject of the Environmental Impact Assessment (EIA's). EIA's are commonly submitted to regulators in support of approvals for industrial development.

1.5 Areal and Geological Scope of Study

The area of this study is the southeast part of the EUB-designated administrative area known as the Athabasca Oil Sands Area (Figure 1.1). In particular, this study examines that part of the area where commercially significant bitumen deposits are known to exist but are buried too deep to economically mine from surface. Because of the area's probable suitability for bitumen-recovery by in-situ methods like CSS, SAGD, or solvent extraction, for the purpose of this report we have adopted the informal designation of the area as the Athabasca Oil Sands (In Situ) Area, to distinguish it from the surface-mineable area north of Fort McMurray and the bitumen and heavy oil deposits in the EUB-designated Cold Lake Oil Sands Area to the south. Proposals for in-situ recovery projects surrounding the oil-sands mines have somewhat undermined the utility of this informal designation, but the expectation is that the type of work entailed in this report will have to be extended to those areas in the near future.

The area is a sparsely populated part of the province; the major community being the City of Fort McMurray located at the confluence of the Athabasca and Clearwater rivers (Figure 1.1). Provincial Highway 63 links Fort McMurray with smaller villages such as Wandering River and Mariana Lakes located in the southwest part of the area. The only other major transportation corridors are Provincial Secondary Highway 881 and the Canadian National Rail line, both of which cross the central part of the map area, connecting the community of Lac LaBiche with Fort McMurray. Road and aerial access are restricted in southeast part of the study area, which is occupied by the Department of National Defence Air Weapons Range. Road access continues to increase in response to new economic activity in the region, the main of which is forestry and oil sands development.

The study area is hydraulically bounded by the Athabasca River to the west and northwest and the Clearwater River to the northeast. The Alberta-Saskatchewan Border defines the limit of the study area to the east. The political border fortuitously approximates the eastern limit of the Christina River sub-drainage basin. The southern limit of the study area is defined by the Mostoos Uplands – May Hills ridge. This ridge forms the drainage divide between the sub-drainage basins of the House, Horse, and Christina rivers that drain northward to the Athabasca River as part of the Athabasca Drainage Basin, and the various smaller rivers that flow south into the Beaver River- Cold Lake Drainage Basin.

Extension of regional hydrogeological studies to natural hydrological boundaries is standard practice. This is because if mathematical equations of flow are invoked to explain natural observations, they can best be solved if the bounding features can be expressed as mathematical boundary conditions. Drainage divides and rivers make excellent mathematical boundary conditions. The same motivation was used by Petro-Canada to prepare the first detailed maps of hydraulic heads in Cretaceous aquifers in the study area for use in its intervention to the Gulf (now Conoco) Surmont Hearing (Petro-Canada, 1999) on gas-over-bitumen issues. That work was summarized and extended by Barson et al. (2002).

The geological scope of this report extends from the Pre-Cretaceous Unconformity to the modern land surface (Figure 1.2). The Pre-Cretaceous Unconformity is a buried surface of extensive sub-areal erosion marking the top of Devonian strata. Sitting directly atop the unconformity is the Lower Cretaceous

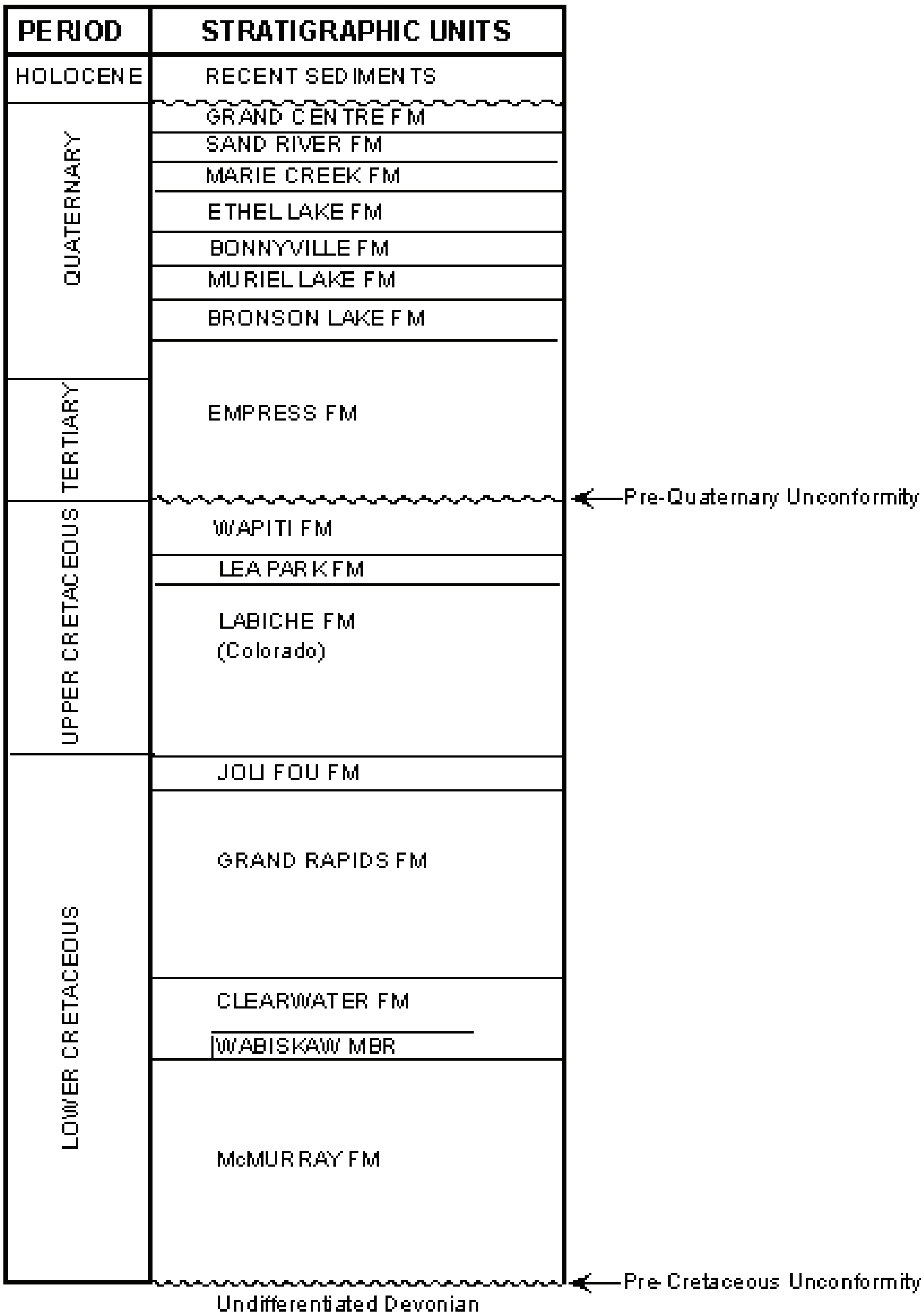

Figure 1.2. Stratigraphic column for study area.

McMurray Formation, which hosts the bitumen as well as substantial gas resources, in addition to being a major regional aquifer. The landscape of lowermost McMurray time was a karsted limestone terrain characterized by broad, north-trending fluvial valleys. The McMurray records the infill of these broad fluvial valleys, and then fluvial-estuarine deposits, and finally estuarine-bay fill deposits as the sea transgressed over the landscape. Overtop of the McMurray are the sandstones and shales of the Lower Cretaceous Clearwater and Grand Rapids formations, which host natural gas deposits as well as being used as waste-water injection zones and as aquifers for water supply. These sediments mark the cyclic regression of the sea to the north with consequent clastic-shoreface progradation. The Wabiskaw Member, a major marine-flooding shale, of the Clearwater Formation separates the McMurray from the Clearwater-Grand Rapids Succession. In all but the northeastern part of the study area, the Grand Rapids Formation is overlain, in turn, by the Joli Fou Formation, a relatively thin but regionally extensive shale, the discontinuous sandstones of the Viking (or locally, the Pelican) Formation, and the thick and regionally extensive Colorado (or locally, the La Biche) Formation, another shale. The Viking Formation is not a significant regional aquifer in the study area nor does it host hydrocarbon resources of any consequence. Bedrock geology is illustrated in Figure 6.10.

The top of the Lower Cretaceous strata is marked by another regional erosive unconformity, probably of Tertiary age. Like the landscape of lowermost McMurray time, the landscape of the Tertiary was marked by fluvial incision. The infill of these valleys parallels that of the McMurray, but with the difference that the valley infill and later landscape coverage was related to cycles of glacial advance and retreat, rather than the sea. Coarse sediments in deposits of glacial and interglacial landscapes (especially buried channel sediments in infilled valleys) create significant local and regional aquifers. The nature and distribution of sediment on the modern interglacial landscape are significant controls on site-suitability for solid-waste storage facilities and landfills.

The formations below the Pre-Cretaceous unconformity act as both significant regional aquifers and as zones suitable for subsurface solid and liquid waste disposal. These formations are not discussed in this report.

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2 A Conceptual Framework for Groundwater Resource Assessments

Groundwater-resource assessments blend together the theory of flow to a well with the theory of regional groundwater flow. This section briefly reviews the conceptual frameworks of flow to a well and regional groundwater flow. Modern concepts of regional groundwater resource assessments are then explored in order to provide the scientific motivation for the work presented in this report.

Injection-capacity assessments add additional complexities covered by the theories of density-dependent flow, rock-water interaction, and hydraulic fracturing of aquifers. Because of these added complexities, theories pertaining to waste-water injection in the Athabasca In Situ Area will be not discussed in this report

2.1 Basic Concepts of Flow to Wells

For the reader totally unfamiliar with hydrogeology, a primer of hydrogeological concepts is found in Alley et al. (1999) or in Taylor et al. (2001), both available at no cost from the United States Geological Survey on the Internet at http://water.usgs.gov/pubs/.

Groundwater is water extracted from wells that have been screened or left open across zones of porous and permeable rock or sediment lying below the water table. The zone below the ground surface but above the water table is termed the unsaturated or vadose zone. All pore and fracture space below the water table is saturated with groundwater (with localized exceptions where the water is displaced by oil, bitumen, or natural gas). Porous and permeable zones or strata below the water table capable of delivering water to a well are called aquifers. Zones or strata that are not capable of delivering water to a well are called aquitards. Aquitards still can transmit groundwater flow over geological time, however. The geology of aquifers and aquitards is reviewed in textbooks like Domenico and Schwartz (1990). The regional geology of aquifers in North America is discussed in detail in Back et al. (1988).

Groundwater flows to a well because pumping in the well reduces the potential energy of the groundwater in the aquifer at the well. This reduction creates the driving force that draws groundwater into the well. The measure of potential energy in an aquifer, pumped or not, is usually expressed in terms of a parameter called hydraulic head, h[L], or simply head. Head is most simply defined as the elevation to which water in a well would rise if allowed to do so. Head can be measured in wells by converting measurements of depth to water in wells to elevations, provided ground elevation is known. In deep wells, heads can be calculated from pressure measurements by the simple relationship:

$$h = z + P/\rho g \qquad \text{(Equation 1)}$$

Where h = hydraulic head [L]; z = elevation of the point of measure [L]; P = fluid pressure [M^2T^2/L^2], ρ = fluid density [M/L^3]; g = the gravitational constant [L/T^2]. In static fluid systems, all hydraulic heads are equal and fluid pressures will increase with depth in proportion to their density. Such pressure conditions are termed hydrostatic.

Hydraulic heads measured and mapped in the vicinity of a pumped well will show a constant increase in head back to non-pumping values away from the well. This pattern is called the cone of depression of a pumped well. The greater the discharge of the well (Q_w), the larger and steeper will be its cone of depression, all other things being equal. The other controls on the shape, extent, and rate of growth of the cone of depression are: the aquifer thickness (b), the hydraulic conductivity (K), which measures the ease of transmission of water through the aquifer under head gradients, and the specific storage of the aquifer (S_s), which relates the amount of water released by elastic expansion of water and elastic compression of the aquifer when head is reduced to the magnitude of that reduction in head.

The difference between pumping and non-pumping head values anywhere in an aquifer is known as the drawdown (s). The area around a well that provides water to the well after a given interval of pumping is called the capture zone of the well. The cone of depression and the capture zone are not the same, but both increase over time with continued pumping – quickly at first, then evermore slowly in accordance with the mathematical laws governing flow to the well. When a pumped well is shut off, the heads in an infinite aquifer will recover back to their non-pumping values over time. The drawdown left at any point during recovery is called the residual drawdown (s'). Long-lasting residual drawdown in a pumping well is often the first sign of an unsustainable depletion of an aquifer. Flow to wells and well design is discussed in detail in Driscoll (1986). The mathematical interpretation of drawdown in wells during testing or production is summarized in Kruseman and deRidder (1990).

2.2 Basic Concepts of Regional Groundwater Flow

Groundwater does not need the stress of pumping wells to move through aquifers. Natural variations in hydraulic head in the subsurface are in fact the norm. Consequently, most groundwater is in constant motion. The head variations in shallow aquifers are caused primarily by gravity acting to remove topographic variations on the water table that are maintained by precipitation. Regional gravity-flow systems are hydraulically linked to surface-water bodies. Water enters groundwater flow systems by downward-directed percolation of infiltrating precipitation, or in some cases, directly from surface water bodies. Downward-directed, entering flow is called recharge. Water exits groundwater flow systems by upward flow into surface water bodies, marshes, wetlands, springs, etc. Upward-oriented, exiting flow is called discharge.

It is a fundamental axiom of hydrogeology that over geological time all porous or fractured media will conduct flow and transmit fluid pressure (with some possible exceptions like bedded salts). This property of the subsurface is referred to as regional hydraulic continuity. Groundwater flow across aquitards and aquifers is called cross-formational flow (see Toth, 1995, for a summary).

Pore pressures relative to their depth also provide information about groundwater flow. If all groundwater were at rest in the subsurface, the pore pressure would increase with depth in proportion to the density of the groundwater. Such a condition is referred to as the hydrostatic state. In a hydrostatic case, all heads are equal. Pressure-depth gradients associated with such a condition are also termed hydrostatic. The freshwater hydrostatic pore-pressure gradient is 9.8 kPa/m. Mineralized groundwaters have higher hydrostatic pressure-depth gradients due to their greater density. Because groundwater motion is the norm in the earth's subsurface, pore-pressure conditions are not uniformly hydrostatic, but vary from subhydrostatic (<9.8 kPa/m) in areas of downward-directed flow to superhydrostatic (>9.8 kPa/m) in areas of upward-directed flow. Hydrostatic pressure-depth gradients indicate nearly static conditions (rare) or horizontal groundwater flow (common).

The mathematical details of regional, gravity driven, cross-formational groundwater flow in a hydraulically bounded volume of the earth's crust, called a groundwater-drainage basin, in the context of potential-field theory are discussed in textbooks like Domenico and Schwartz (1990). In deeper hydrogeological settings, geomechanical and geochemical forcings like tectonic compression, depositional compaction, dehydration, mineral transformations, pore-dilation due to erosional unloading, glacial loading cycles, or uneven heating may also drive groundwater flow. Neuzil (1995) provides a comprehensive discussion of these driving forces and their manifestations as abnormal subsurface pressures.

Groundwater chemistry changes with flow in drainage basins. The dominant mechanism controlling groundwater chemistry is dissolution of soluble minerals in the rock framework along flow paths. Thus deeper, older groundwaters tend to have higher dissolved solids contents than shallower, younger groundwaters. However, the composition of the dissolved solids and the evolutionary path of groundwater chemistry can be extremely complex. The chemistry of groundwater at any point in a flow system reflects the various mixing, dilution, mineral dissolution, mineral precipitation, ion exchange, organic-reactions, and bacterial processes and their order of interaction during the residence time of the water in the flow system. Discussion of these processes can be found in Drever (1997) as well as Clark and Fritz (1997). More specific discussions of the nature and possible causes of variations in groundwater chemistry in the Athabasca area are found throughout this report.

2.3 The Generalized Framework for Groundwater Resource Assessments

Groundwater-resource assessments are performed at all spatial and time scales, ranging from single wells pumping only for weeks to long-term changes in basin flows over geological time. Though each application is unique in terms of geology and purpose, a generalized framework for ground-water assessments has evolved over the past century and has been extensively discussed in the scientific literature.

2.3.1 A Few Words About Sustainability and Resource Development.

Depending on basin configuration and geological architecture, groundwater resources can be considered as renewable or as non-renewable on a human time-scale. Whenever resources are renewable, there is commonly a desire to quantify a so-called “sustainable” rate at which they can be extracted forever without harm. Alley et al. (1999) use the definition of groundwater sustainability as:

> “the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.”

As discussed below, however, there are situations in which the desired groundwater withdrawal is neither renewable nor sustainable, or the hydraulic behaviour of the system under development cannot be distinguished from an unsustainable development on a human time frame. As well as being difficult to ascertain whether a given groundwater resource is renewable or not, the economic value of groundwater is difficult to quantify. Its value will vary with its degree of “renewability”, one’s definition of sustainability, local competition for its use, intergenerational value, and so on.

The concepts of sustainability and the economic value of groundwater will not be discussed further in this baseline report. The interested reader is directed to National Research Council (1997) for further information.

2.3.2 From Single-Well Safe Yields to Concepts of Regional Capture

Single-well safe yields are the most elementary tool for groundwater resource assessment. A single-well safe yield defined as the rate of continuous pumping of a well that will not use all the available drawdown in the well before some defined length of time, assuming no recharge or leakage to a homogeneous, horizontal and unbounded aquifer. Safe yields are very simply calculated from knowledge of local aquifer properties (e.g., Bibby, 1979). In Alberta, a safe-yield time horizon of twenty years is normally used as a norm of evaluating long-term well performance. The groundwater reconnaissance map of the study area (Ozoray, 1974) was created with this concept in mind.

Single-well safe yield calculations are not appropriate for quantifying regional groundwater resources or for predicting resource sustainability given multiple, large-scale groundwater developments operating over an indeterminate time horizon. Broader concepts of groundwater-basin yield are used instead.

Theis (1940) first described the source of water from a well in terms of regional groundwater resources. He noted that prior to a well being pumped, the groundwater system is in a dynamic equilibrium with the surface water balance in a groundwater drainage basin. At equilibrium, the hydraulic head field does not change over time and recharge to the groundwater system is balanced by discharge from the groundwater system. This state of nature is captured in the equation:

$$R_o - D_o = 0 \qquad \text{(Equation 2.2)}$$

where R_o is the mean recharge to the groundwater basin under original conditions $[L^3/T]$, and D_o is the mean discharge from the groundwater basin under original conditions $[L^3/T]$.

When a well is pumped at some steady discharge, Q $[L^3/T]$, the hydraulic head field is disturbed and water begins to flow to the well. At first, the water to the well comes out of elastic storage in the basin (dV/dt, $[L^3/T]$). As pumping continues, the hydraulic head field evolves towards a new equilibrium with the pumping well by increasing the amount of recharge (induced through falling water tables) and reducing the amount of discharge (by reducing baseflow to streams, lakes, sloughs, etc.). This state of nature can be captured by the equation:

$$(R_o + \Delta R_o) - (D_o + \Delta D_o) - Q + dV/dt = 0 \qquad \text{(Equation 2.3)}$$

When the new equilibrium is reached, there will be no further change in the elastic storage of the basin. The volume of groundwater removed by the well will be balanced by an increase in recharge to the groundwater flow system or a decrease in discharge from the groundwater flow system, or both. Since from Equation 2.2, the original mean recharge is balanced by the original mean recharge, the new state of nature is represented by:

$$\Delta R_o - \Delta D_o - Q = 0 \qquad \text{(Equation 2.4)}$$

Theis called the sum of the increase in recharge and decrease in discharge needed to balance the pumping the “capture” of the well. The increase in recharge may be driven by a reduction in “rejected recharge” or increase in infiltration rates resulting from falling water tables in recharge areas. The decrease in discharge could be manifested by reduction in baseflow to streams, to springs, or upwellings below wetlands, marshes, sloughs, or bogs.

Freeze (1971) used a numerical model to show that there will be an upper limit to the volume of water that can be extracted by a well as capture in a groundwater basin. He called this theoretical upper limit the maximum stable basin yield. In his model, this theoretical limit would be reached when all discharge is captured and the regional fall of water tables has maximized the amount of induced recharge. Past this point, the basin will induce recharge from surface water bodies once fed by discharge and water tables may fall so deep that infiltration evaporates in the vadose zone en route to the water table, rather than providing recharge to the system.

Brehehoeft et al. (1982) found it necessary to publish a correction to the then growing practice of using only the total estimated recharge in a groundwater basin (derived from a modeled water balance, for example) as representing the upper limit to groundwater yield of a basin. They underscored that, as Theis and Freeze argued previously, well or well-field capture will be composed of some combination of reduction of discharge as well as an increase in recharge. Moreover, they furthered these ideas with the argument that decreases in discharge will happen before recharge is induced, and that the sustainable yield may well be limited by societal tolerance to reduced discharge to surface water-bodies or falling water levels in wells during the transition from storage to capture, long before some new steady-state is achieved by inducement of extra recharge in some distant future.

Ophori and Toth (1990) investigated the sensitivity of basin yields to position of wellfields in a flow system. Theis had advocated placement of wellfields in recharge areas, to maximize capture of "rejected recharge", which seemed to presage societal intolerance of reduction of discharge. Ophori and Toth characterized basin responses in terms of the parameters TBY – the transitional basin yield, and SBY – the sustainable basin yield. TBY is defined as the cumulative sum of all the groundwater removed between the time when pumping is initiated to the time when a new steady-state is reached. SBY is defined as the rate of water capture from precipitation into the groundwater system by capture of recharge at the final steady-state condition. In their analyses, they determined that TBY is maximized when wells are placed in discharge areas whereas SBY is maximized (and reduction in discharge is minimized) when wells are placed in recharge areas. Furthermore, they reasoned that industries with high needs for groundwater over long periods of time would optimally place their wells near the midpoint of the unit basin to maximize both TBY and SBY. Like others before them, Ophori and Toth recognized that site-specific analysis, including modeling, would be needed to optimize resource extraction and that the optimal situation could vary in time with changing hydrologic conditions and addition of other groundwater developments in the same groundwater drainage basin.

The values of parameters like TBY, SBY, and the magnitudes and locations of reduced discharge, increased recharge, and change in water-table elevations or hydraulic heads in aquifers are dependent on the number and location of wells, plus any long-term climatic variations experienced by the groundwater basin. Therefore, unique values of sustainable yield have to be forecast by using computer simulations and compared to ongoing monitoring data to have any validity.

The transition of well discharge in a basin from pure mining from elastic storage to pure capture has been developed in detail by several workers. Domenico and Schwartz (1990) note that the time necessary for a new hydraulic head equilibrium to be developed in a homogeneous groundwater basin after steady pumping is initiated is captured by the dimensionless inverse Fourier Number:

$$N_{FO}^{-1} = (r^2S/4T)/t$$

Where r is a characteristic length of the basin [L], S is the representative specific storage [L^{-1}], K is the representative hydraulic conductivity [L/T], and t is the time of pumping [T]. If the value of N_{FO}^{-1} is very small (say on the order of 0.001 or less), then drawdowns related to pumping will change only imperceptibly and the system can be considered to be approaching a new equilibrium.

Balleau and Mayer (1982) used numerical models of realistic groundwater-basin geology to investigate the time of transition from all pumpage being from storage to all pumpage being captured by the definition of Theis, but where the inverse Fourier number suggested by Domenico cannot be easily defined. By examining realistic geologic scenarios, they showed that the transition time from mining storage to reaching pure capture may be so long in some cases that groundwater development would be more akin to mining a non-renewable resource than a renewable one.

The concepts of sustainable groundwater yield have been revisited more recently in Sophocleus (1998) and Alley et al. (1999).

2.3.3 Groundwater as a Non-Renewable Resource

As shown by Balleau and Mayer (1982), the geometry and geology of a groundwater basin may preclude any new, sustainable steady-state from being re-established on any reasonable human time scale. In such cases, groundwater during pumping will come predominantly from storage in the contained aquifer or from leaking confining aquitards, with little or no true “capture” ever reaching the well. It may also be that the maximum sustainable basin yield has been unknowingly exceeded and the basin will never achieve a new equilibrium, a condition often called groundwater mining. It would be difficult to determine whether a groundwater basin is truly being mined or not, but in both of these cases the groundwater could be assessed as a non-renewable resource. In such a case, the strict concept of groundwater development as “sustainable” discussed above is not applicable. Rather the resource is essentially finite, and the longevity of the resource will be function of number of wells and their discharges. The only uncertainty will be as to how large is the volume of the finite resource and at what rates can it be extracted.

Little attention has been paid in the literature to practical quantification of non-renewable groundwater resources. This omission may reflect our preference to only exploit hydraulically well-connected aquifers because a) they tend to be shallow, keeping drilling and pumping costs down, and b) their short water-residence times result in low dissolved mineral content and relatively high chemical quality. Industrial users, like in-situ oil sands operations, are able to use more brackish to saline water for industrial processes, either with treatment, blending, or as-found – depending on the industrial process. Such groundwaters will almost always come from deeper aquifers, increasing the chances that intervening aquitards will essentially isolate them from the surface hydrologic system on a human time scale.

Volumetric assessment of hydraulically isolated aquifers can be easily done by adapting methods of hydrocarbon volume-assessments. At their simplest, hydrocarbon volumes are calculated as the product of drainable pore-volume times hydrocarbon saturation times a formation-volume factor that accounts for elastic expansion of compressible hydrocarbons brought to surface. Because of the commercial value of hydrocarbons and the business needs for managing exploration risks, probabilistic methods of estimating ranges of volumes of original oil-in-place have been developed to a high level of sophistication (e.g., Capen, 1992). The concepts and theories of probabilistic hydrocarbon volume assessment can probably be modified to help assess (practically) non-renewable groundwater resources, but that task is beyond the scope of this project.

2.4 Waste-Water Injection and Storage Capacity of Groundwater Basins

The concepts discussed above regarding groundwater resource development are applicable to the practice of assessing a basin’s suitability and capacity for waste-water disposal by injection. These concepts will not be developed in this report, but a few comments on the general applicability are in order.

When a well injects water, it initially goes into elastic storage. Hydraulic heads will rise in an ever growing “cone of impression” around the injection well. The flow system of the host basin changes in response to this new stress, and evolves to a new steady-state characterized by higher static water-levels in aquifers, higher water tables, reduced recharge and increased discharge. But should a well’s injection rate exceed the maximum capacity of the basin to adjust to the imposed stresses by redistributing the groundwater and ultimately rejecting water at the boundaries, hydraulic heads will rise at the well. Ultimately, the injection zone will hydraulically fracture and/or the well will blow.

The return of injected fluids to surface from a basin under injection can be of concern to regulators. This is because the receiving surface ecosystem may not be able to tolerate or adapt to an increase in the release of natural groundwaters of high dissolved solids or to increases in natural contaminants. The geochemical effects of the release could thus cause an intolerable impact well before any injected waste-waters circulate to the biosphere. And if injected waste-waters return to the surface without sufficient dilution or chemical transformation to render them harmless, they too have the potential to do environmental harm.

Geochemical compatibility of injection waters with receiving aquifer lithologies or native groundwaters is also an important concern. Geochemical reactions can create or destroy porosity in receiving aquifers or aquitards providing containment. Cook et al. (1972) provides an elementary review of issues pertaining to underground waste disposal in sedimentary basins. A updated review of recent literature on deep-well injection, with particular relevance to carbonate aquifers in the Athabasca Oil Sands Area in Alberta, can be found in Appendix 8.

The same time-delay on moving from all injection going into elastic storage to all injection being balanced by basin discharge exists as for moving from all production coming out of elastic storage to all production being balanced by basin capture. Because of intolerance to the surface impacts of basin release or to injected wastes themselves, operators of injection wells usually seek to find recipient aquifers contained by aquitards that are unlikely to transmit head changes or pass injection fluids to the boundaries of the basin over the very long term. This is the opposite of what is desirable for a sustainable groundwater-extraction project.

2.5 Project Motivation

A schematic of a generic SAGD operation is shown in Figure 2.1. The arrows mark the flow of water from fresh and brackish source wells, through the boilers where it’s combined with recycled produced water, and then out as either excess produced water or waste-water for disposal.

A very simplified model of the subsurface water flow for the study area (after Hackbarth and Nastasa (1979), and Bachu et al. (1993), in the style of systems analysis suggested by Engelen and Jones (1986), is shown in Figure 2.2. The arrows again show the flow of water in the natural system. Groundwater enters the sedimentary succession as meteoric water, percolates downwards under gravity, mixes with connate water and/or groundwater from other flow systems, and discharges as baseflow to streams and springs, etc.

Figure 2.3 shows how the two systems become linked. The flow of water becomes very complex as each component of the natural system becomes directly or indirectly stressed by a multitude of SAGD operational elements like wells, landfills, and salt caverns. The successful operation of any given SAGD operation will depend on managing local fluxes in the plant, the reservoir, and in the inlets and outlets of water and other inputs and emissions from the environment. The successful regulation of the entire industry will depend on managing the distribution of the fluxes of water and wastes so as to minimize the cumulative impacts to the biosphere.

Understanding the natural system at the equilibrium shown in Figure 2.2 is the key motivation for this project. A second key goal was to gather geological and hydrogeological data that will help others predict the response of the coupled system as it moves from its natural state of equilibrium to the future state (as in Figure 2.3) in terms of the general conceptual framework of groundwater resource assessments. This information will be needed to design future monitoring programs by which we can judge and mitigate unwanted cumulative effects.

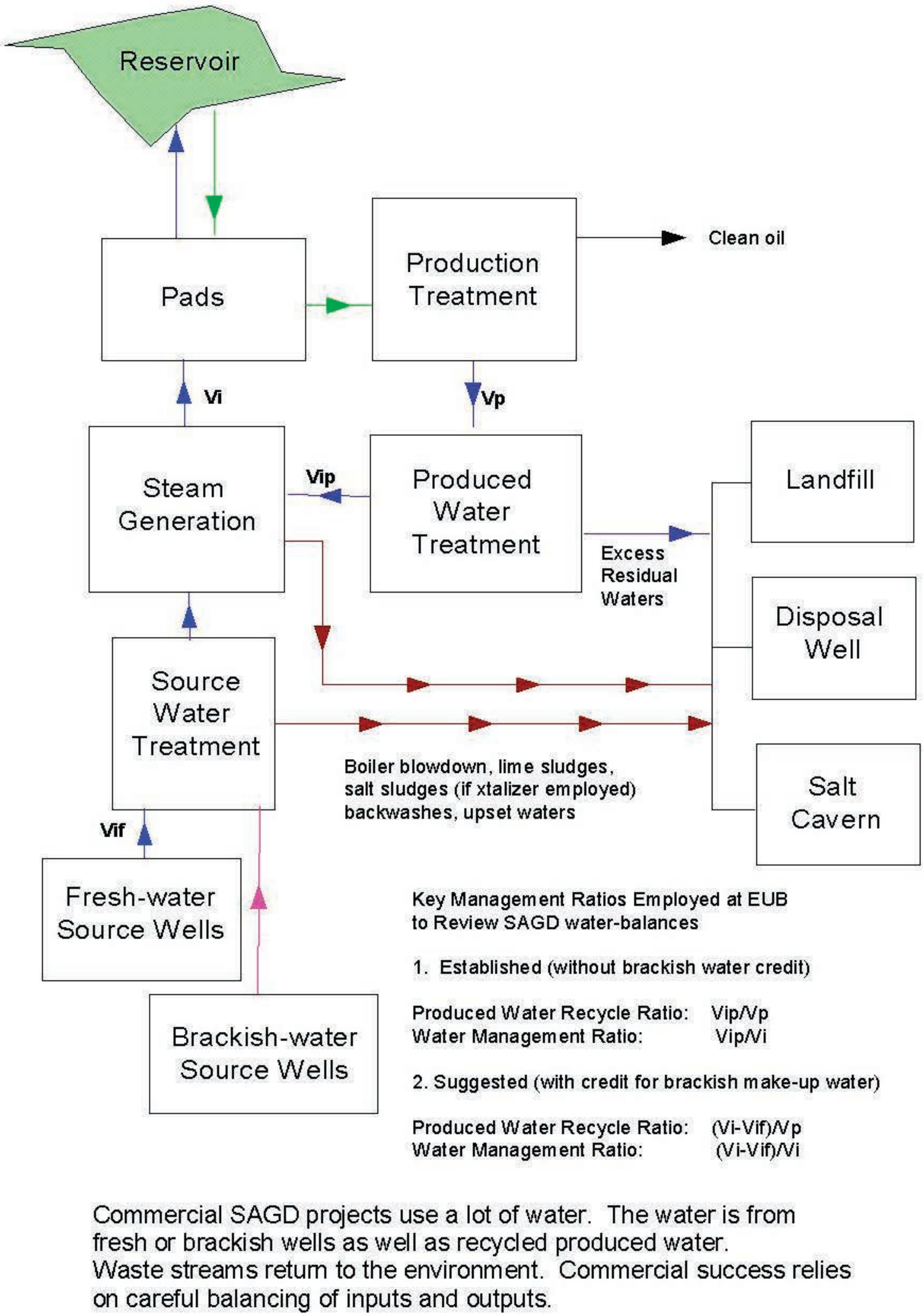

Figure 2.1. Schematic water-balance diagram for a generic SAGD project.

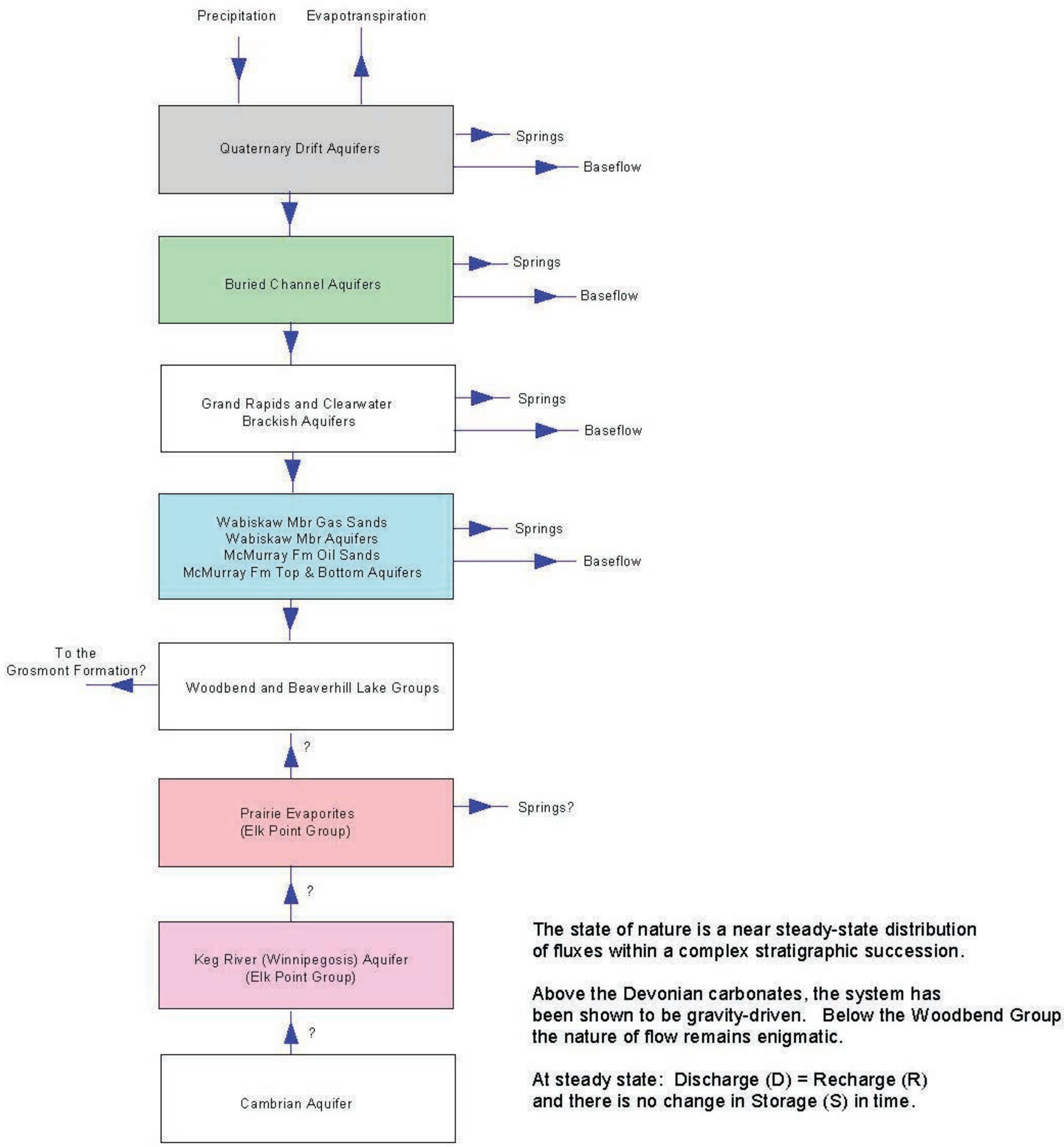

Figure 2.2. Simplified schematic regional water balance for the study area

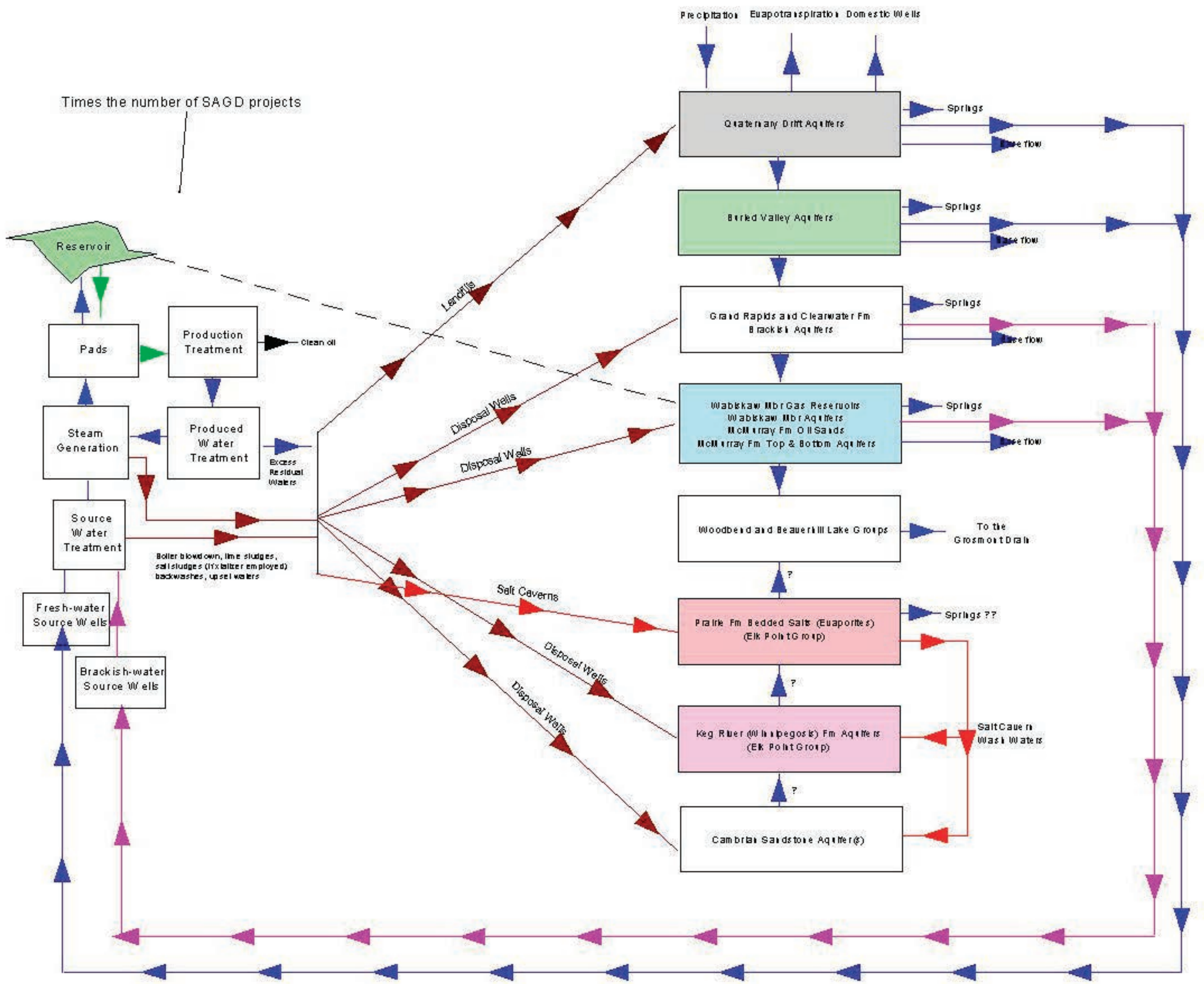

Figure 2.3. Schematic water-balance showing linkage between SAGD projects and the natural system.

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3 Area Topography and Physiography

A discussion of regional groundwater flow cannot occur without considering the exerting influences of the major topographic and physiographic elements in the natural landscape. Positive physiographic elements (uplands) are the engines that drive local and regional groundwater flow, and regional mapping of these enables a first-order conceptual understanding of expected groundwater flow directions.

The major topographic elements of the study area are depicted in a computer generated, coloured digital elevation model (Figure 3.1 Map). Surface elevation ranges from as low as 250 m along the present-day Athabasca River valley at the north end of the study area, to as high as 850 m in the uplands directly north of Wandering River in the southwest part of the study area. The major surface drainage features are the Athabasca and House rivers in the west, and the Clearwater and Christina rivers in the north and east part of the area.

Regional differences in topographic elements (elevation, drainage) form the basis for dividing the study area into seven major physiographic units, each of which include minor subdivisions (Pettapiece, 1986). The most prominent physiographic feature is a dog-leg-style complex of uplands in the central part of the map area, formed by the northeast-southwest trending Stony Mountain Uplands, and the northwest-southeast trending Mostoos Hills Upland (Figure 3.2).

The Stony Mountains Uplands is the more prominent of the two, particularly when viewed from the north. Elevations within most of the Stony Mountain Uplands range from about 600 m to 700 m, with the notable exception of the May Hills bedrock highland where the elevation is as high as 850 m. Surface water drains radially from the Stony Mountain Uplands, ultimately flowing into the Hangingstone, House, Horse, and Christina river basins. The Mostoos Hills Upland (Figure 3.2) is the next most prominent feature. It includes two upland subdivisions: the Pinehurst Hills in the extreme south (650-750m) and the Mostoos Upland in the southeast (600-700 m). The southern flank of the Mostoos Hills Upland drains south along the Sand and Owl rivers, and the northern flank drains north along the Winefred and Christina rivers.

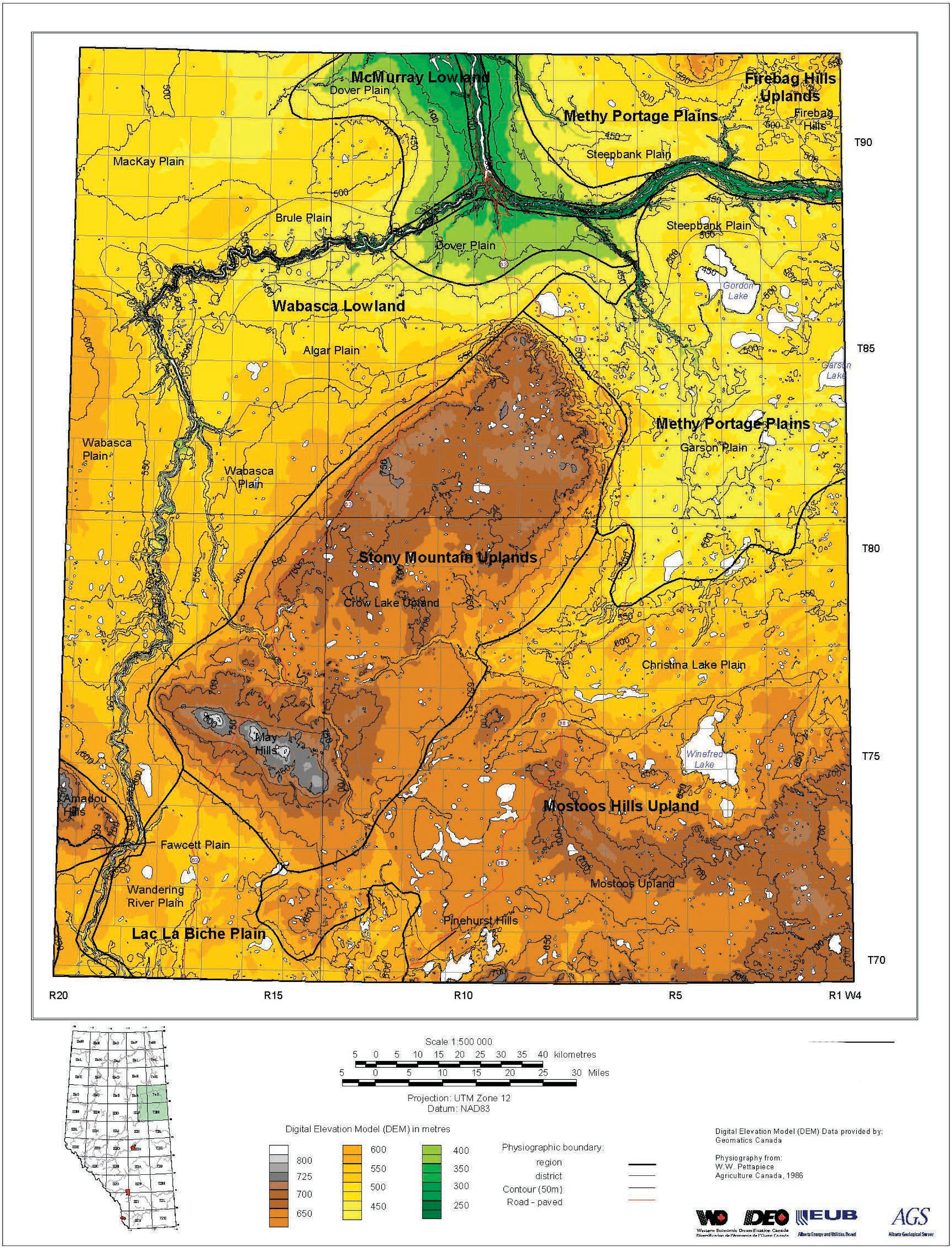

Figure 3.1. 1:500 000 scale surface topography and coloured digital elevation model map.

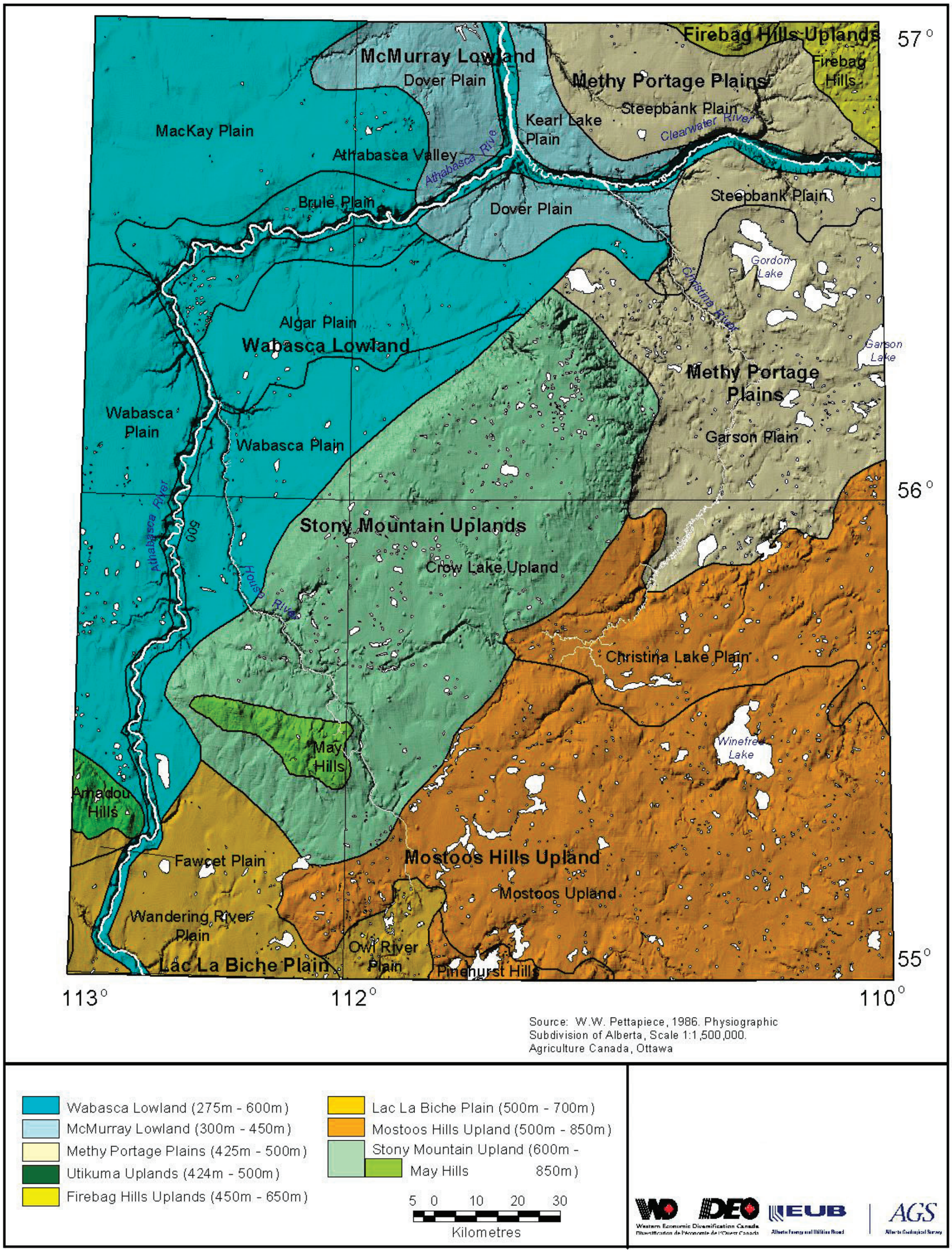

Figure 3.2. Physiographic subdivisions of the study area.

A number of lower-elevation plains and lowlands lie along the perimeter of the central uplands, including: the Lac La Biche Plain in the extreme southwest (500-600 m), the Wabasca Lowland in the northwest (275-600 m), and the Christina Lake Plain (500-600 m) and Methy Portage Plains in the northeast (425-500 m). The Lac La Biche Plain and Wabasca Lowlands are drained by the Athabasca River and its tributaries, the House River, Horse River, and Hangingstone River. The Methy Plains, the Portage Plains, and the Christina Lake plains are drained by the Christina River and its tributaries, and the Clearwater River (Figure 3.2).

3.1 References

Pettapiece, W.W., 1986; Physiographic subdivision of Alberta. 1:500,000-scale map; Agriculture Canada, Ottawa.

4 Baseline Investigations Into Regional Recharge and Discharge

4.1 Introduction

In a steady-state system, annual mean recharge is balanced by annual mean discharge (Equation 2.2). Though the topography and basin configuration are the primary controls on the geometry of gravity-driven flow systems, the actual distribution of recharge to the water table across a basin is a significant secondary control on the distribution of groundwater flow. In terms of the general water balance of a basin, recharge is usually calculated as the difference between average annual precipitation and average annual evapo-transpiration. Estimation of both precipitation and evapo-transpiration is problematic because regional estimates are spatial averages of sparse point data; local variations can be significant relative to regional trends. Discharge of groundwater, on the other hand, is easier to identify and quantify, because of its spatial concentration in wetlands, springs and streams. And again, though topography and basin configuration are the first order controls on the geometry of flow-systems, geology in large measure controls the locations of discharge areas.

This project did not reach a point where regional water balances could be estimated or recharge and discharge areas conclusively identified and mapped. However, significant investigations pertinent to estimation of regional water-balances and mapping recharge and discharge areas were conducted. These investigations included:

- The application of RADARSAT-1 remote-sensing information to describe the spatial distribution of surface-moisture patterns over the entire study area;
- The application of a recently-published recursive filter to identify the baseflow of gauged rivers which, for one reason or another, do not have discharge profiles amenable to more conventional graphical methods of baseflow separation;
- The mapping, baseline monitoring and geochemical sampling of springs emanating from outcrop of a significant regional aquifer system along the banks of the Athabasca River;
- The mapping and geochemical sampling of springs discharging from bedrock units along the Christina and the Clearwater Rivers;
- Installation and monthly monitoring of water levels in vertically-nested piezometers at three background locations in the study area.

4.2 General Hydrological Setting

Hackbarth and Nastasa (1979) describe the climate of the Athabasca Oil Sands Area in detail. Generally, the area is characterized by long cold winters and short cool summers. Precipitation falls mostly as rainfall during the summer months. Annual average precipitation in the 1970s at Fort McMurray was reported to be 465 mm/year. Evapotranspiration had been estimated to be about 463 mm/year in the Fort McMurray area for the same time frame (Hackbarth and Nastasa, 1979). According to Shen (1999), the monthly average of total precipitation over thirty years (1961-1990) for the Fort McMurray area ranges from 22.1 mm in February to 79.1 mm in July, the sum of those averages resulting in about 506.5 mm/yr. Bothe (1993) Calculated a mean areal evapotranspiration (actual evapotranspiration for an infinite area) for Ft. McMurray of 290 mm over the period of January 1972 to December 1992 with a minimum of –5 mm occurring in January and a maximum of 91 mm in July. These numbers may have to be reviewed in light of potential climate change affecting the area.

Published estimates of recharge are not available for the study area. Detailed studies of recharge at till-covered sites elsewhere in North America have estimated recharge from 1.5% of precipitation at a site near Dalmeny, Saskatchewan (Fortin et al., 1991) to 9% of precipitation at a site in North Dakota (Rehm et al., 1982). Horgan (1994) estimated recharge to be of the order of 9-12 % of average annual precipitation for a site south of the study area, near Ardmore, Alberta, in the Beaver River-Cold Lake drainage basin.

The major drainage basins of the study area are shown in Figure 4.1. The heavy outlines define the drainage basin areas. The shadings identify the parts of each basin that drain into each river upstream of their gauging stations. The distinction of these sub-areas was done specifically for this project. These sub-areas may be used in future studies to assign areal recharge rates based on baseflow analysis (discussed below).

The location of precipitation stations for the study area and general vicinity are shown on Figure 4.2. The locations of Environment Canada's stream-gauging stations are also shown on Figure 4.2.

4.3 Application of RADARSAT Data to Mapping of Recharge and Discharge Areas

The Alberta Geological Survey obtained multi-beam radarsat coverage for the study area captured by the RADARSAT-1 satellite in autumn, 1999. Four beam-modes were obtained: Standard Beam Mode 1 and Mode 7 in both the ascending and descending look directions, at 12.5-m resolution. The raw imagery from each beam mode carries composite information about the landscape. The scenes required ortho-rectification by an outside contractor for use in GIS and image analysis systems. A greyscale image of the S1 Ascending beam mode over the NTS 73M mapsheet-area is shown in Figures 4.3 (though the entire WEPA study area has been prepared, only map area NTS 73M is shown here).

To better interpret the radarsat imagery, we have used principle components analysis (PCA) to extract and concentrate the information blended in the multi-beam data. PCA is a standard methodology used to isolate or enhance information blended in multi-dimensional datasets. In the case of the radar imagery, the raw imagery from each beam mode carries composite information about the landscape. The physics of radar imaging tells us that the moisture content, the surface relief and granularity, and the vegetation type and density control each image. The contribution of each factor to the measured response in each beam-mode is different but unknown. PCA can be used to help disentangle the contribution of each factor blended in the radar information.

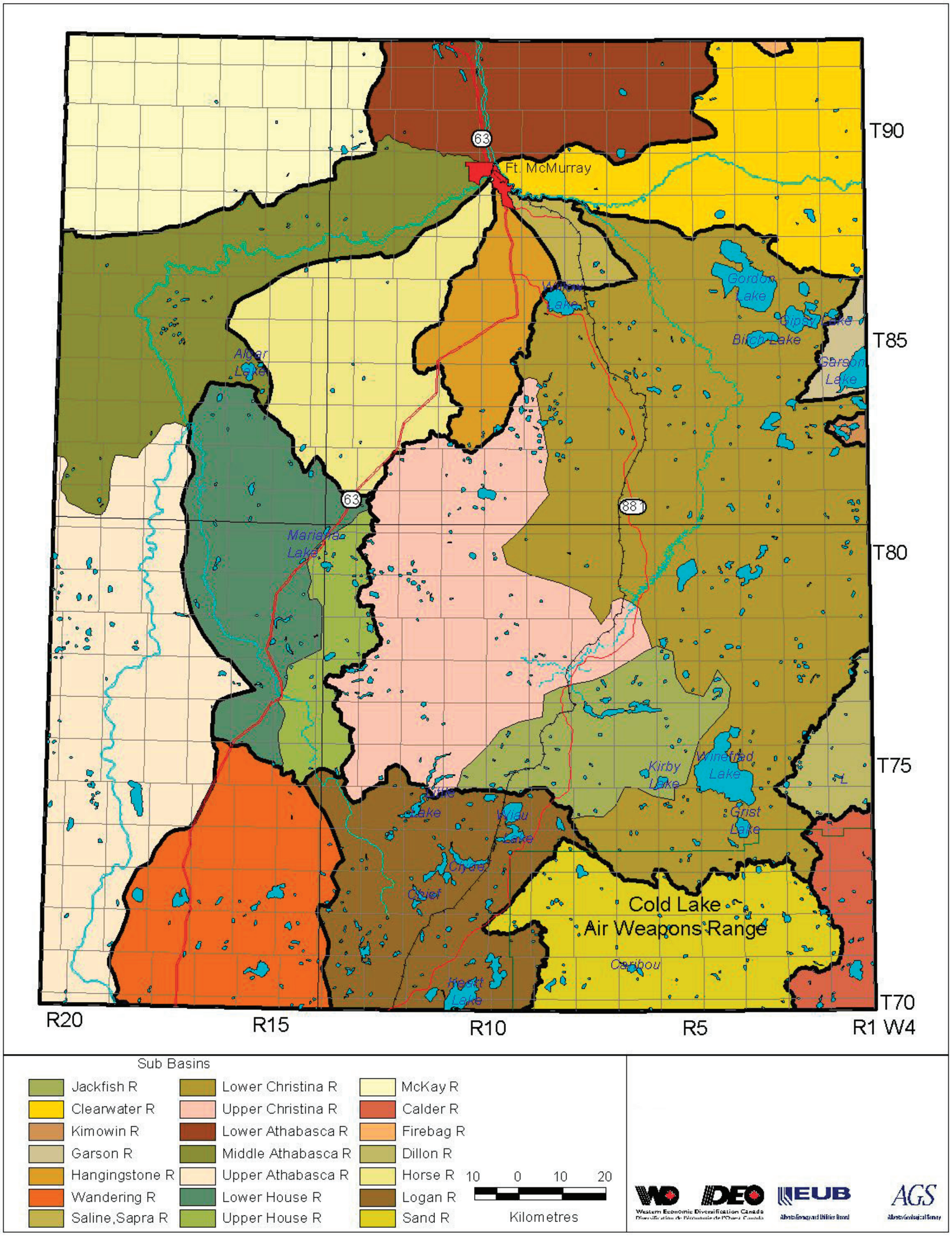

Figure 4.1. Drainage basins in the study area.

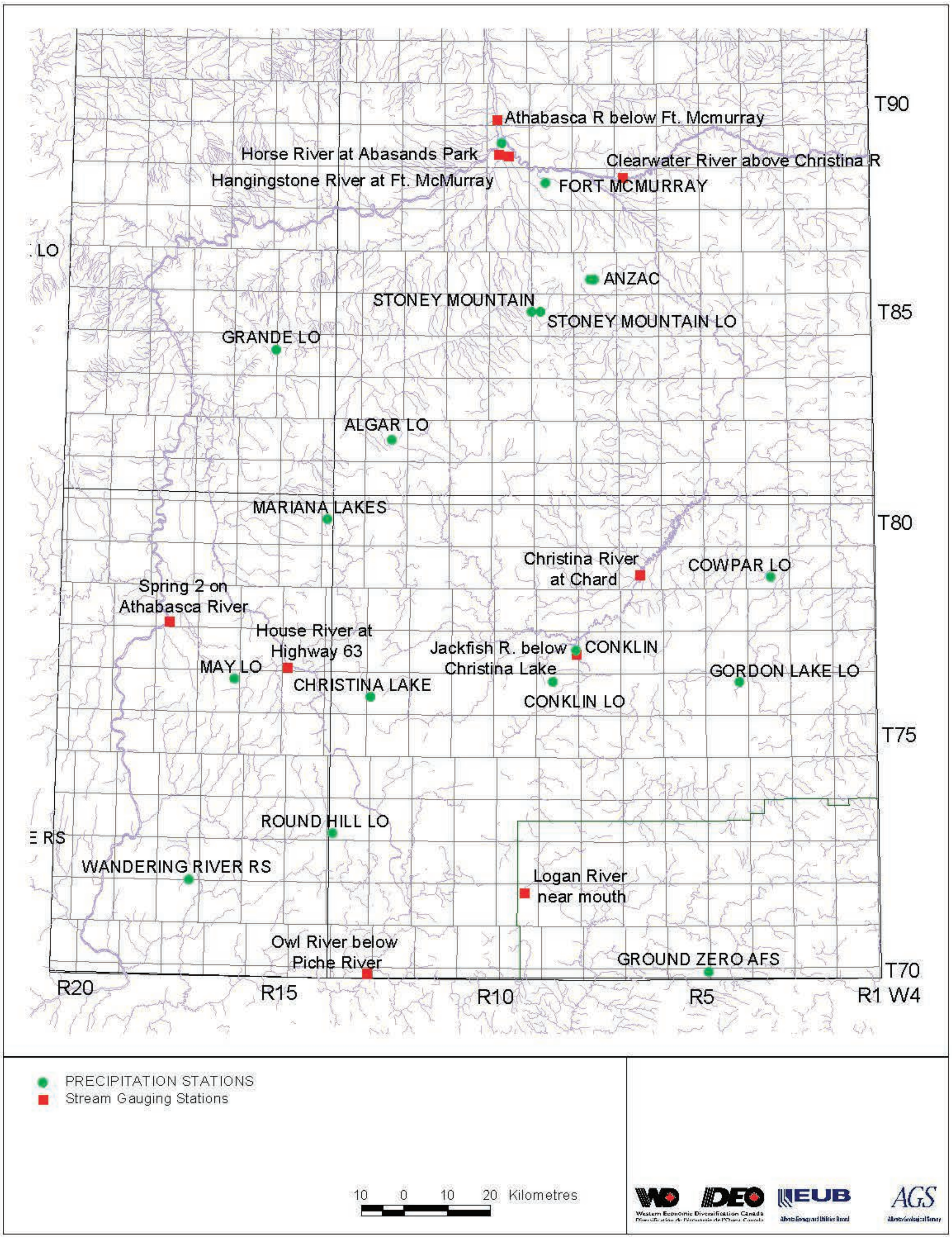

Figure 4.2. Precipitation and stream-discharge monitoring stations (Environment Canada).

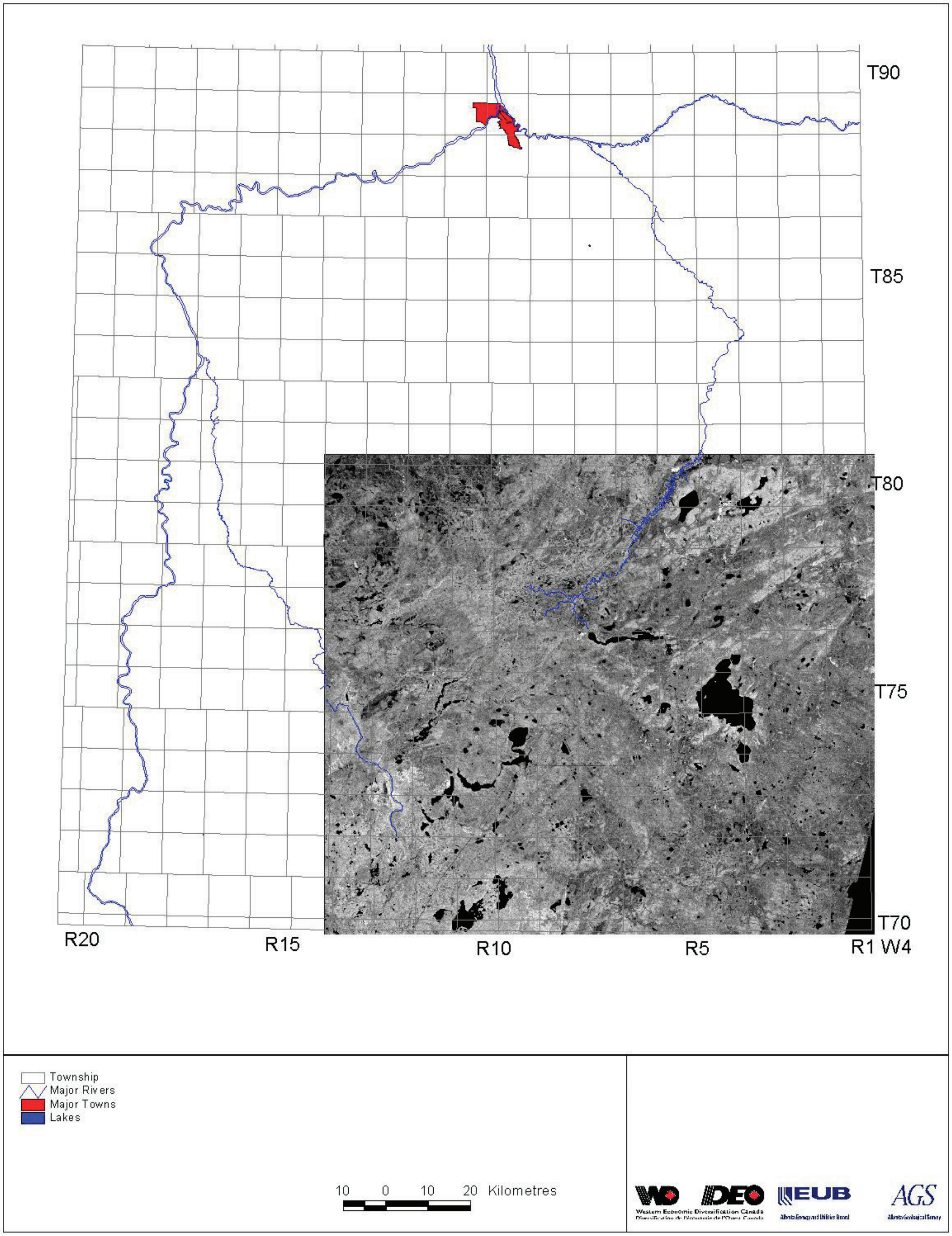

Figure 4.3. Greyscale image of RADARSAT-1 PC1 with lakes not highlighted.

Details of PCA applications in earth science can be found in Davis (1986). Without going into the details, the general processing stream works as follows.

- Each location in the RADARSAT Coverage has four values associated with it, one for each beam-mode. If the four-beam radar data were plotted in a four-dimensional hyperspace using the RADARSAT beam-mode values as coordinates, they would create a four-dimensional data cloud.
- The PCA process then rotates the coordinate axes so that there is a coordinate axis that goes through the longest axis of the data cloud. Then the second coordinate axis is found which goes through the next longest axis of the data cloud orthogonal to the first axis, while the third has to be orthogonal to the first two, and so on.
- Once the new-coordinate axes are all discovered, the values of the original data are recast in terms of their new coordinate system. The first coordinate reflects its location relative to the longest new axis. This value is called the first principal component. The second new coordinate is the second principal component and this reflects the data positions in space relative to the second axis, and so on.
- The proportions of each of the original components contributing to the new principal component axes are called the "loadings" of each principal component. The loadings are also used to convert each raw datum into the new coordinate system. The PCA process defines the length of each new principal component axis. These lengths are directly proportional to the contribution of each principal component to the total variance of the raw data set. If the contribution of any principal component is very small, it signifies that there is a degree of redundant information in the raw data set.

The first significant result of PCA was the recognition that each beam mode is contributing new and independent information to the data set. In statistical terms, this means that the data matrix is full rank and each of the four principal components contributes a significant part of the total data variance. This can be seen on Table 4.1, which shows the relative contribution of each principal component to the total variance of the data set.

Table 4.1. Relative contribution of each principal component to total variance of data set.

	PC1	PC2	PC3	PC4
S1A	48.42651	29.59258998	21.70903	0.27186738
S1D	44.35668	42.51113859	13.104282	0.02789809
S7A	73.93153	0.00875658	14.946969	11.11274255
S7D	78.63394	0.29662049	6.895566	14.17387074

The loadings of the original beam modes onto the each principal component are shown in Table 4.2. The distribution of some part of each beam mode across each principal component also attests to the observation that each beam mode is providing unique information.

Table 4.2. Loadings of each beam mode onto each of the four principal components.

	PC1	PC2	PC3	PC4
S1A	0.695537	-0.54371353	0.4656921	0.05211434
S1D	0.665773	0.65177553	0.3618706	0.01669683
S7A	0.8600221	-0.00935970	-0.3866975	0.33343056
S7D	0.886653	-0.05445644	-0.2625631	-0.37643753

Greyscale images of principal component 1 (PC1) through 4 are shown in Figures 4.3 to 4.7. In the image of PC1 (without the lakes highlighted), the lakes are black while the fresh forest-fire burns and roads are white. These contrasting colours indicate that PC1 is capturing information relevant to moisture. This is unsurprising because radar response is most strongly correlated to the dielectric constant of imaged material, a physical attribute that can vary over several orders of magnitude between wet and dry states of materials.

Inspection of the details of the images shows striking mosaics of differing radar response at several spatial scales: i.e., large patches of darker grey are juxtaposed with patches of lighter grey, while within the darker patches are smaller patches of light and dark grey, and so on.

Preliminary superposition of PC1 imagery with elevation, relief, and surficial-material types have shown some intriguing correlations of PC1 patterns with surficial geology at some scales, but these require considerable further investigation to understand and classify the land surface in terms of relative moisture content. Only then will we be able to use these patterns to map groundwater recharge and discharge areas on the landscape. The meanings of the other principal component imagery will need to be subject to further scrutiny and interpretation as well.

4.4 Baseflow Separation of Area Rivers by Recursive Filtering

Baseflow separation is the process of separating stream discharge due to runoff from discharge due to groundwater discharge (called baseflow) using stream-discharge hydrographs. A hydrograph of the House River is shown in Figure 4.8. Stream discharge and local precipitation are plotted versus time for the gauging station on the House River near Highway 63 (see Figure 4.2 for the location of the gauging station). Each hydrological year is characterized by a rise in flow in spring followed by an often rapid and noisy decline to low flow in winter. There is some correspondence of peak discharge events to high precipitation events recorded at the nearby precipitation-monitoring station, but the correlation is not 1:1. Strongly correlated discharge and precipitation events usually mark passage of regional weather fronts whereas the hydrological noise is usually ascribed to localized precipitation events like thunderstorms. The year-to-year variations are also significant.

Hydrograph separations are of particular interest to hydrogeologists because they can help identify changes in regional groundwater discharge due to well capture (discussed in Chapter 2). Drainage of an infinite aquifer to a line sink can be described by a first-order exponential decay law of the form:

$$Q_t = Q_o \exp(-kt) \qquad \text{(Equation 4.1)}$$

Where Q_t is the stream discharge at some time t in the hydrological year, Q_o is the initial discharge at the beginning of the hydrological year, and k is a recession constant. Plotting the logarithm of Q versus time may reveal a log-linear relationship whose slope is –k. Integrating the function with respect to time reveals the total potential groundwater discharge to the stream above the gauging station. The difference between remaining-potential discharge at the end of one hydrological cycle and the total-potential discharge at the beginning of the next is a measure of total recharge to the system (see Domenico and Schwartz, 1990, p. 16 for details). Dividing the total recharge obtained through a baseflow recession analysis by the drainage area of the basin contributing to stream flow upstream of a gauging station (and assuming that groundwater divides correspond to surface drainage divides) provides a first-order estimate of annual areal recharge rates. Modern techniques of baseflow separation are discussed in Nathan and McMahon (1990) and Piggot et al. (2001).

As drainage basins get smaller and more geologically complex, and if significant runoff volumes are stored in long-lasting snowpack, muskegs, tributary streams dammed by beavers, etc., then stream flow

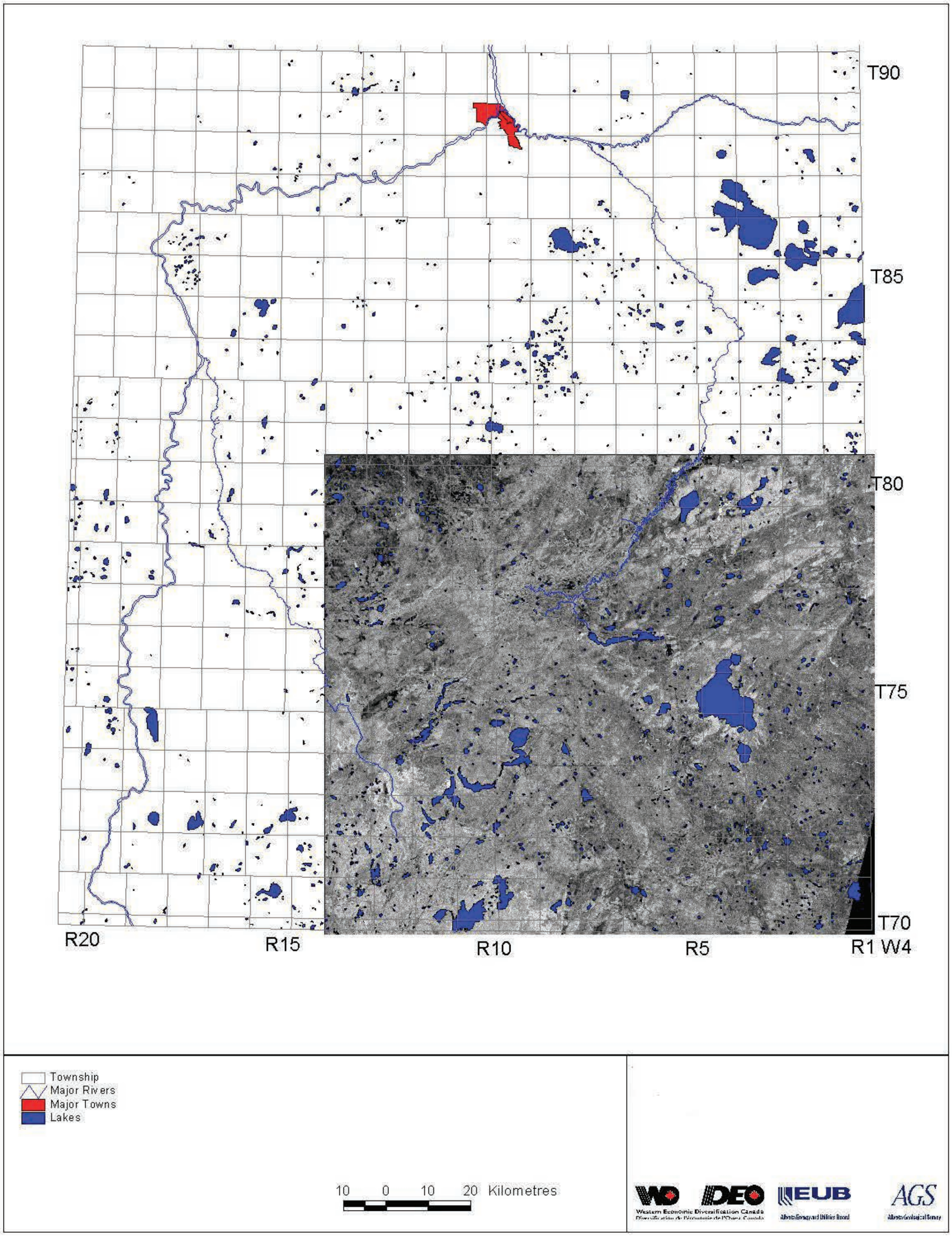

Figure 4.4. Greyscale image of RADARSAT-1 PC1 with lakes highlighted.

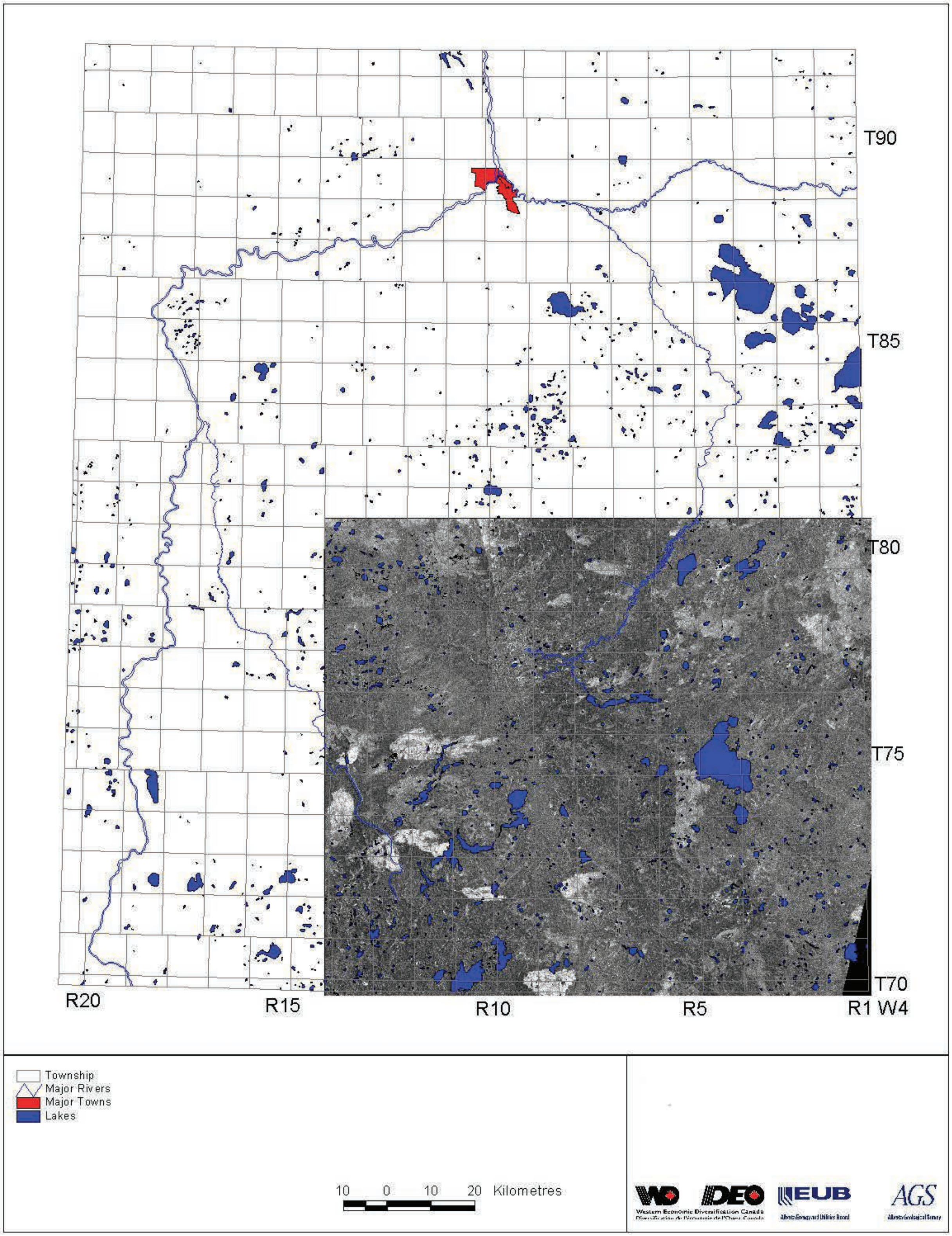

Figure 4.5. Greyscale image of RADARSAT-1 PC2.

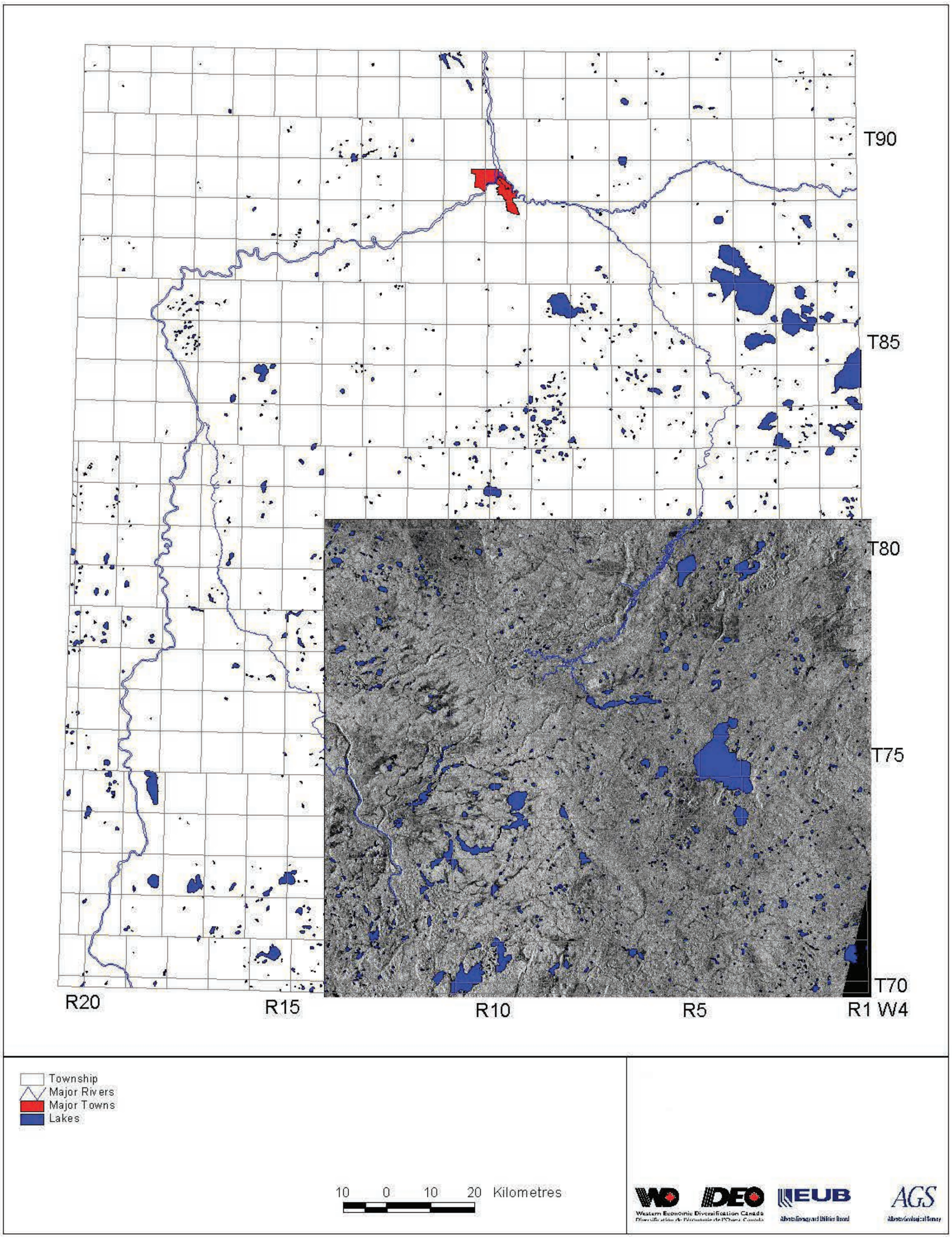

Figure 4.6. Greyscale image of RADARSAT-1 PC3.

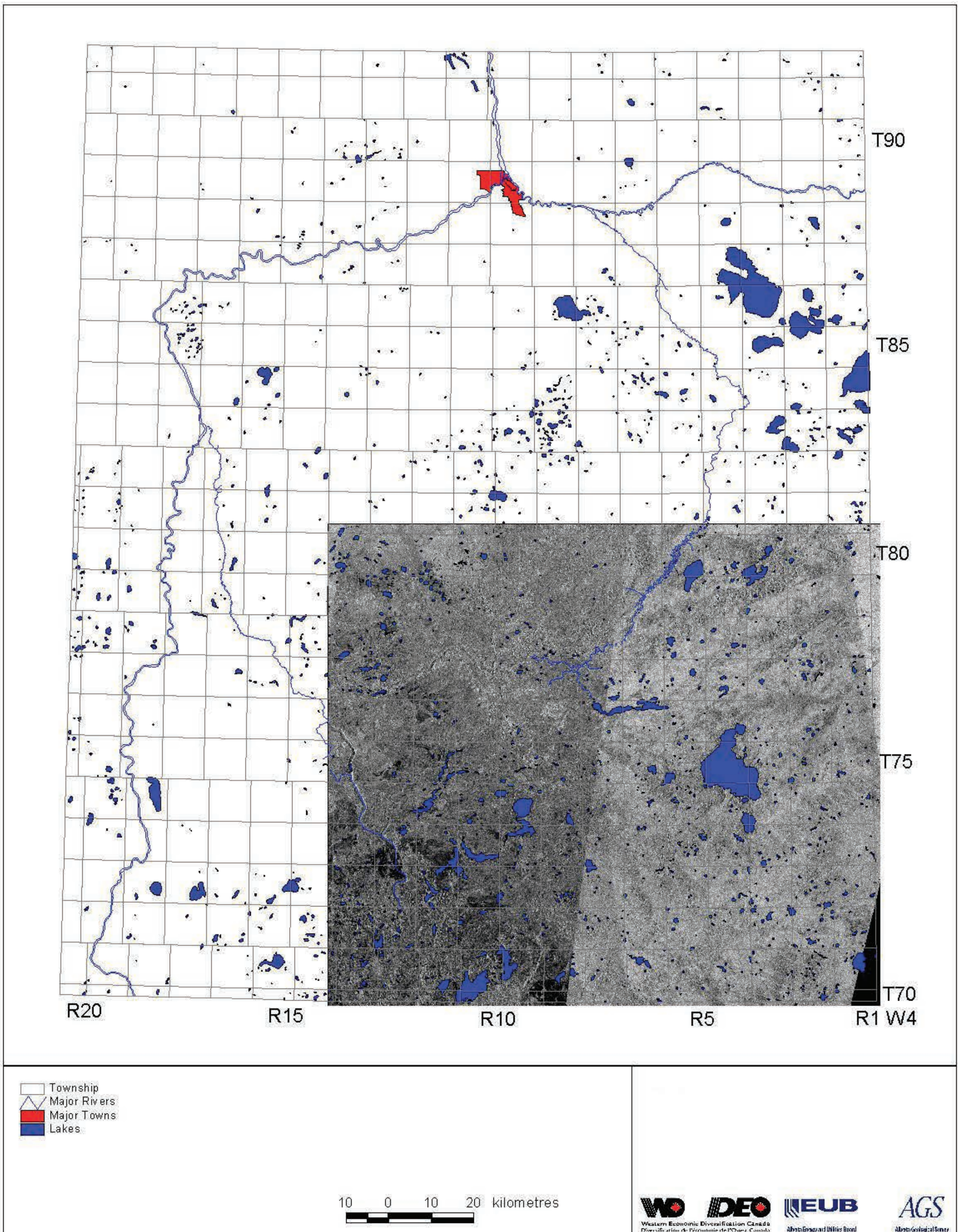

Figure 4.7. Greyscale image of RADARSAT-1 PC4.

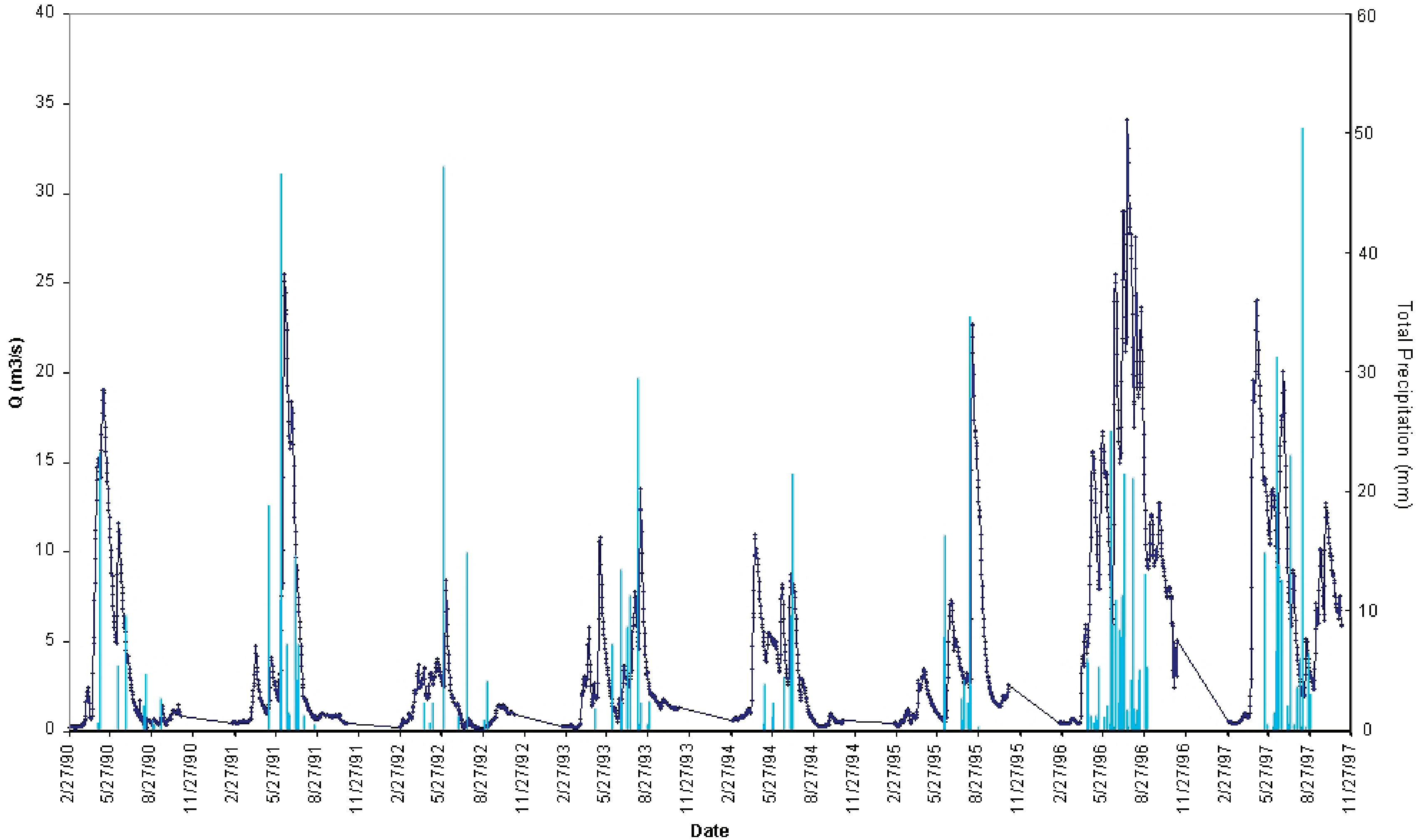

Figure 4.8. House River hydrograph and precipitation.

hydrographs become more difficult to analyse by log-linear graphical methods (Halford and Mayer, 2000). The stream-gauge data in this project's study area certainly suffer from these effects.

In order to arrive at a estimate of baseflow to gauged streams in the Athabasca Oil Sands (In Situ) Area, a recursive digital filter introduced by Nathan and McMahon (1990) was applied because the data were found to be too noisy for conventional log-linear analysis based on Equation 4.1. This simple filter is of the form:

$$f_k = \alpha f_{k-1} + (0.5+\alpha/2)(y_k - y_{k-1}) \qquad \text{(Equation 4.2)}$$

where f_k is the filtered response at the kth sampling instance, y_k is the original streamflow, and α is a filter parameter, and the filtered baseflow is $y_k - f_k$. The baseflow index is the ratio of baseflow to streamflow and indicates the proportion of stream flow coming from groundwater at any instance. Nathan and McMahon (1990) show that unlike other baseflow indictors, the baseflow volumes estimated by this technique actually rise when streamflow rises during storm events, rather than staying constant in such sorts of high-frequency perturbations during the annual recession. This has the effect of making the baseflow index more stable.

The recursive filtering technique was applied to stream-gauge data for the Athabasca, the House, the Horse, the Logan, the Christina, and the Clearwater rivers for the past decade using data obtained from Environment Canada and assuming a filter parameter value of 0.95.

The results show that the baseflow index in all of the streams so analysed was remarkably stable around a value of 0.2 (Figure 4.9). This simply means that about 20% of the water in each stream is coming from groundwater baseflow. This value compares reasonably well to an estimate of 25% of groundwater contribution to stream flow along a reach of the Athabasca River using a method based on stream-flow differences (Hackbarth and Nastasa, 1979).

Future work will use the results of the recursive-filter analysis to estimate areal recharge rates for the drainage basins in the study area. This will be achieved by digitally re-analysing the noisy streamflow data and using Equation 4.2 to estimate time-specific baseflow contributions. Integrating the filtered volumes over the hydrological calendar year will provide an estimate of total yearly baseflow. This number can then be divided by the drainage area above the stream-gauging stations to arrive at a first-order estimate of annual groundwater recharge rates.

4.5 Baseline Discharge and Chemistry at the Wiau Channel Springs Near Wandering River.

A group of freshwater cold springs on the east bank of the Athabasca River, near Wandering River, was monitored from 1999 to 2001 (Figure 4.10). These unnamed springs have been given the working name of the Wiau Channel Springs by AGS, to signify their hydraulic relationship with the sand and gravel of the Empress Formation, which lies on the bedrock surface within the Wiau Channel, discussed in detail in Chapters 6 and 7.

The existence of the springs, presumably long known to local trappers and hunters, was independently forecast to exist by AGS based on the geomorphology of the Athabasca River. Where the Athabasca River intersects buried channels marking pre-glacial incisement of the top of bedrock, fluvial-erosive and spring-sapping processes cause the river to cut back further into the buried channel sediments more than elsewhere along its banks. This geomorphology is known to occur at several other localities in Alberta where modern rivers crosscut buried paleovalleys.

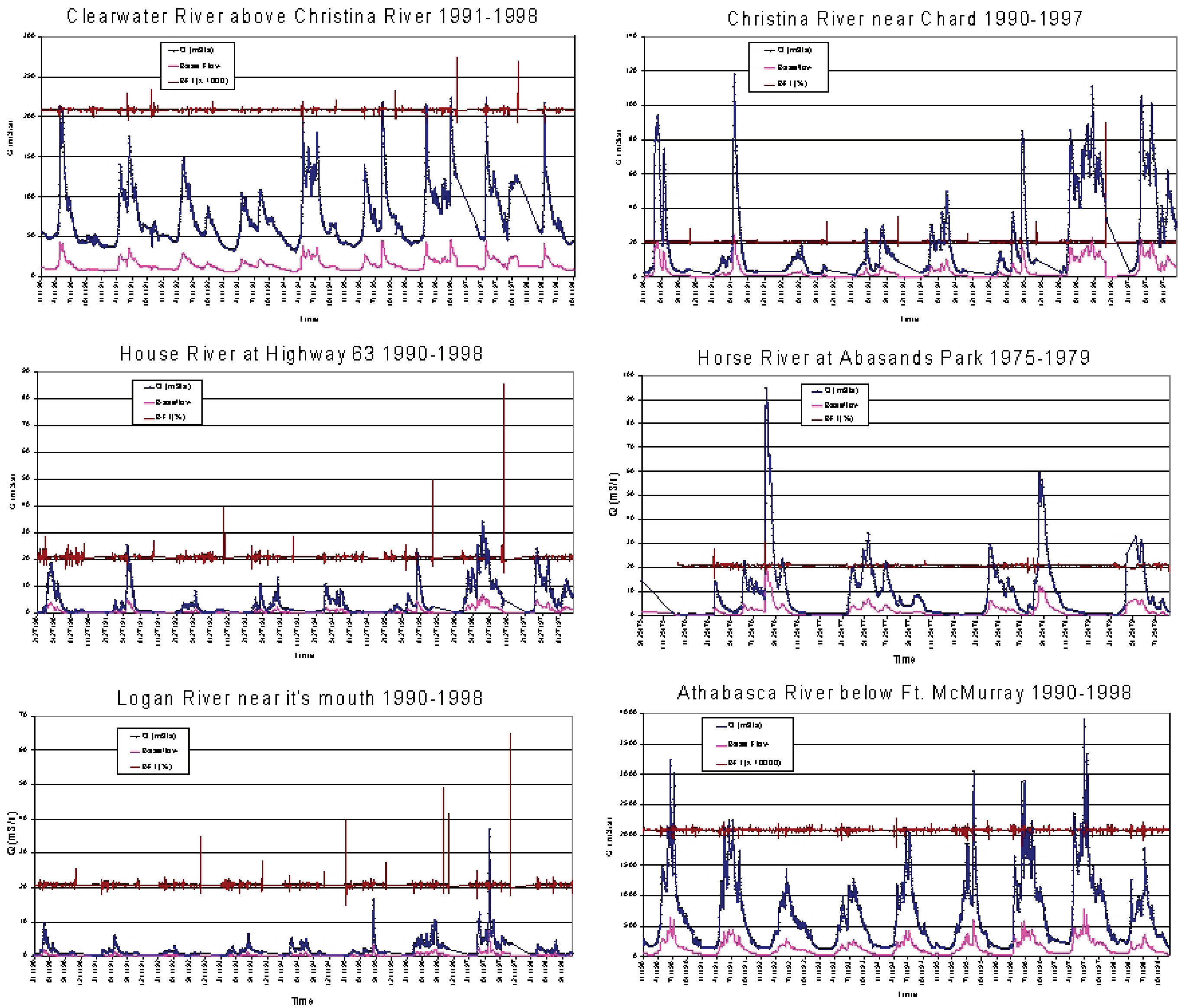

Figure 4.9. Baseflo indices by recursive filterin and hydrographs for selected rivers.

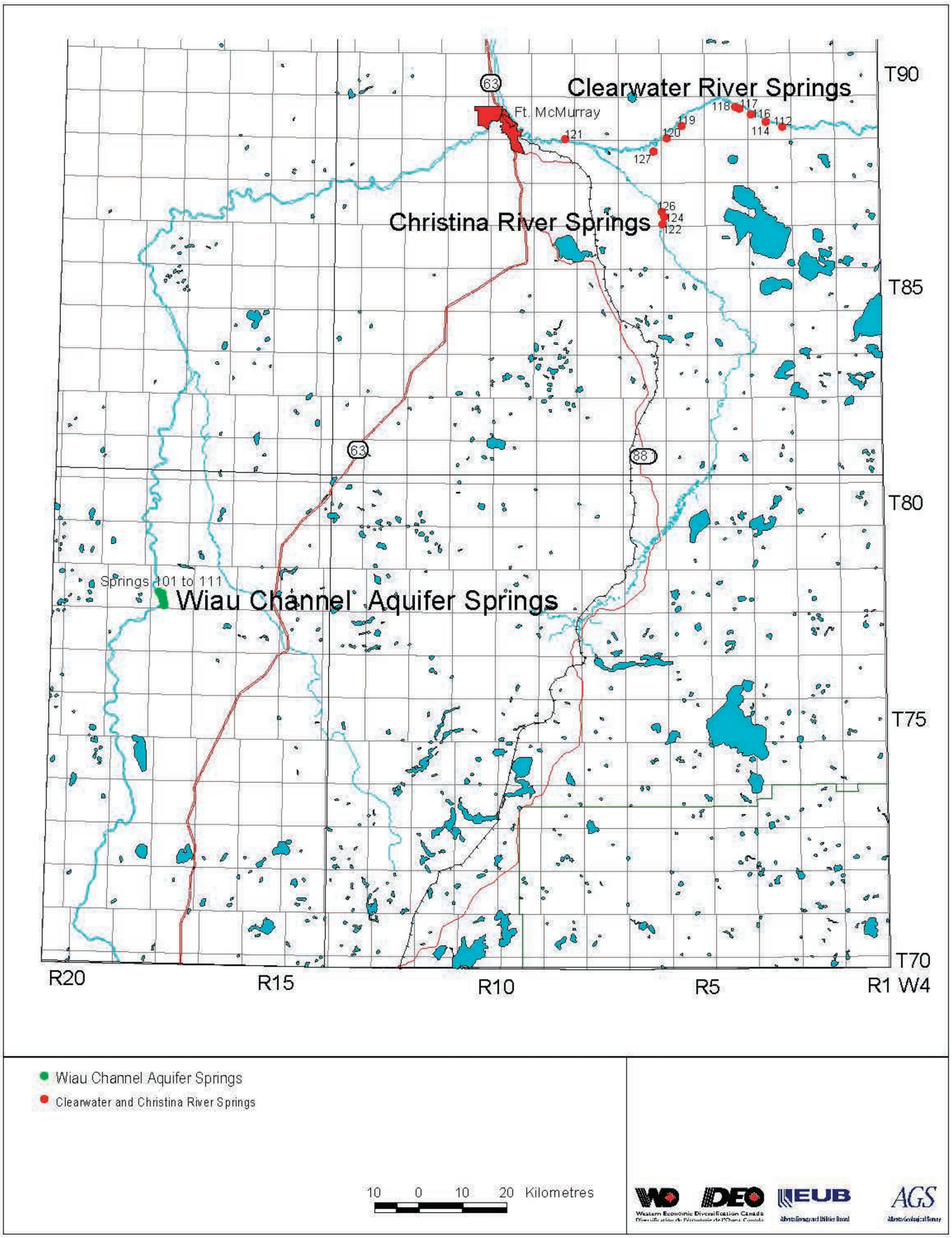

Figure 4.10. Locations of springs in study area known to AGS, 2001.

A traverse by AGS geologists in December 1999 located the springs at the predicted confluence of the Wiau Buried Channel Aquifer and the Athabasca River. Detailed mapping revealed at least nine springs at the locality with discharges great enough to form their own tributary streams feeding the Athabasca River (Figure 4.11). Many smaller springs and seeps undoubtedly exist in the relatively inaccessible and extremely swampy east bank of the Athabasca at the locality.

The springs are believed to be contact springs, formed by the intersection of the phreatic surface in the sand and gravel deposits of the Empress Formation with the underlying low-permeability shale of the Cretaceous Colorado (or equivalently the La Biche) Formation in the Wiau bedrock lowlands. Though the amount of slumping and heavy vegetation seems to have totally covered any sediment-bedrock contact at the locality, mapping of bedrock topography elevations (see Chapter 6) indicates that the elevation of the bottom of the Empress Formation in the Wiau Channel more or less equals the elevation of the Athabasca River. A topographic profile across the Athabasca River showing these relationships is shown in Figure 4.12.

The springs were visited monthly during the course of this project to monitor their stream flows. Photo-documentation of the springs in various seasons taken in 1999 to 2001 is shown in Figure 4.13. Springs fed by local groundwater flow-systems tend to have seasonal variation in discharge, temperature, and chemistry. Springs fed by more regional groundwater flow-systems tend to be more constant in terms of their discharge, temperature, and chemistry. Monthly discharges were recorded in streams whenever accessible (a function of river stage) using an in-stream flow meter. The results are in Table 4.3. The stability of the discharges suggest that the springs are not being sourced locally but represent discharge from a larger, regional groundwater system that is less sensitive to annual climatic variations.

In addition to monthly stream flow monitoring, a weir and still well were constructed on the largest spring-fed stream, emanating from a site referred to as Spring 2. A construction schematic is shown in Figure 4.14. The weir was built according to ASTM Standard Method D 5242-92 (ASTM, 1992). Its function was to more accurately gauge the stream flow in the interval between the monthly visits. The still well is installed behind the weir and is equipped with a float gauge and a continuous chart recorder. The height of the water behind the weir is directly correlated to stream flow over the weir (see Fetter, 1994, p. 69). Construction of the weir is photo-documented in Figure 4.15.

Figure 4.16 shows a hydrograph of stream levels recorded by the still well during 2000 and 2001. For comparison, monthly precipitation values are shown for the nearest monitoring station, May Lookout, as well as a rain gauge installed on site. The hydrograph shows two significant features. First, there is remarkably steady flow over most of the year with fluctuations presumably related to local precipitation events. Second, there is an unexplained and significant rise in average stream level, and therefore spring discharge, from 2000 to 2001. Note that the still well froze during the winter of 2000-2001 even though flow continued.

The rise in stream level is not due to an increase in average annual precipitation because the measured levels are lower in 2001 than in 2000. A hypothesis to explain the increase in spring-fed stream flow is that the higher levels in 2001 actually reflect higher precipitation values in 2000, and that there is a one-year lag time between an increase in precipitation and an increase in stream flow. This would imply that there is a locally-sourced component of groundwater flow to the springs. Several more years of monitoring would be needed to test this hypothesis.

Water samples were obtained from Springs 2 and 8 in accordance to the sampling protocols listed in Appendix 6. The major ion chemistry is plotted on a Piper plot in Figure 4.17. The waters are generally a sodium bicarbonate type. Shallow groundwater tends to be calcium bicarbonate type, with the evolution

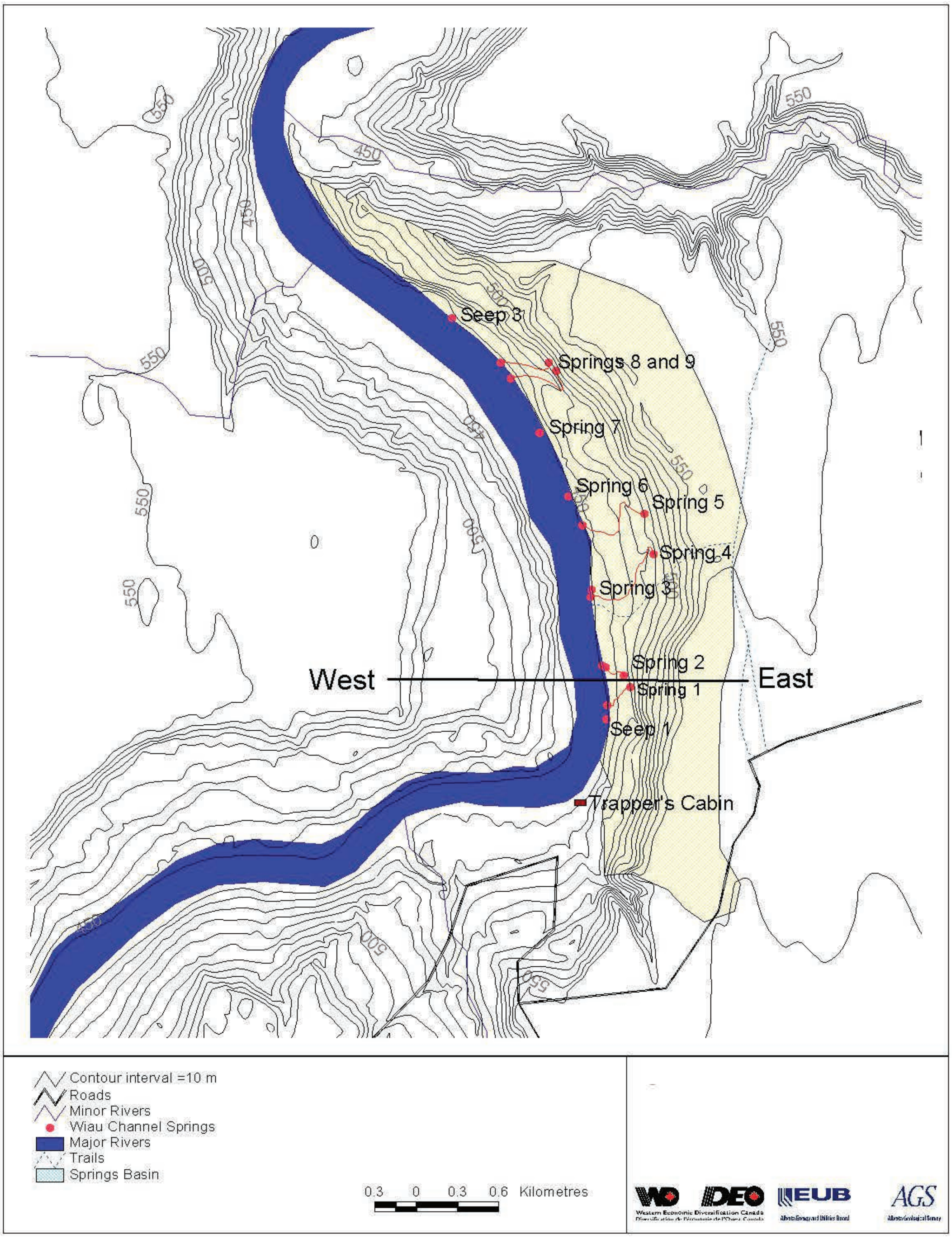

Figure 4.11. Locality map, Wiau Channel Springs.

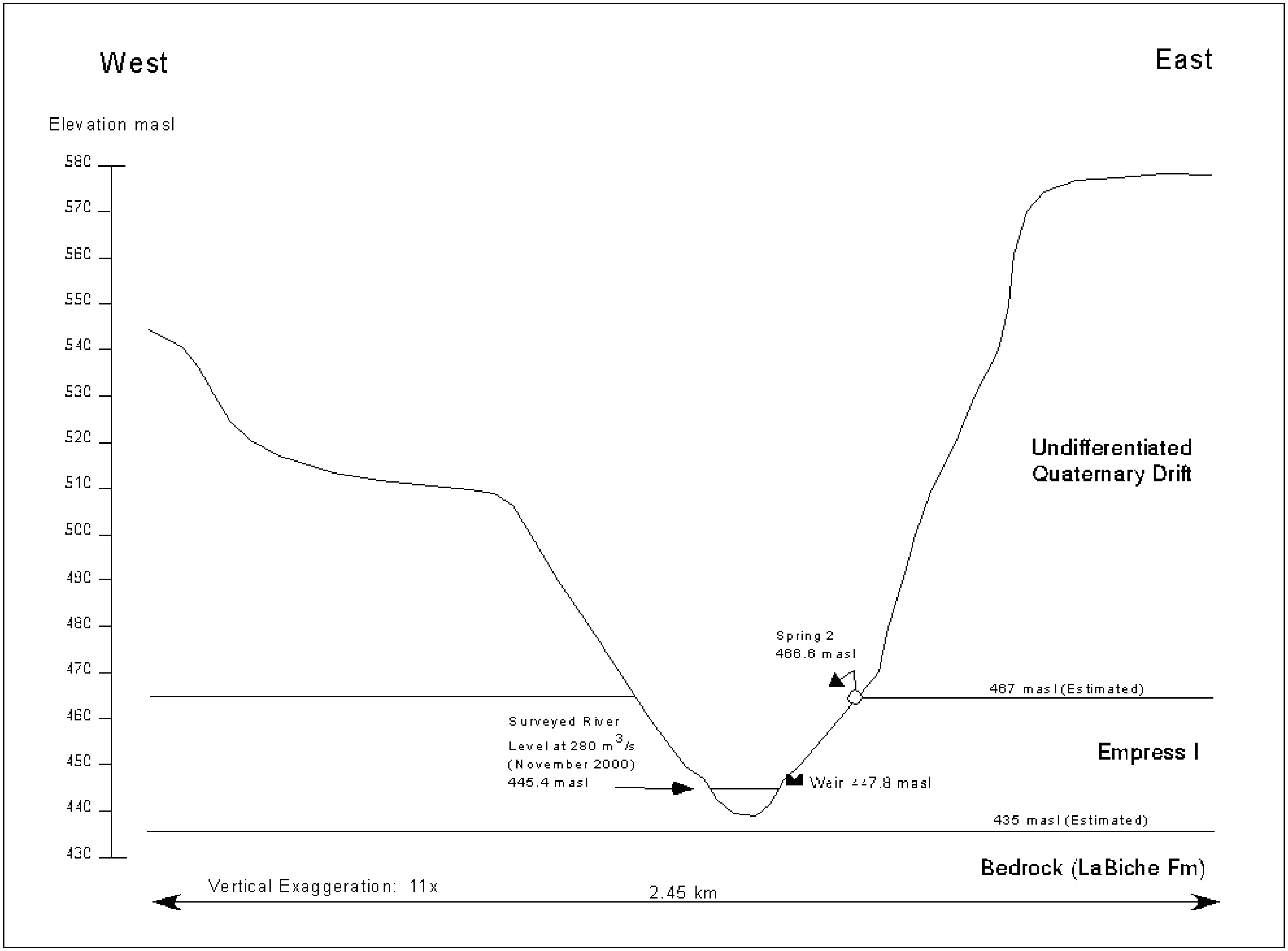

Figure 4.12. Topographic profil across Athabasca River showing postulated geological relationships at Wiau Channel Springs.

Figure 4.13a. Spring 1 November 2001

Figure 4.13b. Spring 2 September 2001

Figure 4.13c. Spring 3 August 2001

Figure 4.13d. Spring 3 April 2001

Figure 4.13e. Spring 5 October 2001

Figure 4.13f. Spring 9 September 2001

Figure 4.13g. Spring 2 source surveyed for elevation November 2000

Figure 4.13h. Spring 1 flowing into Athabasca River November 2000

Figure 4.13i. Year-round plant growth February 1999

Figure 4.13j. Spring 2 source plant growth June 2001

Figure 4.13k. Spring 2 flowing into Athabasca River June 2001

Figure 4.13l. Weir and Still Well setup July 2001

Table 4.3. Monthly stream flo readings of selected spring-fed streams, Wiau Channel Springs locality.

Date	Spring 1 Volume (l/s)	Measurement Method	Spring 2 Volume (l/s)	Measure-ment Method	Head on Guage Board (m)	Spring 2 Vol-ume Calculated from guage board (l/s)	Spring 3 Volume (l/s)	Measurement Method	Spring 4 Volume (l/s)	Measurement Method
16-Aug-00	n/m		35.6362	Flow Meter	0.200	24.755	n/m		n/m	
17-Aug-00	24.1621	Flow Meter	32.7540	Flow Meter	0.200	24.755	9.2535	Flow Meter	14.6243	Flow Meter
14-Sep-00	36.1663	Flow Meter	31.4034	Flow Meter	0.200	24.755	9.4362	Flow Meter	10.0304	Flow Meter
12-Oct-00	30.8099	Flow Meter	23.1827	Flow Meter	0.200	24.755	7.8090	Flow Meter	11.1671	Flow Meter
15-Nov-00	21.4453	Flow Meter	27.5404	Flow Meter	0.195	23.248	2.9596	Flow Meter	12.1828	Flow Meter
18-Feb-01	n/m		n/m		0.216	29.961	n/m		n/m	
20-Mar-01	n/m		28.7750	Flow Meter	0.225	33.153	n/m		5.6800	Estimated
25-Apr-01	26.5913	Flow Meter	35.7188	Flow Meter	0.230	35.010	2.0419	Flow Meter	12.1600	Flow Meter
25-Apr-01					0.230	35.010			4.7000	Estimated
25-May-01	39.24317	Flow Meter	35.6899	Flow Meter	0.232	35.770	3.5037	Flow Meter	6.2268	Flow Meter
25-Jun-01	29.3357	Flow Meter	36.9591	Flow Meter	0.234	36.539	7.3891	Flow Meter	7.4199	Flow Meter
26-Jul-01	27.3488	Flow Meter	40.4373	Flow Meter	0.233	36.153	1.1300	Estimated	8.6622	Flow Meter
28-Aug-01	17.8832	Flow Meter	23.9365	Flow Meter	0.228	34.260	2.8281	Flow Meter	8.8471	Flow Meter
29-Aug-01	n/m		n/m				n/m		n/m	
08-Sep-01	n/m		n/m		0.232	35.770	n/m		n/m	
27-Sep-01	27.0848	Flow Meter	38.5951	Flow Meter	0.234	36.539	8.6771	Flow Meter	8.5575	Flow Meter
28-Sep-01	n/m		n/m				n/m		n/m	
26-Oct-01	22.7700	Flow Meter	28.0848	Flow Meter	0.234	36.539	4.4308	Flow Meter	6.9640	Flow Meter
27-Nov-01	26.2900	Flow Meter	34.5323	Flow Meter	0.230	35.010	5.2990	Flow Meter	4.7790	Flow Meter
27-Nov-01	n/m		n/m		0.230	35.010	n/m		n/m	
Averages	27.4275		32.3747			32.0550	5.3965		8.7144	

Spring 5 Volume (l/s)	Measurement Method	Spring 6 Volume (l/s)	Measurement Method	Spring 7 Volume (l/s)	Measurement Method	Spring 8 Volume (l/s)	Measurement Method
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
6.1000	Estimated	0.0800	Estimated	0.7500	Estimated	0.7800	Estimated
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		4.3658	Flow Meter
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		n/m	
n/m		2.2500	1L bottle	n/m		3.5591	Flow Meter
n/m		n/m		n/m		n/m	
n/m		n/m		n/m		3.1212	Flow Meter
n/m		n/m		n/m		n/m	
1.7000	Estimated	n/m		n/m		3.2858	Flow Meter
n/m		n/m		n/m		3.5668	Flow Meter
n/m		n/m		n/m		n/m	
3.9000		1.1650		0.7500		3.1131	

Spring 9 Volume (l/s)	Measurement Method	Seeps Volume (l/s)	Measurement Method	Total volume from flowmeter (l/s)	Total volume from flowmeter (m3/d)	Precipitation (mm)	Type of Precipitation
n/m		n/m		115.4292	9973.0833		
n/m		n/m		146.0617	12619.7327		
n/m		n/m		145.4976	12570.9944		
n/m		n/m		102.7021	8873.4585	35.000	rain
n/m		n/m		110.3257	9532.1401	10.000	ice
n/m		n/m					
7.6000	Estimated	0.3000	Estimated	92.2694	7972.0731		
n/m		n/m		114.4858	9891.5737	14.000	rain
n/m		n/m					
6.3200	Flow Meter	n/m		131.4943	11361.1046	13.500	rain
n/m		n/m		119.4460	10320.1362	36.000	rain
n/m		n/m		130.0982	11240.4833	61.000	rain
n/m		n/m		107.7915	9313.1883	250.000	rain
4.4292	Flow Meter	n/m					
n/m		n/m				70.000	rain
n/m		n/m		130.4910	11274.4240	15.000	rain
n/m		n/m				1.600	rain
5.5210	Flow Meter	n/m		124.2132	10732.0218	12.400	ice
6.5355	Flow Meter	n/m		117.1288	10119.9273	2.500	ice
n/m		n/m		35.2398	3044.7201	77.500	snow
6.0811		0.3000		123.0482	10631.3615		

Notes1	Notes2
Environment flowmeter	
Environment flowmeter	
Environment flowmeter	
Environment flowmeter	
AGS uncalibrated flowmeter (measurements suspect)	
Environment flowmeter	
AGS Calibrated flowmeter	Rainguage cracked, measurement suspect, sealed temporarily with tape
AGS Calibrated flowmeter	New Rainguage
AGS Calibrated flowmeter	
AGS Calibrated flowmeter	
AGS Calibrated flowmeter	
AGS Calibrated flowmeter	Rainguage not emptied, subtract 1.6mm from next reading
AGS Calibrated flowmeter	
AGS Calibrated flowmeter	
AGS Calibrated flowmeter	

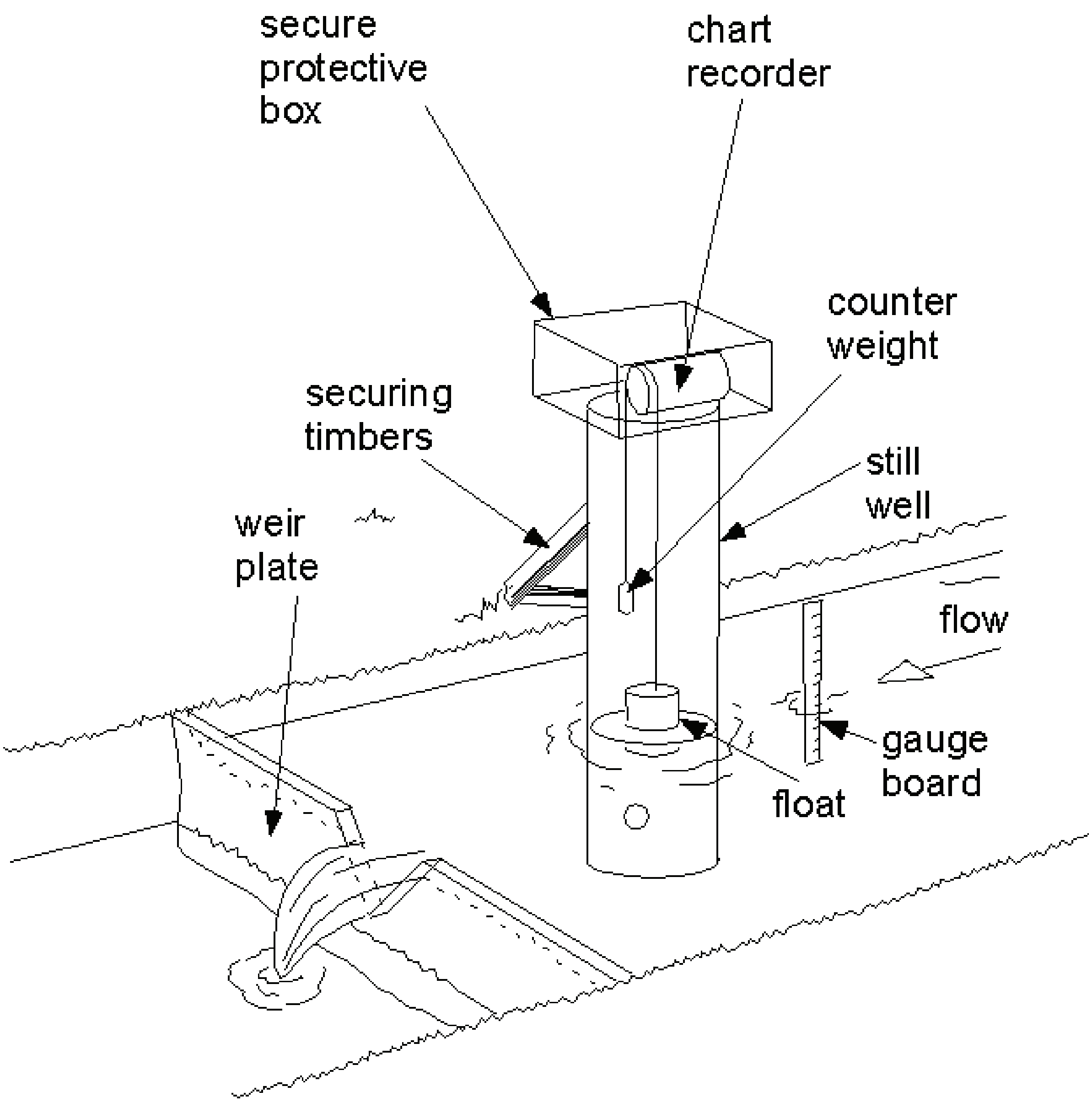

Figure 4.14. Construction schematic of weir and still well on stream from Spring 2 at Wiau Channel Springs (not to scale).

Figure 4.15a. Spring 2 before monitoring August 2000.

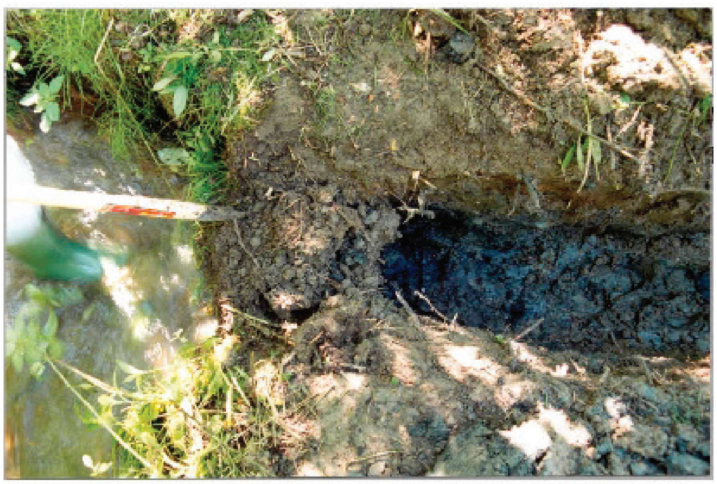

Figure 4.15b. Diversion trench August 2000.

Figure 4.15c. Diversion trench August 2000.

Figure 4.15d. Weir plate installation august 2000.

Figure 4.15e. Still well installation August 2000.

Figure 4.15f. Dam release August 2000.

Figure 4.15g. Flow over weir plate August 2000.

Figure 4.15h. Chart recorder setup August 2000.

Figure 4.15i. Flow measurements August 2000.

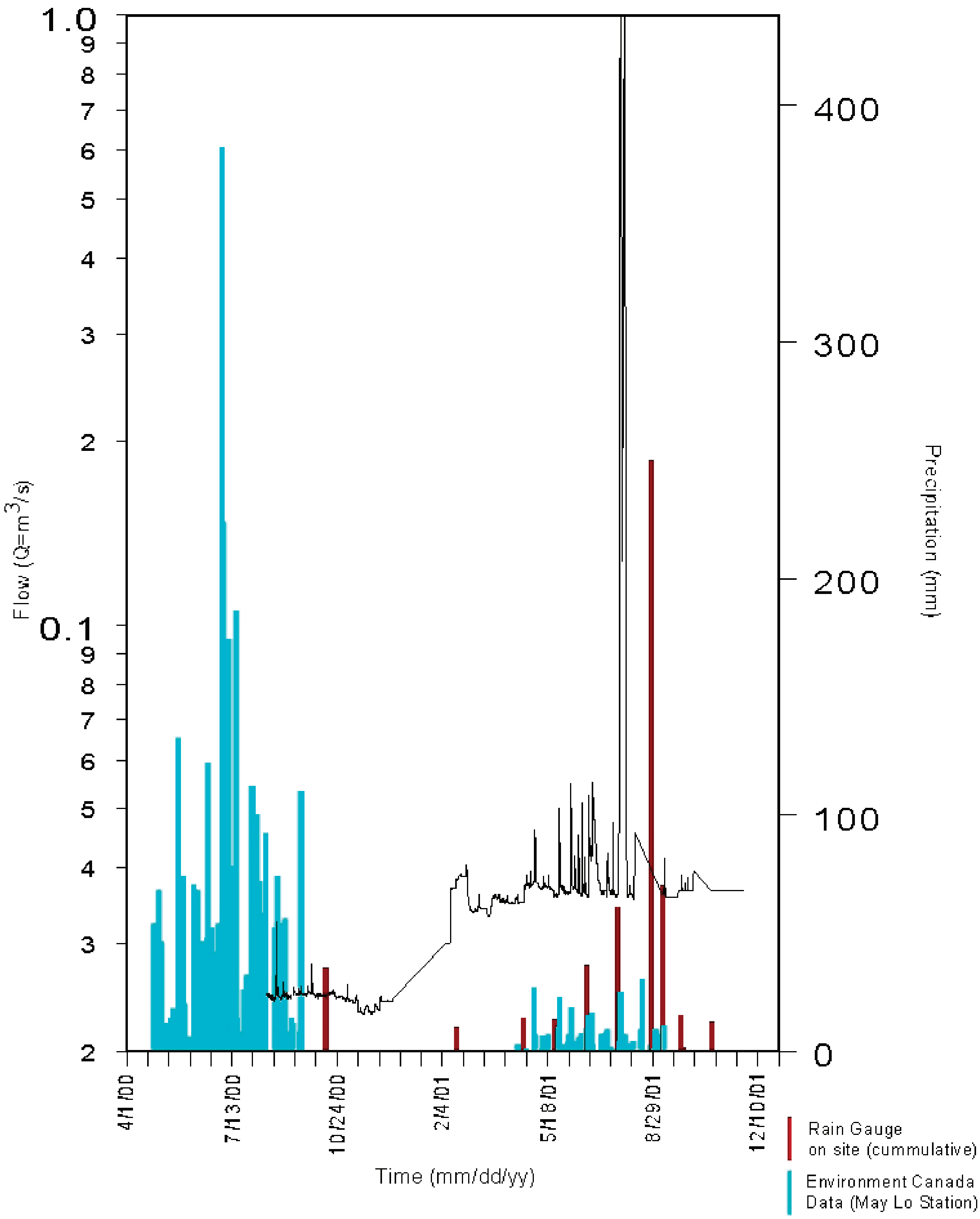

Figure 4.16. Stream-level hydrograph from still well and monthly precipitation from on-site rain guage, Wiau channel Spring 2, 2000 and 2001.

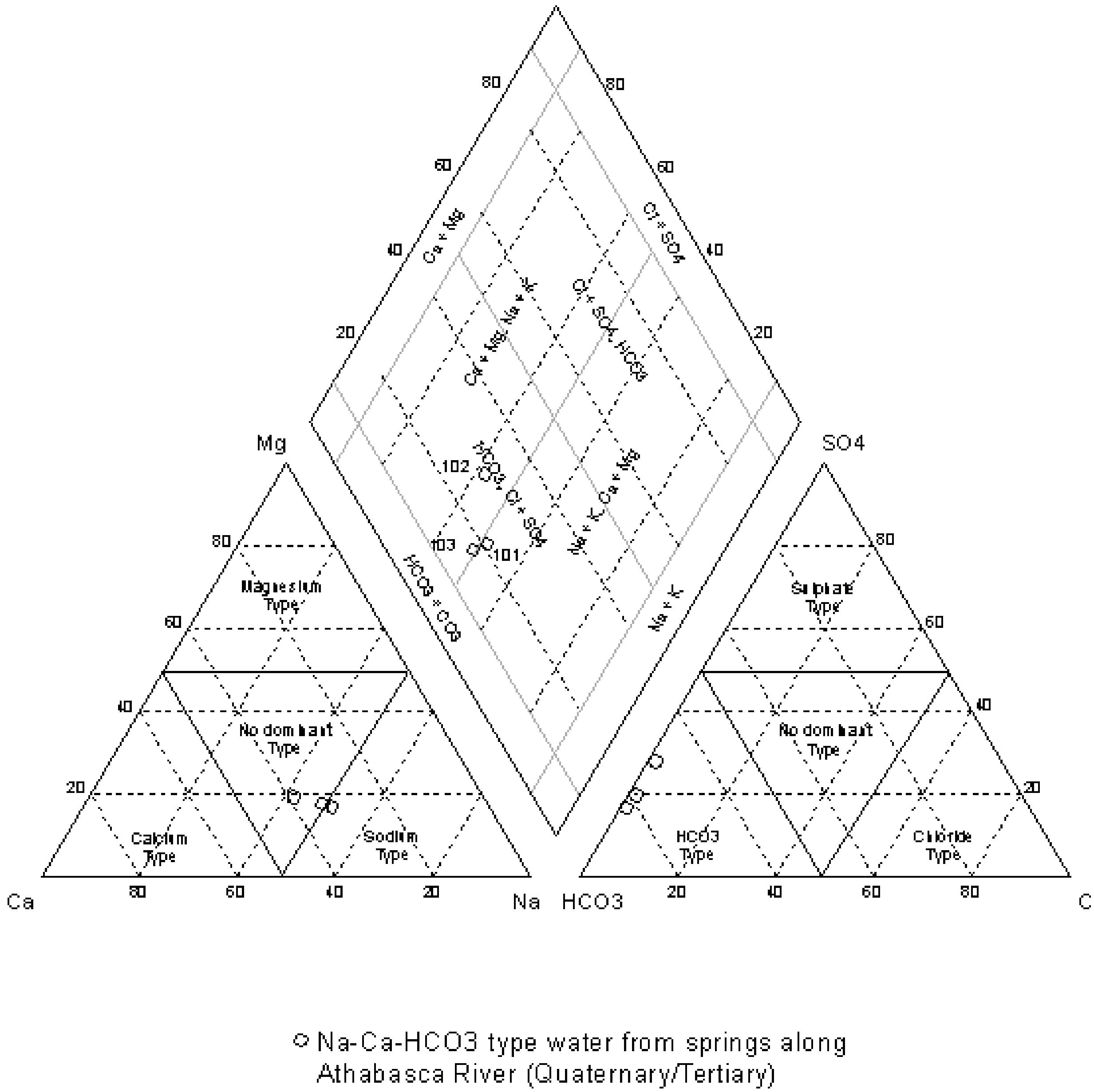

Figure 4.17. Piper plot showing Wiau Spring water samples.

towards a sodium bicarbonate type being the result of natural water-softening processes active in the clay-rich tills which blanket the area. This process is discussed more in Chapter 8. The observation that these are very nearly sodium bicarbonate waters suggests that the water emanating from the springs is at least partly composed of groundwaters that have undergone natural water softening.

Water samples were collected from the same springs and analysed for isotopes of hydrogen and oxygen. Natural distillation processes in the atmosphere cause progressive depletion in the $\delta^{18}O$ and $\delta^{2}H$ ratios with distance north of the equator. The average progression of isotopic depletion for a given area is represented on a graph of $\delta^{18}O$ versus $\delta^{2}H$ by a local meteoric water line ((e.g. Clark and Fritz, 1997). Water whose isotopic ratios fall on or near the meteoric water line are considered to be of meteoric origin. Water that has undergone evaporation or rock-water interaction will tend to fall a significant distance away from the meteoric water line. It needs to be remembered, however, that past variations in humidity causes upward or downward shifts in the paleo-meteoric water lines.

The $\delta^{18}O$ and $\delta^{2}H$ ratios for the Wiau Channel Springs are shown in Figure 4.18. There are more than two samples because the springs were sampled repeatedly during the project. The position of the samples from Wiau Channel Springs on the graph relative to the local meteoric water line (Rozanski et al, 1993) indicates that the water is meteoric in origin. The values are isotopically enriched relative to snowmelt from the area, indicating that they are not being fed directly by snowmelt.

The spring waters were also analysed for stable isotope composition of carbon in dissolved inorganic carbon. The results are shown in Figure 4.19. The $\delta^{13}C$ values are plotted on a chart representing the abiotic evolution of $\delta^{13}C$ ratios in groundwater in natural systems (after Clark and Fritz, 1997). The values of $\delta^{13}C$ are in the ranges of values expected for groundwater that is dissolving calcite under closed conditions characterized by a low ambient partial pressure of CO_2. There is no indication of bacterial-mediated methanogenesis in these water samples.

Full chemical analysis results for the Wiau Channel Springs water-samples are in Table 4.4.

4.6 Baseline Chemistry of Saline Springs along the Christina and Clearwater Rivers

Saline and effervescent springs occur along the Christina and Clearwater rivers in the northeast part of the study area (see Figure 4.10). Grab samples of selected spring waters were collected by AGS in 2001 for geochemical characterization. Because of their high salinity, their locations close to known outcrops of Lower Cretaceous formations, and their location proximal to the subsurface edge of dissolution of the Prairie Formation evaporites, these saline springs have long been presumed to be discharging fluids from these formations, presumably at the discharge ends of deep, regional groundwater flow-systems (R. Stein, pers. comm.).

The springs have TDS values that range from 6900 to 40,500 mg/l. Full chemical analyses are shown in Table 4.4.

The chloride/bromide ratios were examined to determine if any of the saline water was sourced from the deeply buried evaporites. Davis et al. (1998) report that atmospheric precipitation will have Cl/Br mass ratios between 50 to 150, shallow groundwater between 100 and 200, and water affected by the dissolution of halite between 1000 and 10000. Seawater has a Cl/Br mass ratio of approximately 289. The calculated mass ratios fall between 1000 to 3000 (Figure 4.20), suggesting that dissolution of halite is contributing to the composition of the groundwater or formation water at some of these springs. Interestingly, the oxygen and hydrogen isotope values are relatively depleted and fall above the meteoric water line of Rozanski et al. (1993). The isotopic shift above the meteoric water line may indicate meteoric origin of the water but at different conditions of humidity at the time of recharge. The degree of depletion suggests that these waters could be partly comprised of snow or glacial meltwaters.

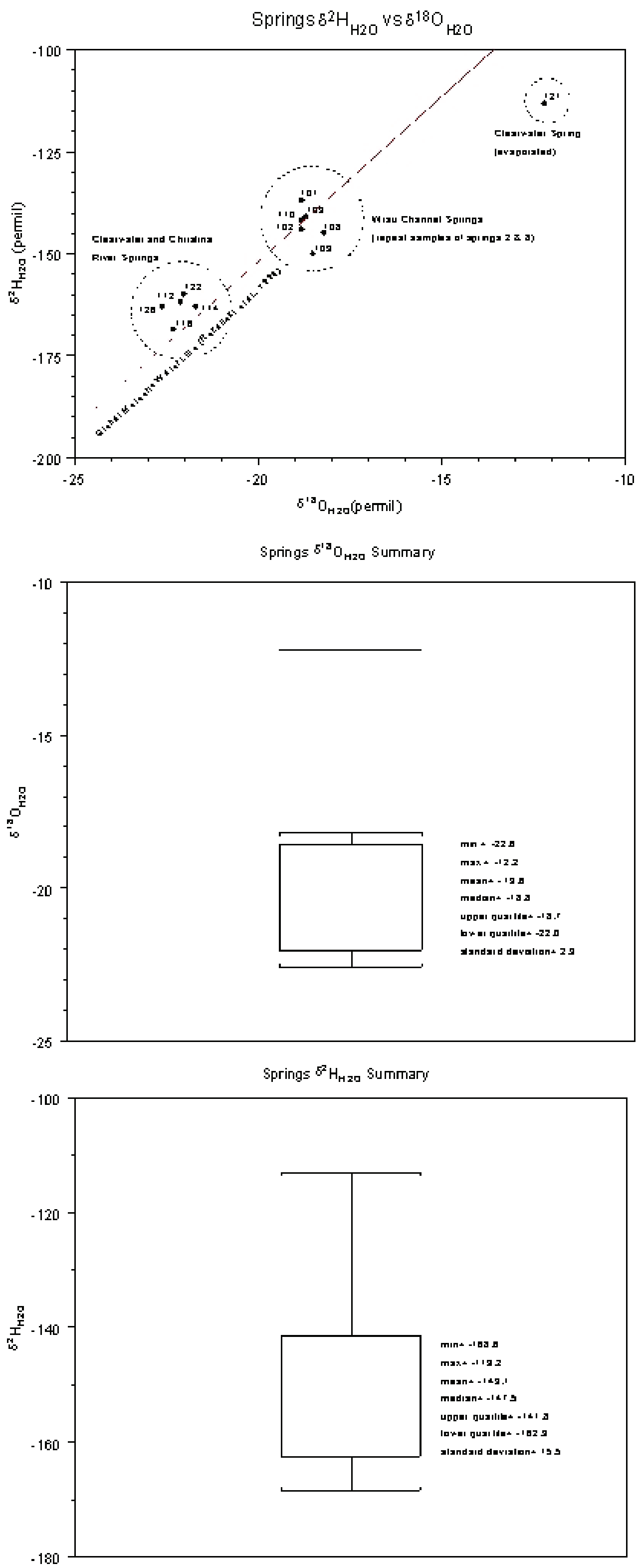

Figure 4.18. δ^2H versus $\delta^{18}O$ of Wiau channel springs samples with meteoric water line for reference.

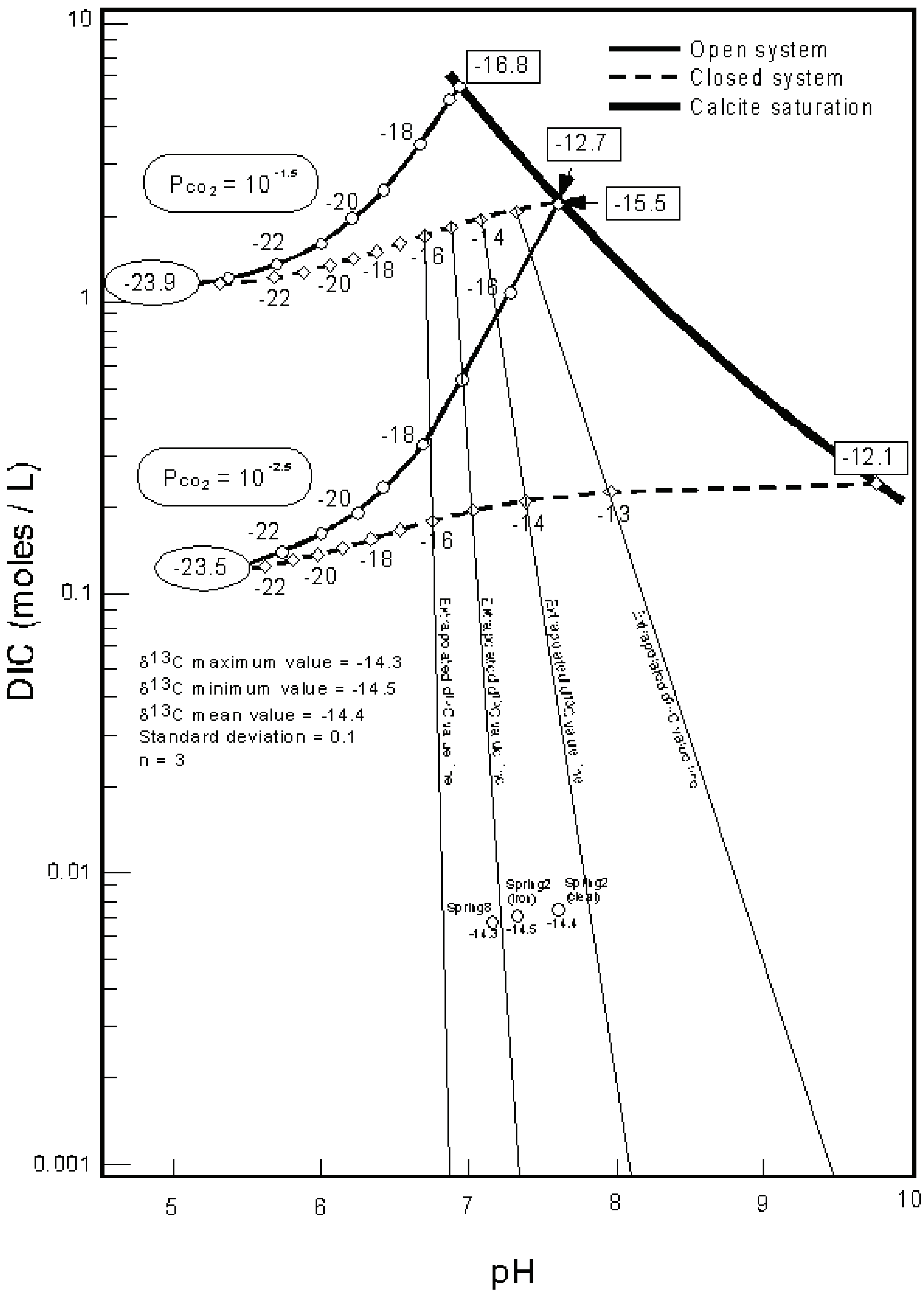

Figure 4.19. Plot of $\delta^{13}C$ values from Wiau Channel Springs relative to abiotic evolution of $\delta^{13}C$ in waters (modified from Clark and Fritz, 1997, Environmental Isotopes in Hydrogeology).

Table 4.4. Chemical analyses of waters from selected springs at Wiau channel springs locality and along the Christina and Clearwater Rivers.

Key	DLS	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (m)	Elevation Determined by	Formation	Spring
101	09-05-078-17W4	55.731800	112.594100	399892.9	6177164.9	466.6	Surveyed	Quaternary/Tertiary	Spring2(clear)
102	09-05-078-17W4	55.731800	112.594100	399892.9	6177164.9	466.6	Surveyed	Quaternary/Tertiary	Spring2(iron)
103	02-17-078-17W4	55.751510	112.602890	399396.0	6179587.0	490	Map estimate	Quaternary/Tertiary	Spring8
104	09-05-078-17W4	55.729870	112.596150	399928.0	6177301.0	470	Map estimate	Quaternary/Tertiary	Spring1
105	04-09-078-17W4	55.739710	112.591250	400096.0	6178257.0	487	Map estimate	Quaternary/Tertiary	Spring4
106	16-05-078-17W4	55.737300	112.598300	399649.0	6178002.0	450	Map estimate	Quaternary/Tertiary	Spring3
107	05-09-078-17W4	55.742350	112.592410	400030.0	6178553.0	491	Map estimate	Quaternary/Tertiary	Spring5
108	09-05-078-17W4	55.731800	112.594100	399892.9	6177164.9	466.6	Surveyed	Quaternary/Tertiary	Spring2(iron)
109	09-05-078-17W4	55.731800	112.594100	399892.9	6177164.9	466.6	Surveyed	Quaternary/Tertiary	Spring2(clear)
110	09-05-078-17W4	55.731800	112.594100	399892.9	6177164.9	466.6	Surveyed	Quaternary/Tertiary	Spring2(iron)
111	09-05-078-17W4	55.731800	112.594100	399892.9	6177164.9	466.6	Surveyed	Quaternary/Tertiary	Spring2(clear)
112	06-11-089-03W4	56.709306	110.354666	539513.6	6284933.6	280	Map estimate	Devonian?	RS94-01
114	10-16-089-03W4	56.719306	110.416444	535703.6	6286065.2	280	Map estimate	Devonian?	RS94-02
116	06-19-089-03W4	56.734200	110.471900	532290.5	6287718.8	290	Map estimate	Devonian?	RS94-03
118	11-26-089-04W4	56.749222	110.529222	528771.5	6289372.5	290	Map estimate	Devonian?	RS94-05a
121	03-02-089-08W4	56.684583	111.156833	490393.6	6282083.2	260	Map estimate	Devonian?	RS96-20
122	05-06-087-05W4	56.513300	110.798100	512420.2	6263033.1	310	Map estimate	Devonian?	RS97-44
126	04-18-087-05W4	56.537916	110.800167	512274.7	6265758.4	320	Map estimate	Devonian?	RS97-55

Key	Sample Date	Field Temp	Field pH	Field Cond	Field Cond units	Field ORP (mV)	Field Eh (mV)	Field DO (mg/L)	Field T-Alk (mg/L)	pHL	Laboratory Conductivity	Laboratory Conductivity units
101	September 26, 2001	8.60	7.60	600.00	uS/cm	-68.00	147.50	3.8	192.00	8.34	830	uS/cm
102	September 26, 2001	6.10	7.35	578.00	uS/cm	-70.00	147.80	3.22	172.00	8.13	867	uS/cm
103	September 26, 2001	5.80	7.19	551.00	uS/cm	-66.00	152.20	0.1	175.00	8.41	771	uS/cm
104	September 27, 2001	5.40	7.55	564.00	uS/cm	-144.00	74.50	0.25	175.00	N/A	N/A	
105	September 27, 2001	5.30	7.68	416.00	uS/cm	16.00	234.70	3.45	138.00	N/A	N/A	
106	September 27, 2001	5.10	7.50	465.00	uS/cm	-167.00	51.90	0.33	167.00	N/A	N/A	
107	September 27, 2001	5.50	7.65	525.00	uS/cm	53.00	271.50	2.3	196.00	N/A	N/A	
108	September 14, 2000	7.60	7.97	627.00	uS/cm	-145.00	71.40	6.35	200.00	N/A	N/A	
109	November 15, 2000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
110	June 25, 2001	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
111	June 25, 2001	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
112	October 13, 2001	4.60	7.39	9.52	mS/cm	-297.00	-77.60	0.62	312.00	8.22	11700	uS/cm
114	October 13, 2001	4.80	7.06	19.60	mS/cm	-326.00	-106.80	0.1	280.00	7.79	24000	uS/cm
116	September 12, 1994	6.40	6.85	18100.00	umohs	N/A	N/A	N/A	N/A	7.80	30900	uS/cm
118	September 12, 1994	3.90	7.05	13400.00	umohs	N/A	N/A	N/A	N/A	7.90	12400	uS/cm
121	August 26, 1996	19.40	6.11	44000.00	umohs	N/A	N/A	N/A	N/A	7.28	24400	uS/cm
122	October 13, 2001	4.40	7.25	45.60	mS/cm	-239.00	-19.40	3.4	1630.00	7.86	43800	uS/cm
126	October 13, 2001	5.00	6.87	33.00	mS/cm	-166.00	53.00	1.23	653.00	7.80	32400	uS/cm

Key	Laboratory P-Alkalinity (mg/L CaCO3)	Laboratory Total Alkalinity (mg/L CaCO3)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	Cl (mg/L)	Cl by NAA (ug/ml)	Br by NAA (ug/ml)	Br by IC (mg/L)	I by NAA (ug/ml)
101	6	388	64.3	20.4	113.0	4.6	460	7	3.50	3.23	0.03		0.025
102	<5	362	81.2	24.5	97.9	4.6	442	<6	3.90	2.77	0.02		0.018
103	21	383	63.0	19.7	101.0	4.5	416	25	2.50	1.67	0.01		0.013
104	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
105	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
106	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
107	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	<5	386	74.2	22.9	113.0	4.8	471	<6	3.00	2.99	0.05	N/A	0.002
109	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
110	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
111	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
112	<5	313	169.0	79.2	2430.0	9.7	382	<6	3670.00	3905.00	3.57	N/A	<0.14
114	<5	275	386.0	152.0	5830.0	13.0	336	<6	8650.00	8193.00	3.71	N/A	<0.2
116	N/A	380	610.0	218.0	6810.0	23.0	464	N/A	9670.00	9670.00	N/A	3.93	N/A
118	N/A	430	400.0	206.0	5060.0	31.3	525	N/A	7750.00	N/A	N/A	4.38	N/A
121	N/A	672	233.0	155.0	6410.0	9.6	819	N/A	8780.00	N/A	N/A	<0.2	N/A
122	<5	794	364.0	327.0	15000.0	38.4	968	<6	23400.00	22600.00	10.80	N/A	0.250
126	<5	714	291.0	278.0	10700.0	35.6	871	<6	15800.00	16200.00	8.18	N/A	0.100

Key	I by IC (mg/L)	SO4 (mg/L)	Hardness (mg/L CaCO3)	TDS (mg/L)	Charge Balance Error (%)	As (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Li (mg/L)	Mn (mg/L)
101		91.4	244	530	1.9	<0.01	0.361	<0.0005	<0.0008	0.0014	<0.001	0.005	<0.002	0.056	0.105
102		138.0	303	567	1.0	<0.01	0.321	<0.0005	<0.0008	0.0010	<0.001	0.006	<0.002	0.057	0.159
103		66.4	239	487	5.7	<0.01	0.384	<0.0005	<0.0008	0.0014	<0.001	0.013	<0.002	0.056	0.144
104	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
105	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
106	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
107	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	N/A	119.0	280	568		<0.01	0.329	<0.0005	<0.0008	0.0013	<0.001	0.158	<0.002	0.057	0.053
109	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
110	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
111	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
112	N/A	431.0	747	6980	0.9	<0.1	1.190	<0.0005	<0.0008	0.0180	<0.001	0.044	<0.002	0.161	0.047
114	N/A	1130.0	1590	16300	3.3	0.110	1.240	<0.0005	<0.0008	0.0290	<0.001	0.075	<0.002	0.256	0.047
116	0.36	1690.0	N/A	20900	3.0	<0.0004	1.510	<0.002	<0.002	<0.002	<0.01	0.010	<0.01	0.248	0.020
118	<0.1	958.0	N/A	15500	2.2	0.003	1.300	<0.01	<0.01	<0.01	<0.01	1.730	<0.05	0.78	0.600
121	63300.00	1320.0	1220	17300	2.6	<0.01	2.890	<0.0005	0.004	<0.0007	0.012	0.060	0.003	0.903	0.009
122	N/A	912.0	2260	40500	0.3	<0.01	2.230	<0.0005	<0.0008	0.0024	<0.001	0.013	<0.002	1.18	0.270
126	N/A	868.0	1870	28300	2.7	<0.01	2.520	<0.0005	<0.0008	0.0025	<0.001	0.014	<0.002	1.11	0.204

Key	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)
101	<0.0001	0.007	0.002	0.220	0.015	9.010	8.340	17.8	<0.001	0.58	30.5	<0.004	<0.0004
102	<0.0001	0.007	0.002	0.080	0.009	9.740	8.890	19.0	<0.001	0.64	45.9	<0.004	<0.0004
103	<0.0001	0.008	0.002	0.200	0.006	9.810	8.990	19.2	<0.001	0.54	22.1	<0.004	<0.0004
104	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
105	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
106	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
107	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
108	<0.0001	0.006	<0.001	0.200	0.006	8.170	7.740	16.600	<0.001	0.64	39.5	<0.004	<0.0004
109	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
110	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
111	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
112	<0.0001	<0.001	<0.01	<0.3	0.066	3.700	3.600	7.7	<0.001	4.14	144.0	<0.004	<0.0004
114	<0.0001	<0.001	0.011	<0.3	<0.004	4.190	4.050	8.7	<0.001	8.19	375.0	<0.004	<0.0004
116	N/A	<0.004	0.002	<0.06	<0.0004	3.170	N/A	N/A	<0.002	3.84	N/A	<0.05	<0.005
118	N/A	<0.02	0.010	<0.3	<0.0004	2.830	N/A	N/A	<0.01	10.20	N/A	<0.3	<0.03
121	N/A	<0.001	0.001	0.019	<0.003	1.480	N/A	N/A	<0.001	6.45	379	<0.004	0.0
122	<0.0001	<0.001	0.006	0.120	<0.004	2.130	2.720	5.8	<0.001	24.40	304.0	<0.004	<0.0004
126	<0.0001	<0.001	0.006	0.050	<0.004	2.400	2.800	6.0	<0.001	21.10	289.0	<0.004	<0.0004

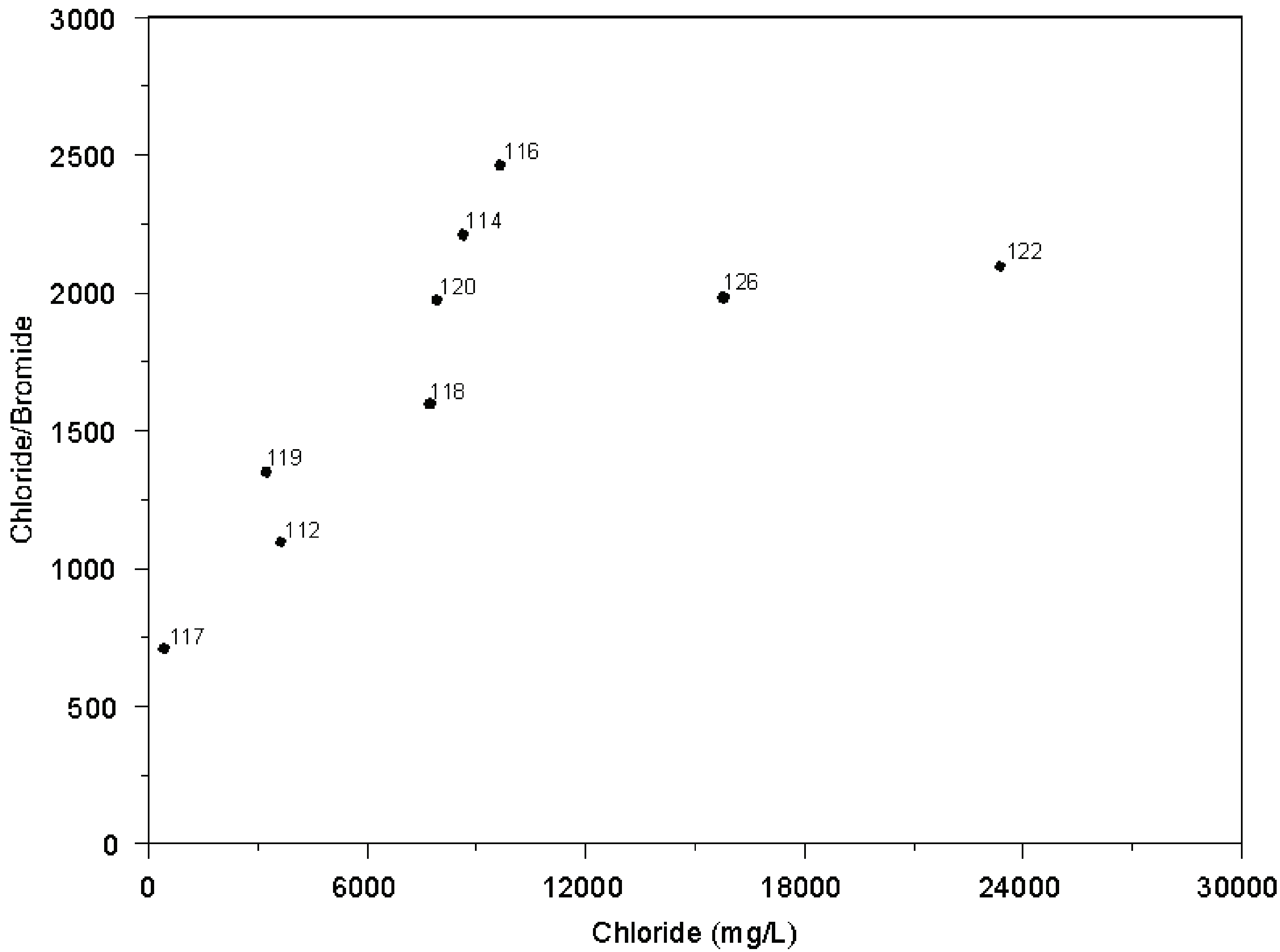

Figure 4.20. Plot of chloride/bromide ratio versus chloride concentrations, samples from selected springs on the Christina and Clearwater rivers.

The chloride-bromide ratios and the depleted oxygen-hydrogen isotope ratios suggest that meteoric water may have reached depths great enough to mix with deep brines, either under gravity-drive or under conditions of glacial surging like that suggested by Grasby et al. (2000) to explain isotopically depleted brines in Manitoba.

4.7 Baseline Hydrographs of Water-Table Piezometers

Three nests of piezometers were installed by AGS in 2000 for investigation of groundwater chemistry and vertical hydraulic gradients in the Quaternary sediments. The locations of the nests are in Figure 9.1. Completion details are in Appendix 5 and borehole logs are shown in Figures 7.5, 7.11, 7.12, 7.13, 7.15, 7.16, and 7.17. The shallowest well in each location was completed as a water table well. Water levels were monitored on a monthly basis from November 2000 to December 2001. The hydrographs of each of the wells are in Figure 4.21 to 4.23.

The hydrographs show water level fluctuations on the order of nearly one metre over the course of a year. In the water table piezometer WEPA00-1-15(WT) (Figure 4.21), the water levels fell during winter and spring of 2000-2001, only to more than recover past the initial recorded water level in the summer of 2001. Water levels in the piezometer WEPA00-3-17(WT) (Figure 4.22) rose in a similar fashion, although the peak water-level rise event preceded the former event by one month. In contrast, the water levels in the piezometer WR99-1-8(WT) (Figure 4.23) rose consistently during summer and autumn of 2001.

The fluctuations in these piezometers are significant in several ways. First, they document that there are natural water table fluctuations in the Athabasca Oil Sands (In Situ) Area unrelated to any known oilsands developments, and that these natural fluctuations can be of the order of one metre in magnitude. Second, the fluctuations suggest that there is annual recharge to the groundwater in the summer months, which means that precipitation during these time intervals exceeded local evapotranspiration. The third significant observation is that annual recharge events in the study area are not synchronous.

Water table fluctuations can be used to evaluate recharge rates. Horgan (1994) documents several methods of applied hydrograph analysis for piezometers, which can be used to estimate recharge. It is intended that these hydrographs will be so analysed at a future date. The piezometers may also be equipped in the future with data loggers or chart recorders if they are chosen to become part of Alberta Environment's regional monitoring network. If that is the case, then these water-table piezometers may provide additional estimates of groundwater recharge rates in the future.

4.8 References

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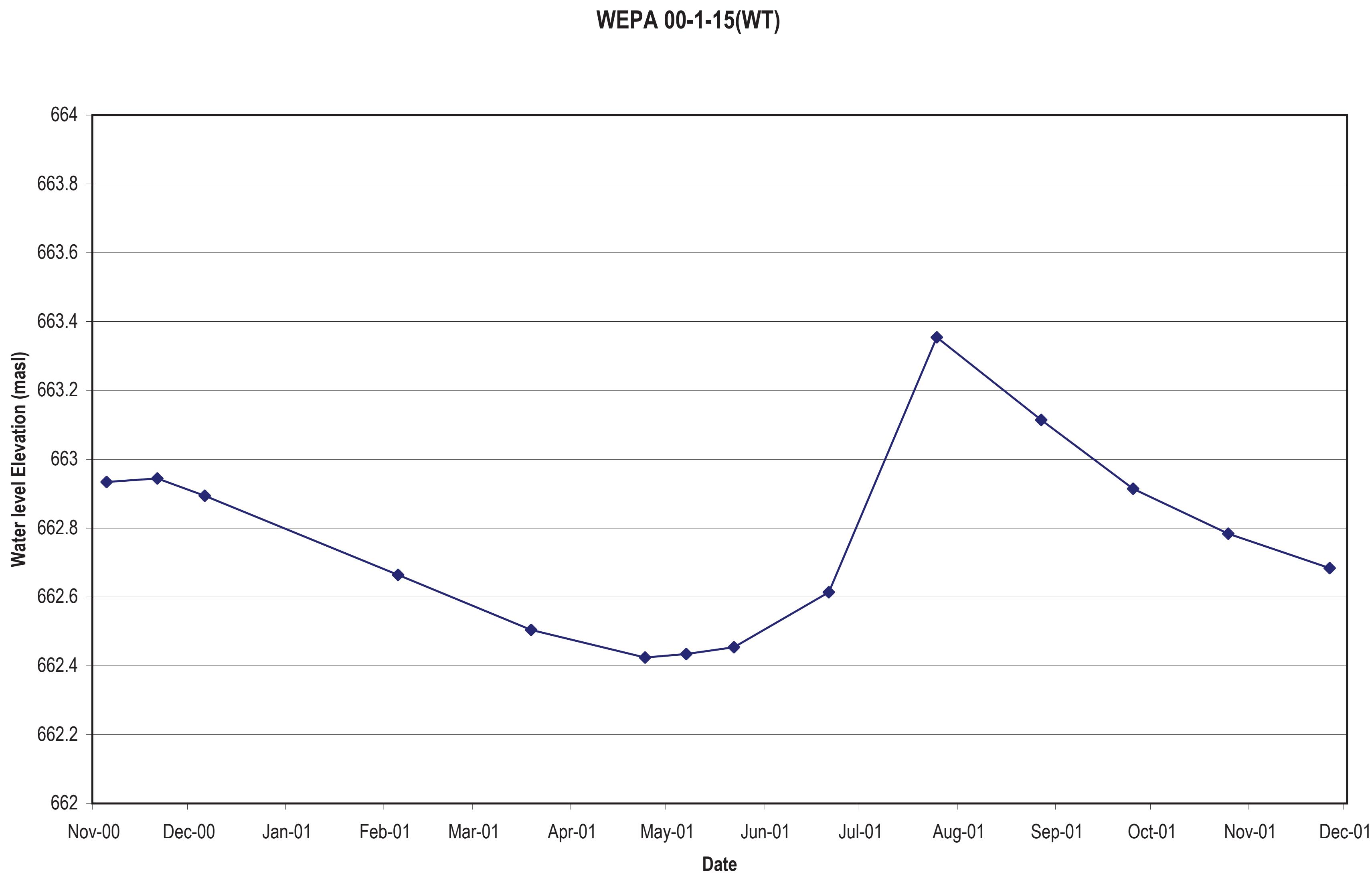

Figure 4.21. Water table hydrograph: WEPA 00-1-15(WT), November 2000 - December 2001, also included in Appendix 5 as Figure A5-11.

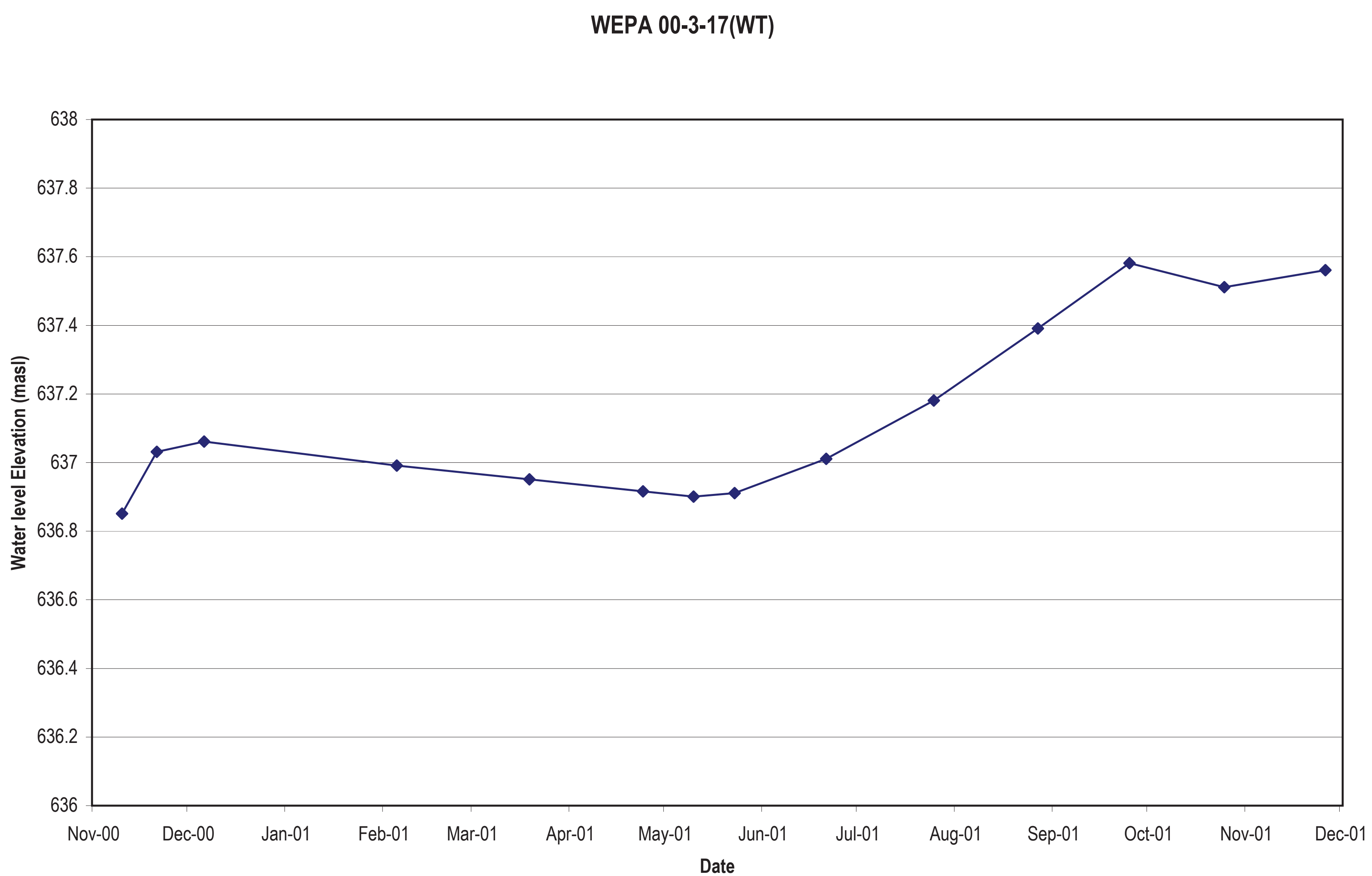

Figure 4.22. Water table hydrograph: WEPA 00-3-17(WT), November 2000 - December 2001, also included in Appendix 5 as Figure A5-16.

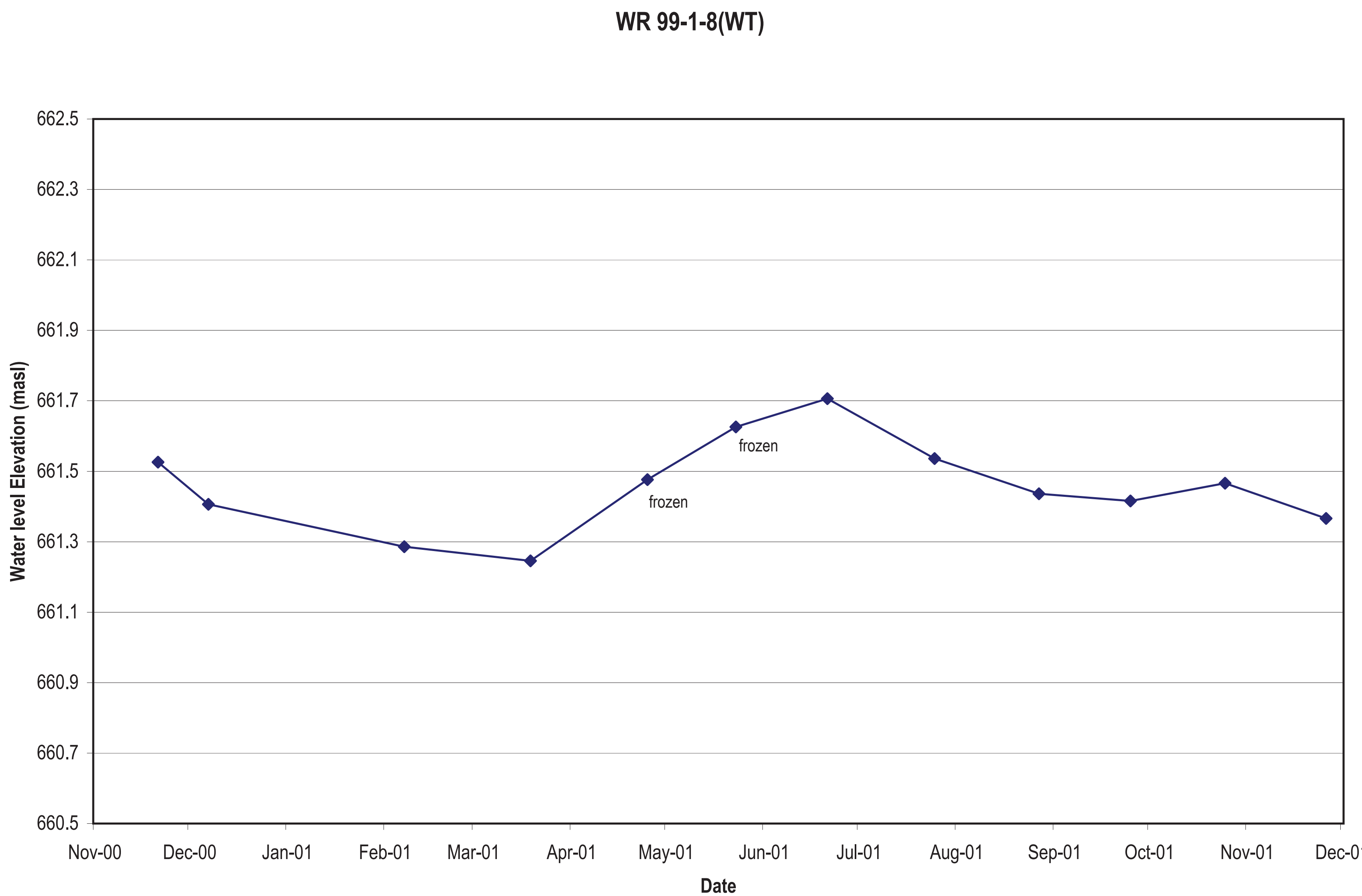

Figure 4.23. Water table hydrograph: WR99-1-8(WT), November 2000 - December 2001, also included in Appendix 5 as Figure A5-20.

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5 Terrain Analysis of Surficial Deposits

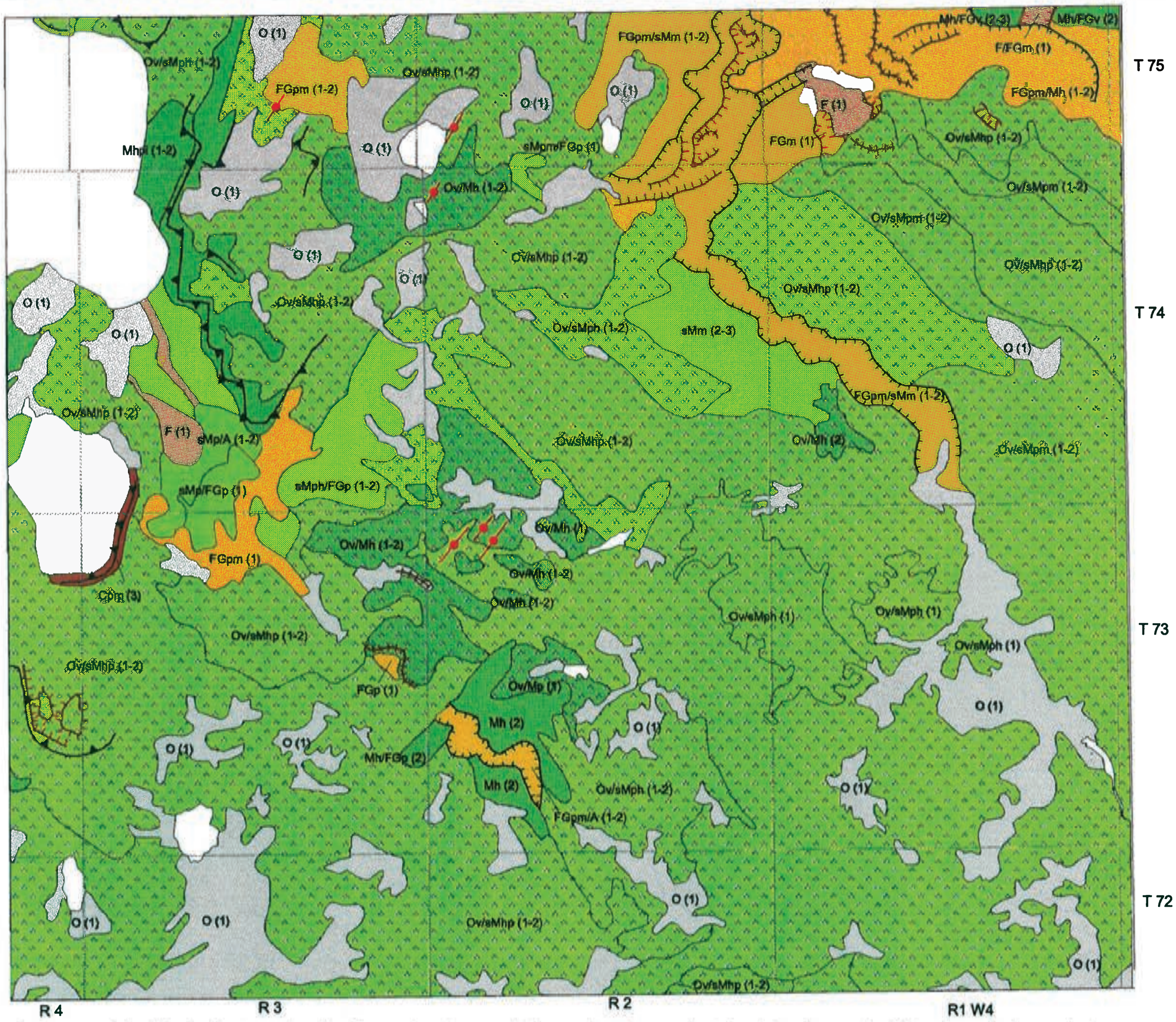
5.1 Introduction

Analysis of surficial geological materials, aspects of local relief, and morphological characteristics of surface landforms form an integral component in the evaluation of recharge fluxes to regional groundwater flow systems. To assist in the evaluation of groundwater recharge, terrain analysis maps were constructed in GIS format at a scale of 1:50,000 and 1:250,000 for most of the WEPA study area, including all of map NTS73M (Winefred), the southern three quarters of map NTS74D (Waterways), and the southeast part of NTS84A (Algar). Mapping of the portion of the WEPA study area that lies within map area NTS83P (Pelican) is currently being undertaken by the surficial geology group in the Minerals section of the Alberta Geological Survey.

The terrain analysis maps were constructed almost entirely from the interpretation of 1:60,000 scale aerial photographs, supplemented with only a minor amount of ground verification in some parts of the study area. Classifications of the terrain incorporate interpretations of landform types, tonal reflections of surface materials, differences in vegetative cover, and in drainage patterns and characteristics, all of which can be differentiated on aerial photographs. It is for this reason that the maps are referred to aerial photo terrain-analysis maps, rather than surficial geology maps, which generally have a greater amount of ground verification. The reader is therefore cautioned that a higher degree of uncertainty exists regarding the information depicted on the terrain-analysis map units, compared to that on a surficial geology map.

The photo-interpreted terrain analyses of surficial deposits were transcribed onto thirty-six mylar transparencies at 1:50,000 scale and scanned into images. These images were then geo-referenced and rectified based on a minimum of four known coordinates. The projection used for geo-referencing is Zone 12 Universal Transverse Mercator (UTM) in NAD83. The average registration error is three metres. The rectified images were converted (vectorized) into lines in Arc/Info™. These lines were extracted into separate files (Arc/Info coverages) based on their feature types – all unit boundaries were put into one coverage while surface linear features such as esker, glacial fluting, etc were placed into separate coverages. Editing was performed on all coverages in ArcEdit (editing module in Arc/Info) with special emphasis on map unit boundaries, which must be closed and properly identified to create polygon topology. These processes were performed on all 36 of the 1:50,000 scale maps that cover the study area. Combining the information in the 36 maps into one created a 1:250,000-scale compilation map of surficial materials in the study area. Deposit boundaries from all adjacent maps were dissolved and many of the more detailed surface linear features were simplified. The final map compilation was accomplished in ArcView™.

The mapping scheme chosen for the 1:50,000 scale terrain classification is a variant of the scheme adopted by Andriashek and Fenton (1989) to map the surficial geology map of the Sand River area, NTS 73L, directly south of the study area. In this terrain classification scheme, each map unit includes a component of genesis, morphology, and relief (Figure 5.1). Where available, additional information regarding the properties of the genetic unit is included as a genetic modifier. For example, the map unit “sMh1” denotes hummocky (h), low relief (1) sandy (s) moraine (M). Genesis of geological material is considered to be the primary component of the map unit, and thus colours on the map depict differences in genesis. In the above example, the map unit colour would correspond to the legend colour chosen for moraine (M). An attempt has been made to reclassify the surficial geological units depicted in the surficial geology map of area NTS 74D (Bayrock and Reimchen, 1973) using this mapping scheme, but without significantly changing the polygon shapes of that previous work. The mapping scheme permits the use of complex map unit notations to describe areas in which two (or more) major genetic classes are present within the map polygon (Figure 5.1).



Geological material modifiers (prefixes to genetic unit)
c clayey
s sandy
g gravelly
pb pebbly

Morphological modifiers (suffixes to genetic unit)
f fan
h hummocky
m rolling
p plain
pi pitted
r ridged
v veneer - a blanket of sediment, generally less than 1 metre thick; veneers of organic sediment are depicted by "^" symbol

Relief modifiers (suffixes to genetic unit)
1 low: local relief generally less than 3 metres
2 medium: local relief generally between 3 and 10 metres
3 high: local relief generally more than 10 metres

The mapping scheme permits the use of complex map unit notations to describe areas in which two (or more) major genetic classes are present within the map polygon. An example of this is an area where both glaciofluvial sediment and till may be present, but which cannot be differentiated at the map scale presented, as in the unit "Mmp1/FGm1". A decision is made as to which is likely to be the dominant material exposed at the surface, and this is reflected in the both map unit color, and the order in which units are depicted in the unit notation (primary units are always identified in the first part of the notation). In the above example, glaciofluvial sediment (FG) is considered to be less continuous or extensive than the till (M), and therefore the map unit color depicts moraine (till), the dominant component. A complex map unit notation is also applied where thick (>1m) sediments of one genetic process overlie sediment of a different process, either as a continuous blanket, or as small, isolated deposit, as in the example "O/Mh2", meaning thick (>1m) organic sediment (O) overlying moderate relief (2), hummocky (h) moraine (M). In the special case of widespread, but discontinuous to thin (<1m thick) organic sediment, the "^" symbol is placed on the colored geological map unit to denote a thin to discontinuous veneer, and the "O" label is omitted.

Multiple or combinations of morphological and relief modifiers can be used to also denote areas with transitional morphological features or relief, or to describe areas in where two or more elements are present but which cannot be differentiated at the scale presented. An example of such a map unit is "FGhm1-2", which describes hummocky to rolling (hm), low to moderate relief terrain (1-2) composed of glaciofluvial sediment.

1 0 1 2 3 4 5 kilometres

- Colluvial Deposits (C)
- Fluvial Deposits (F)
- Glaciofluvial Deposits (FG)
- Morainal Deposits (M)
- sandy Morainal Deposits (sM)
- Organic (O)
- Organic Venreer

- scarp
- dune
- esker
- glacial fluting
- moraine ridge
- palimpsest meltwater channel
- small meltwater channel
- large meltwater channel

Figure 5.1
Example of a 1:50,000 scale terrain analysis map
(NTS sheet 73M/8)

An example of this is an area where both glaciofluvial sediment and till may be present, but which cannot be differentiated at the map scale presented, as in the unit “Mmp1/FGm1”. A decision is made as to which is likely to be the primary or dominant material exposed at the surface, and this is reflected in the both map unit colour, and the order in which units are depicted in the unit notation (primary units are always identified in the first part of the notation). In the above example, glaciofluvial sediment (FG) is considered to be less continuous or extensive than the till (M), and therefore the map unit colour depicts moraine (till), the dominant component. A complex map unit notation is also applied where thick (>1m) sediments of one genetic process overlie sediment of a different process, either as a continuous blanket, or as small, isolated deposits, as in the example “Mh2/O”, meaning thick (>1m) organic sediment (O) overlying moderate relief (2), hummocky (h) moraine (M). In the case of organic deposits, two symbols are used to denote organic overlays: thick organic deposits (>1m) that occur in conjunction with other geological units, are shown by a marsh or swamp vegetation symbol (Figure 5.1); widespread, but discontinuous to thin (<1m thick) organic deposits are depicted by the “^” symbol which is placed on a coloured geological map unit.

Multiple or combinations of morphological and relief modifiers are also used to denote areas with transitional morphological features or relief, or to describe areas in where two or more elements are present but which cannot be differentiated at the scale presented. An example of such a map unit is “FGhm1-2”, which describes hummocky to rolling (hm), low to moderate relief terrain (1-2) composed of glaciofluvial sediment.

GIS-formatted digital maps enable each of the elements of the mapping scheme to be depicted as separate, stand-alone map entities, and at various scales. For example, Figure 5.2 (map) is a 1:250,000 scale compilation of the 1:50,000-scale terrain maps, showing only the distribution of the dominant surficial material on the landscape, irrespective of relief or morphology. In the special case of organic deposits, symbols are used to denote veneers or overlays on the underlying geological material. Similarly, the range and variability in local relief of surficial landforms can be portrayed independent of surficial material and morphology, as shown in Figure 5.3.

5.2 Discussion of the Surficial Geology

5.2.1 Morainal Landforms and Deposits

Most of the surficial geological features are the result of the last glaciation in the region, the Late Wisconsin, which ended approximately 11,000 to 12,000 yrs. B.P. in the study area. Morainal landforms form the major surficial geological features in the study area, and are differentiated on the terrain analysis maps on the basis of variations in matrix grain size: sandy moraine (map unit ‘sM’), in which the sand fraction constitutes the major component of the till matrix, and/or, sand is interbedded with till; clayey moraine (map unit ‘cM’) in which silt and clay are the dominant constituents of the till matrix; and, undifferentiated moraine (map unit ‘M’) in which the till matrix is interpreted to be composed of roughly equal amounts of sand, silt, and clay.

Morainal landforms fall into one of two major morphological categories: active ice, streamlined features such as flutes and drumlinoid ridges (depicted by red glacial flute symbols, Figures 5.1 and 5.2), and stagnant, dead-ice features characterized by hummocky landforms (map units Mh in Figure 5.1). Orientations of glacially streamlined landforms reveal the dominant ice-flow direction during the late stages of the last glaciation was from the northeast, with local flow directions varying between due north to due east (Figure 5.2). Morphological features and outcrop observations indicate that at some time during the glacial history glaciotectonic thrusting and displacement of underlying sediments occurred in parts of the study area. Examples include: the drumlinized, ridged landform directly southwest, or

Genetic Units

Terrain Analysis Map Legend

RECENT

O Organic Deposits: undifferentiated black humic to fibrous peat occurring in undifferentiated wetlands (bog, fen, swamp, slough); generally interpreted to be one or more metres thick.
C Colluvial Deposits: materials that have reached their present position as a result of direct, gravity-induced movement; commonly occurs as slope and slump deposits confined to valley slopes and floors.

CS - Colluvial Slump Deposits: slumps can include a mixture of glacial and bedrock materials; extremely unstable, new movements of material downslope are expected.
CE - Eroded Colluvial Deposits: colluvial materials and eroded banks along recent streams and rivers
CM - Colluviated Morainal Deposits: colluvial deposits derived primarily from morainal material.

E Aeolian Deposits: wind-deposited sediments; well sorted fine-to-medium grained sand and minor silt (loess); massive to locally cross-bedded or ripple laminated; includes both active and vegetated deposits; sand dunes generally medium grained, massive, between 2 and 10 metres in height and thickness; sand sheets generally 0.5 to 2 metres thick.

F Fluvial Deposits: sediments transported and deposited by recent streams and rivers (synonymous with alluvial); includes well-sorted stratified sand, gravel, silt, clay and organic sediment occurring in channel and over-bank deposits; includes floodplains, terraces, fans.

L Lacustrine Deposits: sediments deposited in and adjacent to recent lakes: offshore sand, silt, and clay, minor organic deposits; littoral (near-shore beaches and bars) sand and silt and minor gravel; includes deltas.

QUATERNARY

FG Glaciofluvial Deposits: sediments deposited by glacial meltwater streams directly in front of glacier margins, either as subaerial or subaqueous outwash; includes sand and gravel, commonly stratified, minor silt, and may show evidence of ice melting (collapse slump structures); features include meltwater channels, terraces, outwash plains, pitted plains; unless identified otherwise, glaciofluvial deposits are interpreted to be dominantly sand. Gravelly deposits are donated by the symbol gFG

FGI- Ice-contact glaciofluvial deposits: sediments deposited by glacial meltwater streams in direct contact with glacial ice, either in front of (kame terraces), or within glacial ice (eskers, kames, crevasse fillings); includes massive to stratified, poor to moderately sorted coarse sediments (predominantly pebbly gravel and coarse sand, locally diamict), and may show evidence of ice melting (collapse slump structures); features generally form positive elements in the landscape including sinuous ridges, cone-shaped or rounded knobs, and kettles.

LG Glaciolacustrine Deposits: undifferentiated distal and littoral sediments deposited in or along the margins of glacial lakes, including sediments that were released by the melting of floating ice (e.g. water-laid diamicts); includes laminated (rhythmically bedded) to massive fine sand, silt, and clay, as well as ice-rafted stones and layers of bedded diamict deposited in distal settings; massive to stratified, well sorted silty sand, pebbly sand, and minor gravel deposited as beaches, bars, spits; and, foreset deltaic sediments deposited during regression and lowering of glacial lakes.

Textural modifiers are used to denote differences in grain size:
cLG - clayey
pbLG - pebbly
sLG - sandy

M Morainal Deposits: material deposited directly by glacial ice without modification by any other agent of transportation; includes nonsorted diamicton (mixture of clay, silt, sand and minor pebbles, cobbles, and boulders) deposited as till at the margin or beneath a glacier; moraine can locally contain blocks of glacially displaced and transported bedrock, pre-existing stratified drift and till, and can include areas of prominent relief, glacially deformed and thrust bedrock mantled by a till cover; beds of syngenetic glaciolacustrine or glaciofluvial sediment may also be present.

Textural modifiers are used to denote differences in grain-size composition of the diamicton (till):
cM - clayey moraine in which the till matrix is enriched with clay, or inclusions of clay-rich beds or layers are common
sM - sandy moraine in which the till matrix is enriched with sand, and inclusions of beds or layers of sand are common.

PREQUATERNARY

ER Eroded Bedrock: undifferentiated bedrock units recently exposed by erosion

Geological material modifiers (prefixes to genetic unit)
c clayey
s sandy
g gravelly
pb pebbly

Morphological modifiers (suffixes to genetic unit)
f fan
h hummocky
m rolling
p plain
pi pitted
r ridged
v veneer - a blanket of sediment, generally less than 1 metre thick; veneers of organic sediment are depicted by "^^" symbol

Relief modifiers (suffixes to genetic unit)
1 low: local relief generally less than 3 metres
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3 high: local relief generally more than 10 metres

Description of Map Classification Scheme

Terrain analysis maps have been constructed in GIS format at a scale of 1:50,000 and 1:250,000 for most of the WEPA study area, including all of map NTS73M (Winefred), the southern three quarters of map NTS74D (Waterways), and the southeast part of NTS84A (Algar) (see index map). Mapping of the portion of the WEPA study area that lies within map area NTS83P (Pelican) is currently being undertaken by the surficial geology group in the Minerals section of the Alberta Geological Survey.

The terrain analysis maps were constructed almost entirely from the interpretation of 1:60,000 scale aerial photographs, supplemented with only a minor amount of ground truthing in some parts of the study area. Classifications of the terrain incorporate interpretations of landform types, tonal reflections of surface materials, differences in vegetative cover, and in drainage patterns and characteristics, all of which can be differentiated on aerial photographs. It is for this reason that the maps are referred to aerial photo terrain analysis maps, rather than surficial geology maps, which generally have a higher degree of ground truthing. Aerial photograph interpretation was conducted primarily by L. Leslie of Geo-Environmental Ltd., with final edits and revisions done by L. Andriashek of the Alberta Geological Survey.

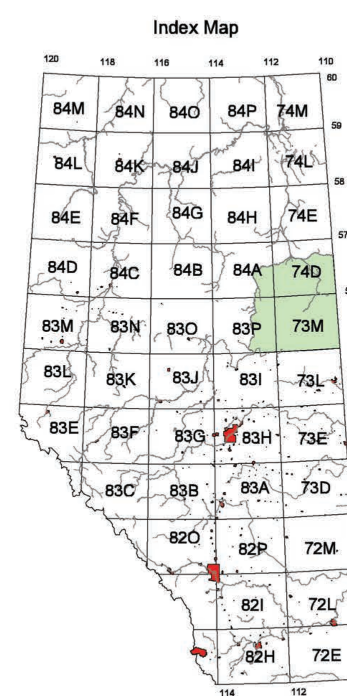
The mapping scheme chosen for the terrain classification is a variant of the scheme adopted by L. Andriashek and M. Fenton (1989) to map the surficial geology map of the Sand River area, NTS 73L, directly south of the study area. In this terrain classification scheme, each map unit includes a component of genesis, morphology, and relief. Where available, additional information regarding the composition of the genetic unit is included as a genetic modifier. For example, the map unit "sMh1" denotes hummocky (h), low relief (1) sandy (s) moraine (M). Genesis of geological material is considered to be the primary component of the map unit, and thus differences in genesis are depicted by colors on the map. In the above example, the map unit would correspond to the legend color chosen for moraine (M).

[illegible]

[illegible]

Multiple or combinations of morphological and relief modifiers can be used to also denote areas with transitional morphological features or relief, or to describe areas in where two or more elements are present but which cannot be differentiated at the scale presented. An example of such a map unit is "FGhm1-2", which describes hummocky to rolling (hm), low to moderate relief terrain (1-2) composed of glaciofluvial sediment.

Index Map



References

73L - Surficial geology Sand River, NTS 73L
M. Fenton and L. Andriashek, 1983; 1:250,000 map, Bulletin 57, Alberta Geological Survey, Alberta Research Council

73M - Terrain Analysis Winefred, NTS 73M
L. Leslie and L. Andriashek, 2002; 1:50,000 and 1:250,000 (Map 250) digital maps, Alberta Geological Survey, Alberta Energy and Utilities Board

74D - Surficial geology Watereays, NTS 74D
L. Bayrock and T. Reimchen, 1974; 1:250,000 map Alberta Geological Survey, Alberta Research Council

74D - Terrain Analysis Waterways, NTS 74D (1-2)
L. Leslie and L. Andriashek, 2002; 1:50,000 and 1:250,000 digital maps, Alberta Geological Survey, Alberta Energy and Utilities Board

74E - Surficial geology Bitumount, NTS 74E
L. Bayrock, 1971; Map34, 1:250,000; Alberta Geological Survey, Alberta Research Council

83I - Surficial geology Dapp Creek, NTS 83I (9,10,15,16)
S. Richard, 1981; Map 1-1979, 1:100,000; Geological Survey of Canada

83P - Surficial geology Pelican, NTS 83P
J. Campbell, M. Fenton and J. Pawlowicz, in. prep.; 1:100,000 (Map 243) and 1:250,000 digital maps, Alberta Geological Survey, Alberta Energy and Utilities Board

84A - Terrain Analysis Algar, NTS 84A (1,2,7,8)
L. Leslie and L. andriashek, 2002; 1:50,000 and 1:250,000 digital maps, Alberta Geological Survey, Alberta Energy and Utilities Board

Scale 1:250 000

5 0 5 10 15 20 25 30 Kilometres

5 0 5 10 15 20 Miles

Projection: UTM zone 12
Datum: NAD83

RECENT

- Thick discontinuous Organic Deposits Thickness (>1m)
- Thin discontinuous Organic Deposits Thickness (<1m)
- Organic Deposits (O)
- Colluvial Deposits (C)
- Colluvial Slump Deposit (CS)
- Eroded Colluvial Deposits (CE)
- Aeolian Deposits (E)
- Fluvial Deposits (F)
- Lacustrine Deposits (L)
- Ice-contact Glaciofluvial Deposits (FGI)

QUATERNARY

- Glaciofluvial Deposits (FG)
- gravelly Glaciolfluvial Deposits (gFG)
- Glaciolacustrine Deposits (LG)
- clayey Glaciolacustrine Deposits (cLG)
- pebbly Glaciolacustrine Deposits (pbLG)
- sandy Glaciolacustrine Deposits (sLG)
- Morainal Deposits (M)
- clayey Morainal Deposits (cM)
- Horse River Till (HM)
- Kinosis Till (KM)
- sandy Morainal Deposits (sM)
- Gipsy Till (GM)

PREQUATERNAY

- Eroded Bedrock (ER)

Features Legend

- scarp / steep slope
- dune
- esker
- glacial fluting
- moraine ridge
- palimpsest meltwater channel
- small meltwater channel
- large meltwater channel
- beach
- slump

Figure 5.2 Surficial Materials in the study area (NTS 73M, part of 74D and 84A)

Interpretation: L. Leslie
Edited: L. Andriashek
GIS/Cartography: D. Chao and J. Meeks

Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
Alberta Energy and Utilities Board
Alberta Geological Survey

Digital base maps provided by:
Spatial Data Warehouse

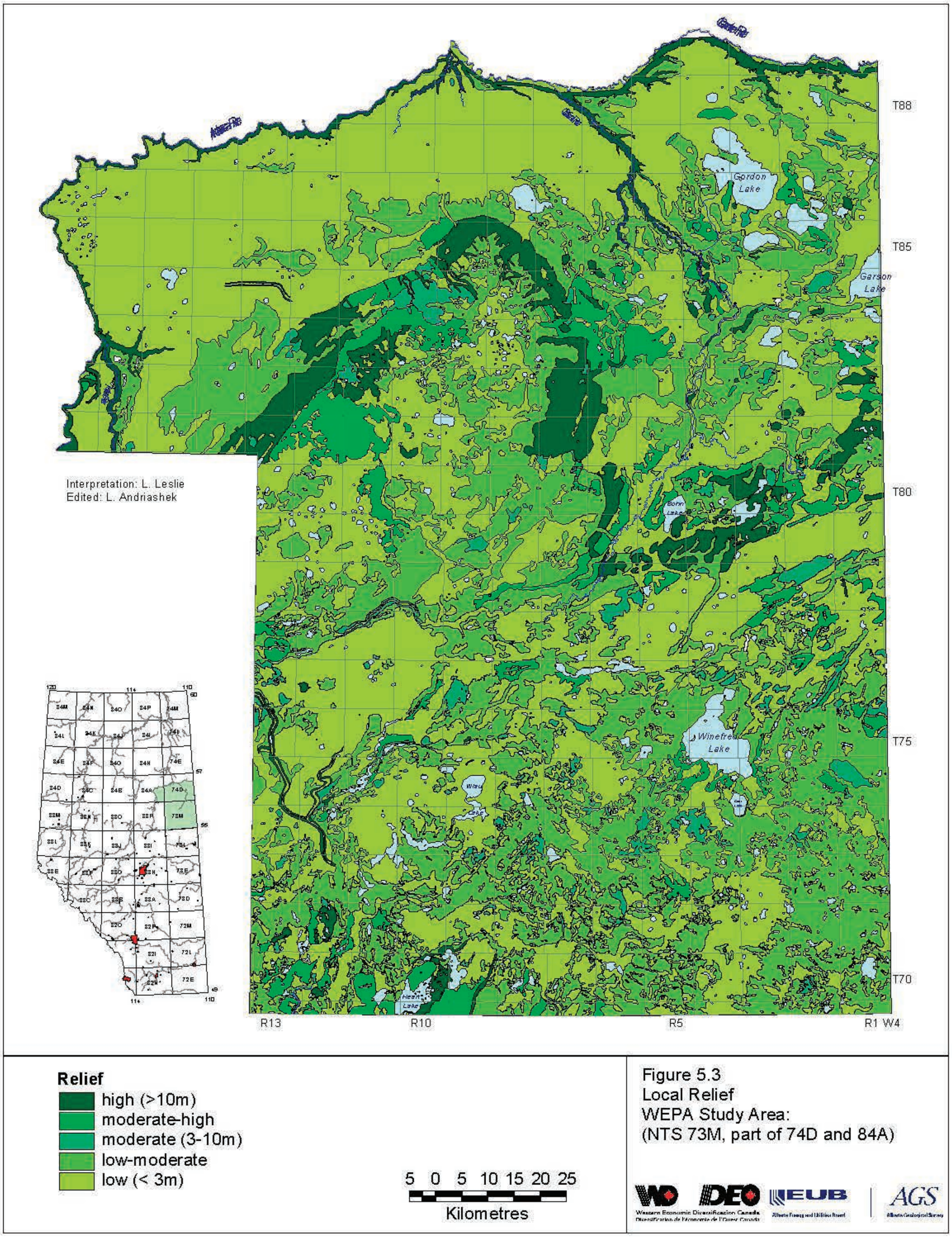


Figure 5.3
Local Relief
WEPA Study Area:
(NTS 73M, part of 74D and 84A)

down-ice, of Winefred Lake, inferred to be material glacially displaced from beneath the lake, as well as stair-stepped scarps along the eastern edge of the lake which are interpreted to be tear-faulted features; the scarp-edged landforms north of Piche, Heart, and Logan lakes in the southwest part of the map area, also inferred to be glacial tear-fault features; and, glacially displaced shale and siltstone observed in outcrop within a high-relief ridged landform in Tp 78, Rgs 7-9 (Figure 5.2). Glacial thrusting may have also played a role in forming the high-relief, ridged to rolling ice-marginal landscape that characterizes the area around Bohn and Cowper lakes in Twp 79 to 82, Rgs 1 to 5 (Figures 5.2 and 5.3). Borehole and outcrop observations in that area indicate a highly varied composition to the moraine, including thick masses of glacial sand, which may have been deposited by ice-thrust, or ice-contact glaciofluvial processes.

Stagnant, dead-ice collapse features are the dominant morainal landforms on the Stony Mountain and Mostoos Hills upland physiographic units. The moraine is characterized by circular to semi-circular closed–ridged till hummocks with organic sediment occupying the central depressions, depicted by the ‘organic veneer’ map symbol superimposed on the hummocky moraine (Mh) map unit (Figures 5.1 and 5.2).

From the limited surficial geology information collected in the field (Appendix 1), some comments can be made regarding regional differences in the internal composition of the moraine in the study area. In general, large areas in the east half of the study area are characterized by till with a much greater sand content than till to the west (map unit sM, Figure 5.2). In the northeast part of the area, defined by the Methy Portage Plains physiographic unit (Figure 3.2), Bayrock and Reimchen (1973) described the till as being composed of more than 90% sand, with the remainder being silt, pebbles, and boulders (Gipsy Till, map unit ‘GM’, Figure 5.2). The sand content of the till in the northeast is so great that the authors initially interpreted the landscape as ice-contact glaciofluvial sand deposited as kames. However, on the basis of the amount of silt in the matrix, the landscape was reinterpreted as till, formed by glacial over-riding and reworking of outwash sand that was derived from sandstone of the Athabasca Formation.

Although the sand content of the surface till decreases southward as the till becomes enriched with silt and clay, in the Mostoos Upland the till matrix still contains as much as 50% sand, yielding a sandy clay loam texture (Figure 5.1 map unit sM). In addition, interbeds of sand are commonly found in the upper 2 to 3 m of the till, making an overall sandy composition to the moraine with relatively high internal drainage characteristics (Figure 5.4). This aspect of high internal drainage is reflected in the sharp crests of hummock ridges (denoting sandy composition), and vegetative cover with plant species such as Caribou moss and Pines, which have tolerance for dry, well-drained soils (Figure 5.5). In places sinuous, sharp-crested till hummocks have an appearance very similar to that of ice-contact glaciofluvial eskers, and the differentiation between moraine and glaciofluvial outwash can be difficult from aerial photo analysis (Figure 5.6).

Although there are local exceptions, in general the grain-size composition of the surface till becomes progressively more clayey in a westward direction, with roughly equal amounts of sand, silt, and clay (clay loam) on top of the Crow Lake Upland (Figure 3.2). In the northern part of the upland, Bayrock and Reimchen (1973) refer to the till as the ‘Kinosis Till’, and describe it as loamy textured with an abundance of rounded quartzite clasts derived from Tertiary gravel, which the authors believed may still overlie the bedrock surface in the upland. The abundance of small lakes and widespread organic deposits on the surface of the Crow Lake Upland (Figure 5.2) leads one to speculate that, in part, the downward percolation of surface water is being retarded by a more clayey till composition. The most regionally clayey surface till, referred to as the “Horse River Till’ (Bayrock and Reimchen, 1973), occurs within the Wabasca Lowland physiographic unit along the western flank of the Stony Mountain Uplands (Figure 3.2). The till is described as generally thin with a clay-rich matrix containing very few stones.

Figure 5.4. Poorly sorted glaciofluvial sand and sandy diamiction complex, Christina Lake area

Figure 5.5. Sharp-crested ridges on hummocky, sandy moraine on the Mostoos Upland.

Figure 5.6. Sinuous-ridged hummocky, sandy moraine, Mostoos Upland.

5.2.1.1 Glaciofluvia Landforms and Deposits

During the last stages of deglaciation, glaciofluvial outwash sand and gravel (FG map unit) was deposited on the ice surface in form of kames and eskers (eskers depicted by symbol on Figure 5.2), or in meltwater channels eroded on the moraine surface (map unit FG). Glaciofluvial deposits are differentiated on the basis of two grain-size categories; sandy deposits, denoted by map unit label ‘sFG’, and gravely deposits, shown by map unit label ‘gFG’. Major outwash deposits are mapped within: a north-south trending meltwater channel system in the southwest part of the area; an east-west meltwater channel system currently occupied by Christina Lake in the centre of the study area (Figure 5.7); and a north-south trending channel system east of Winefred Lake, and along the margins of the present-day Christina and Athabasca rivers (Figure 5.2). In addition to isolated kames and small eskers that occur from place to place within the hummocky moraine complexes, extensive ice-contact and glacial meltwater-channel complexes occur along the upper margins of the Stony Mountain Uplands. A number of these deposits are mined as sources of aggregate (Figure 5.8).

5.2.1.2 Glaciolacustrine Landforms and Deposits

Glaciolacustrine landforms and materials generally have a subdued appearance and cannot be easily mapped from aerial photos. Glaciolacustrine sediments are absent in the most of the study area, the exception being those deposits mapped by Bayrock and Reimchen (1973) within the Wabasca and McMurray lowlands, and the northern part of the Methy Portage Plains (Figures 3.1 and 5.2). Glaciolacustrine map units are subdivided on the basis of dominant grain size, and include: bedded silt and clay deposits, denoted by the map-unit label ‘cLG’; sandy deposits, denoted by the map unit label ‘sLG’, pebbly, clayey diamicts, denoted by the map label ‘pbGL’, and undifferentiated deposits, map label ‘LG’. There is little information to indicate the range in thickness of glacial lake sediments, though observations along the Athabasca River indicate a thickness of about one to two metres (J. Pawlowicz, pers. comm.). Observations of outcrops along the northern ends of the Christina River and Edwin Creek (sites NEQ96-Sec17, NEQ96-Sec3, NEQ96-Sec4, Appendix 1) indicate about a one-to-three metre thick, poorly stratified diamicton unit at the top of the section, which is interpreted to be a pebbly, water-laid glacial lake deposit, similar to the pbLG map unit in Figure 5.2.

5.2.1.3 Aeolian Landforms and Deposits

Immediately following deglaciation, and prior to stabilization of the landscape by vegetation, strong winds reworked and modified many of the exposed glaciofluvial sand deposits. Dominant wind direction at that time appears to have been from the northwest, forming sheet sand or aeolian dunes along the southeast, or down-wind, margins of meltwater channels and outwash deposits. Sporadic, but distinct, sand dunes are depicted by a red dune symbol on the terrain analyses maps (Figure 5.2), but large dune fields are mapped as a separate units, as the case along the south and east flanks of the Athabasca and Christina river valleys (Figure 5.2). Most aeolian features are confined to the northeast part of the map area where glacial meltwater deposits overlie sandy till of the Gipsy moraine. It is probable that small isolated dunes occur elsewhere than depicted on the terrain analysis maps, but they are too small to identify or map at the 1:60,000 air-photo scale.

5.2.1.4 Colluvial Landforms and Deposits

Colluvial deposits are found predominantly in areas of high local relief, and within the study area three colluvial map units are defined: eroded colluvial landforms (map unit CE) consisting of colluvial veneers found on steeply eroded slopes such as along major river valleys; colluvial slump deposits (map unit CS) formed by large, unstable slump blocks of undifferentiated glacial and bedrock material, commonly

Figure 5.7. Ice-contact glaciofluvial sand and gravel pit, east of Christina Lake

Figure 5.8. Glaciofluvial sand and gravel pit on Stony Mountain Upland

forming a series of sub parallel arcuate ridges; and undifferentiated colluvial deposits (map unit C) which includes material referred to as ‘colluviated ground moraine’ in the 1:250,000-scale surficial geology map of NTS map area 74D (Bayrock and Reimchen, 1973). The largest areas of colluvial slump deposits are found along the northern perimeter of the Stony Mountain Upland where unstable bedrock shale is exposed, or lies near the surface, along the flanks of the upland (Figure 5.2). Eroded colluvial deposits are confined primarily to the steep valley walls of the major rivers including the Athabasca, Christina, and Clearwater rivers.

5.2.1.5 Recent Fluvial and Lacustrine Deposits

Recent fluvial deposits are found along present-day stream and river channels and floodplains. Sediments include a wide range in grain sizes from cobbles and boulders along streambeds of major rivers, to poorly sorted muds along small, slow-moving streams. Where thick and coarse, recent fluvial deposits can be a potential source of aggregate.

Recent lacustrine deposits are found along the margins of the larger lakes. They are interpreted to consist of coarse, waved-washed beach sediment such as sand, to poorly sorted, organic-rich muds. Recent lacustrine deposits are likely to be less than 1 m in thickness.

5.2.1.6 Organic Deposits

Organic deposits are possibly the most widespread surficial material, covering an estimated 65% of the study area (Figure 5.9).

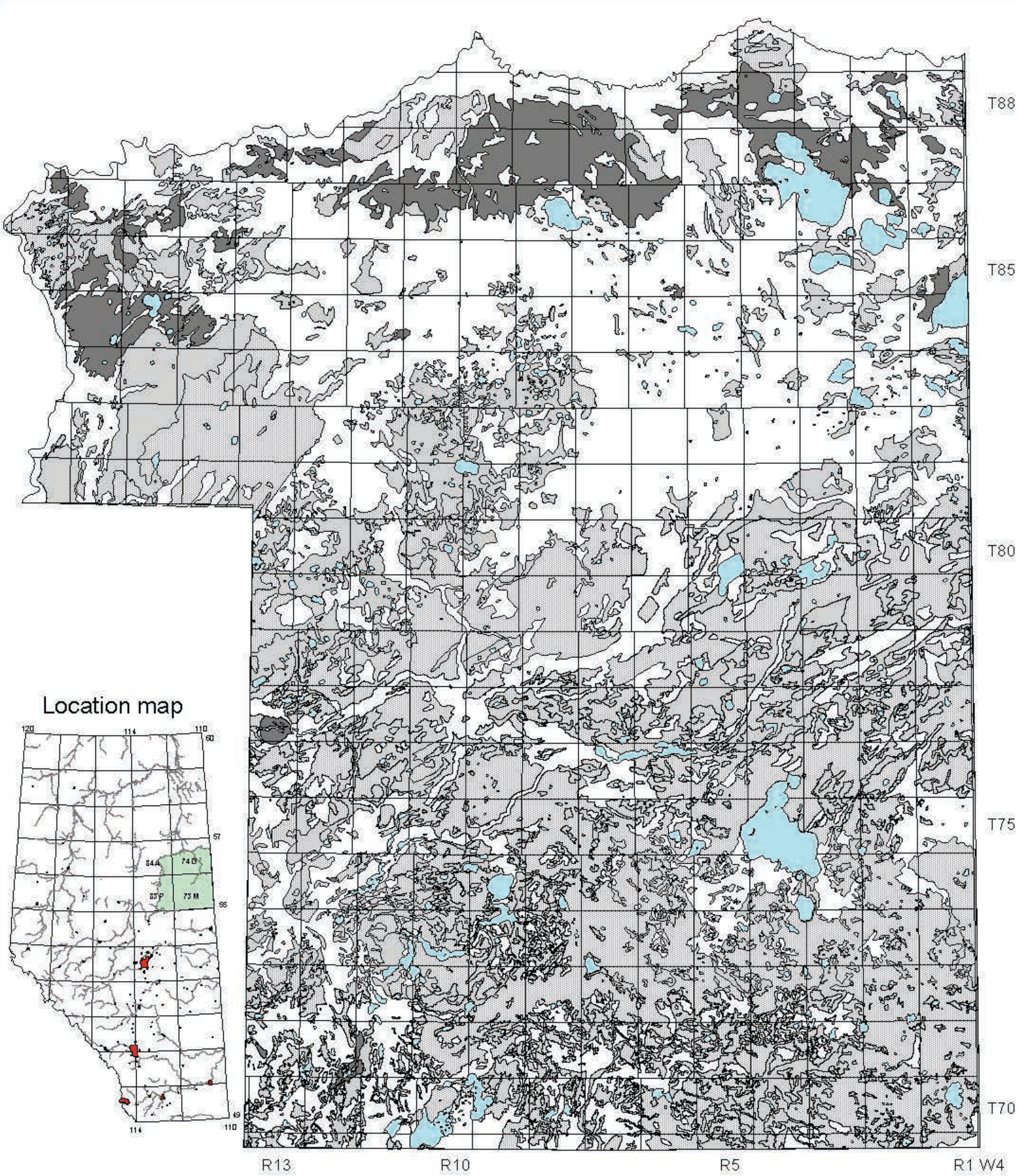
Organic deposits can be easily recognized on air photos, and because they are hydrogeologically and geotechnically significant in terms of moisture retention on the landscape, an attempt has been made to show their distribution even if they are not the primary surficial geological unit. Organic deposits are depicted in three ways in the terrain analyses maps: areas interpreted to be dominantly thick organic deposits (>1m thick, map unit ‘O’), thick organic deposits in association with other surficial materials, as in the example ‘Mm1/O’ (depicted by swamp or marsh symbol overlying a coloured morainal map unit), and thin organic veneers on top of, or in conjunction with, other surficial materials (<1m thick, depicted by ‘^’ symbol overlying coloured map units).

Organic deposits occur in a number of different terrain settings. As mentioned, they are an integral part of hummocky morainal landscapes, filling in the circular depressions within stagnant ice collapse hummocks, or depressions between neighbouring hummocks (see Figure 5.5 moraine in DND air weapons range). The areas interpreted to have the most widespread, continuous and thick organic sediments are: much of the top of the Stony Mountain Upland, the area defined by the Algar and Dover plains, between the Athabasca River and the Stony Mountain Upland, the area around Clyde and Bohan lakes in the Mostoos Upland, much of the area within the Christina Lake Plain, and the area around Gordon and Gipsy lake in the Methy Portage Plains (Figures 3.1 and 5.9).

5.3 References

Andriashek. L.D. and M.M. Fenton, 1989: Quaternary stratigraphy and surficial geology of the Sand River area, 73L. Alberta Geological Survey, Alberta Research Council Bulletin 57, 154 pages.

Bayrock and Reimchen, 1973: Surficial geology of the Waterways map area, NTS74D. 1:250,000-scale map, Alberta Geological Survey.



Thick continuous organic deposits (thickness > 1m)

Thin discontinuous organic deposits (thickness <1m)

Thick discontinuous organic deposits (thickness >1m)

10 0 10 20 Kilometers

Figure: 5.9
Map of the distribution of organic sediment in the study area (NTS 73M, part of 74D and 84A)

6 Bedrock Topography and Buried Channels

6.1 Background and Methods

Bedrock topography maps depict a model of one of the major unconformable surfaces in the Western Canadian Sedimentary Basin – the pre-Quaternary unconformity, representing the period of erosion from the Late Cretaceous - early Tertiary to the onset of glaciation in the early Quaternary. The model presented in this study represents the current understanding of the paleotopography of the pre-Quaternary unconformity based on previous studies (Gold, 1983; Alberta Environment, 1986; Stein and Andriashek, 1993) as well as new interpretations resulting from recent work in the region by the AGS.

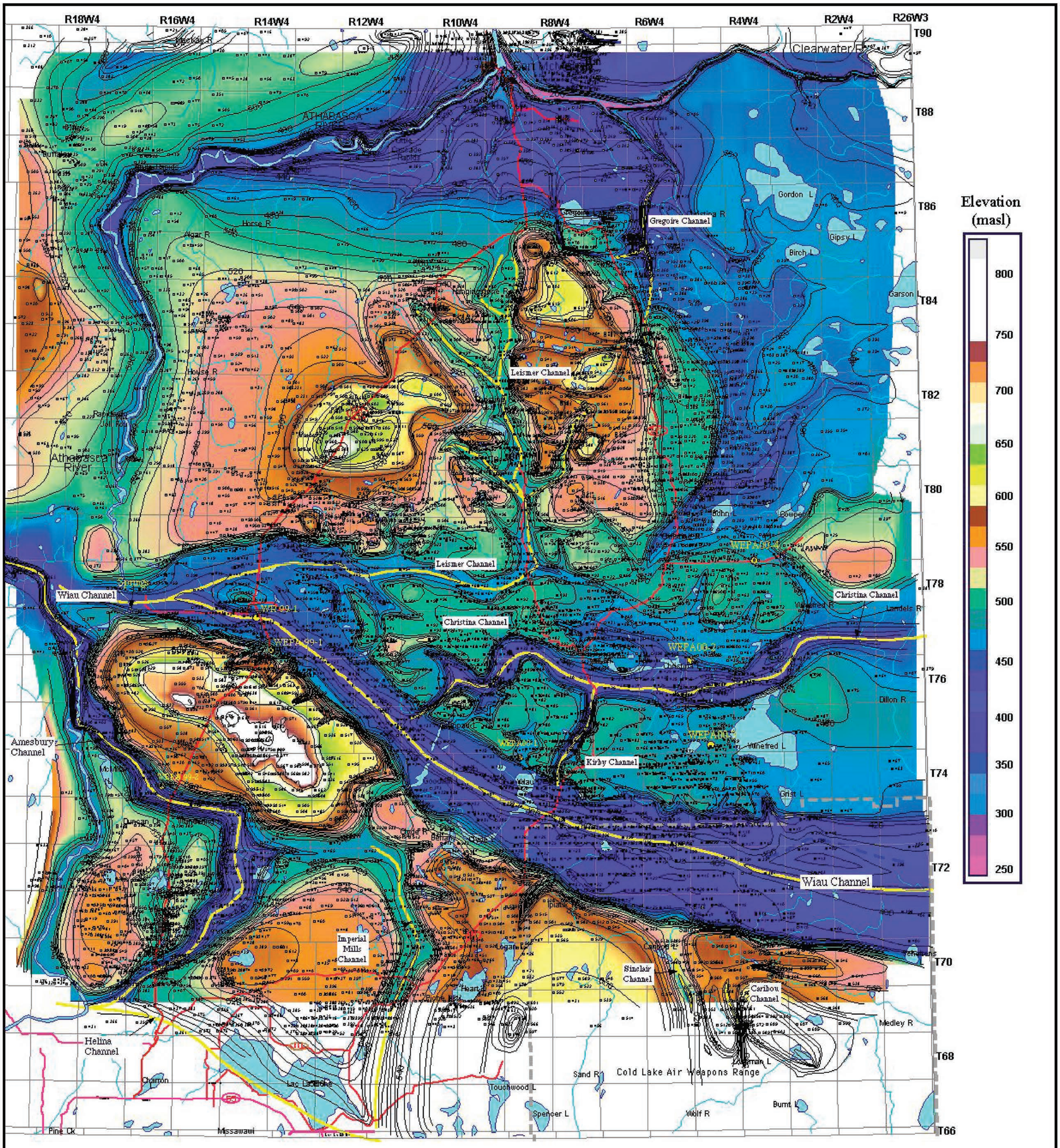
The topography of the underlying bedrock surface was constructed almost entirely from borehole log information, supplemented with only a few observations from outcrops along natural exposures. Approximately 7300 well logs were evaluated to establish the top of the bedrock surface in the study area, the vast majority of which are oil and gas exploration industry petrophysical logs, supplemented with lithologs from the water-well drilling industry, and seven core-hole logs obtained during drilling by the AGS as part of this study (see distribution of data in Figure 6.1). Well information was entered into a digital database (Microsoft ACCESS™), which records location, well owner, elevation of top of the hole, as well as important contacts such as elevations of bedrock top, drift thickness, and other stratigraphic markers within the drift succession.

About 4300, or 65%, of the wells provided some useful petrophysical log information regarding the top of the bedrock surface. The majority of these consist of electric logs, primarily resistivity and conductivity traces, recorded in uncased, open-hole conditions. In many areas where the drift is thick, drill-casing depths terminated within the drift sequence, and resistivity logs recorded the lower part of the Quaternary sequence, as well as the bedrock contact and deeper bedrock strata. Approximately 1750 wells recorded the drift-bedrock contact (shown as filled black circles on Figure 6.1), and these established the baseline data to contour the bedrock surface. In the holes where casing was set into the bedrock, the elevation of the bedrock surface cannot be determined from electric logs, but a 'higher-than-base-of-casing' elevation value is recorded in the database (about 2800 entries), and depicted on the map as filled white circles. These 'higher than' values are useful in that they provide some constraints on contouring the bedrock surface, particularly in areas of high bedrock relief. More recently, gamma ray logs have been run in cased holes, providing a log record (somewhat suppressed in the section of steel casing) almost to surface. Approximately 200 boreholes, mostly water wells, were not drilled deep enough to intersect the bedrock surface. These are entered as 'less-than' values, indicating that the bedrock surface lies at an elevation lower than the bottom of the hole. The lithologs from these wells do, however, provide useful information regarding the nature of Quaternary sediments beneath the site.

The map of the bedrock surface was created in digital format using MCadContour™ computer-mapping software. However, the data points were not contoured by the software, but rather, digitally hand contoured on screen to reflect the author's understanding and concept of fluvial erosional landforms and features. These digitally hand-drawn contour lines were later rendered into grid data to generate three-dimensional models of the bedrock surface, one view of which is shown in Figure 6.2

6.2 Bedrock Physiographic Units

The topography of the bedrock surface of the study area represents a landscape that has been extensively eroded during the late Tertiary, and later modified by glacial and present-day fluvial processes. Erosion and incision of the exposed bedrock has produced a landscape characterized by isolated remnants of bedrock uplands, and deep, broad relicts of paleoriver channel systems (Farvolden, 1963). An



EUB Alberta Energy and Utilities Board

AGS Alberta Geological Survey

WD DEO Western Economic Diversification Canada / Diversification de l'économie de l'Ouest Canada

WEPA Baseline Groundwater Investigation NE Alberta	
Bedrock Topography and Channel Talwegs	
Contour Interval 10 m	
(50 Km)	
L. D. Andriashek	Figure 6.1
Date:4/18/02	Scale 1:500,000

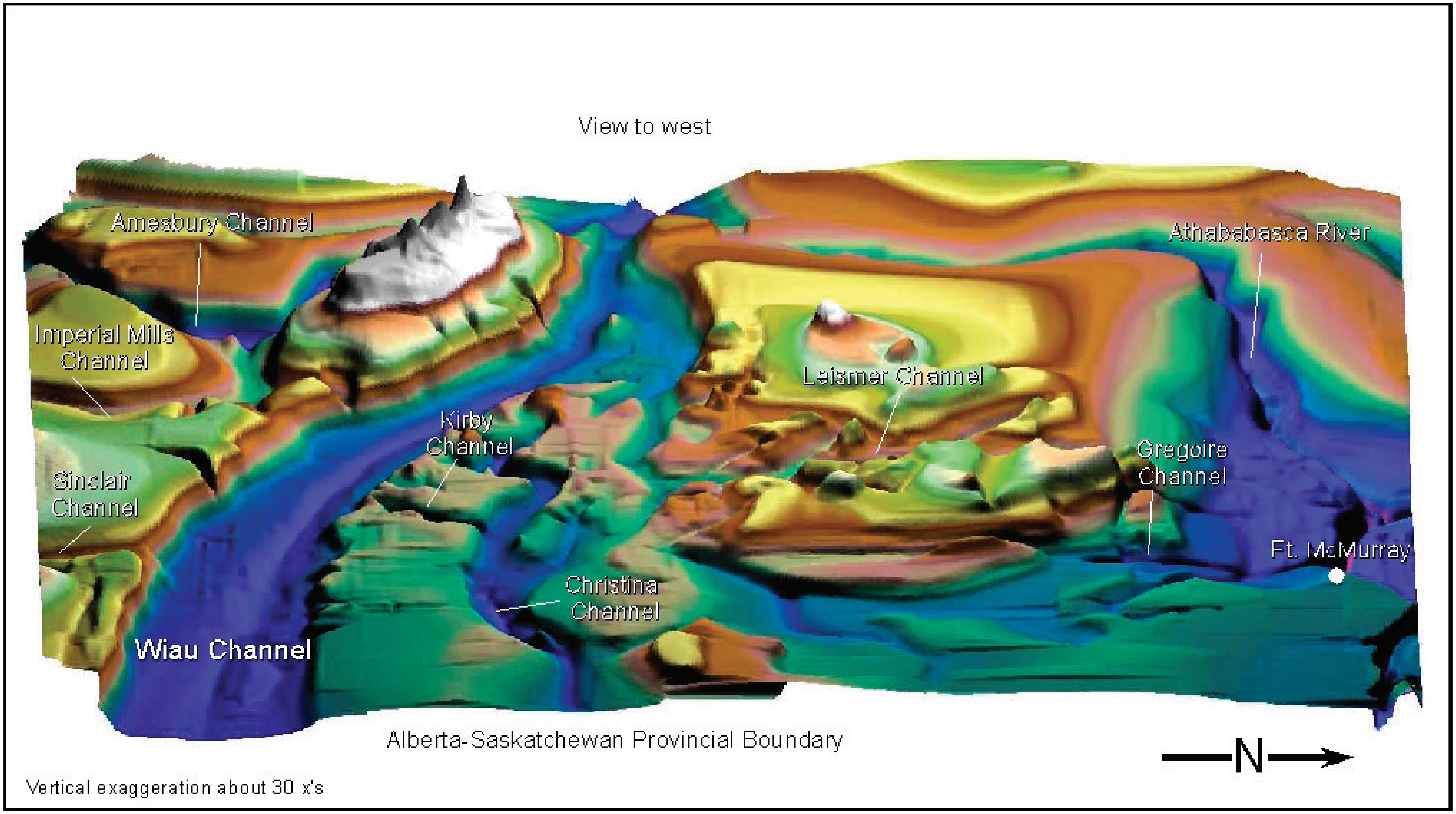


Figure 6.2. Three-dimensional perspective of the bedrock topography in the study area.

understanding of the distribution and geometry of these erosional elements of the bedrock landscape becomes important in the overall evaluation of groundwater resources because these are the foci for accumulations of thick, permeable sediment, which make up the major drift aquifers of the region.

In terms of the character of the bedrock landscape in the study area, the difference in elevation between the highest and lowest bedrock elements is about 600 m, ranging from a high of about 840 m in the May Hills in the southwest, to a low of about 240 m in bedrock outcrops along the present-day Athabasca River (Figure 6.1). Excluding the present-day Athabasca River Channel, the lowest bedrock elevations correspond to the talwegs of buried channels, the deepest of which are the Wiau, Christina, and Amesbury channels.

Just as physiographic classifications facilitate the discussion about present-day surface landforms, the major elements of the bedrock topography can similarly be grouped into bedrock physiographic units for purposes of discussion. As Figure 6.3 illustrates, elements of the bedrock landscape can be classified in decreasing order of elevation and relief into one of four major bedrock physiographic units: highlands, uplands, plains, and lowlands. Profiles of the bedrock surface are also depicted in a series of geological cross-sections that illustrate the stratigraphy of the drift in the study area (Figures 6.5 to 6.9).

6.2.1 May Hills Highland

The May Hills Bedrock Highland is the highest bedrock physiographic unit in the study area, ranging in elevation from about 600 m to as high as 840 m in a series of southeast trending remnant knobs (Figure 6.1). The core of the highland consists of Upper Cretaceous Wapiti Formation siltstone, sandstone, mudstone and coal (Figure 6.10). A comparison of the surface physiography with the bedrock physiography (Figures 3.1 and 6.1) shows that there is almost a one-to-one relationship between the boundaries of the May Hills Highlands bedrock physiographic unit and the May Hill surface physiographic unit, indicating that bedrock lies at, or near the present-day land surface (see cross-section C-C', Figure 6.7). Outcrops of the Wapiti Formation can be seen along road sections at the very top of the highland, where the drift cover is absent to only a few metres thick in places (Figure 6.4).

6.2.2 Caribou Upland

The Caribou bedrock upland forms the next highest physiographic unit in the bedrock landscape. The upland lies along the southern part of the study area, forming a relatively steep southern margin with the adjacent Wiau Lowlands (Figure 6.3). The upland consists of two components; a western component, containing the May Hills Highland, separated from an eastern component by the Amesbury Plains, which forms a saddle between the two upland features.

The elevation of the Caribou Upland ranges from a low of about 500 m to as high as 650 m in the extreme southern part of the study area (Figures 6.1 and 6.3). The majority of the upland, however, lies at an elevation between 550 m and 600 m. Two buried channels, the Sinclair and Caribou channels intersect the upland in Tp 70, Rgs 5 and 6 (Figure 6.1). The lowest part southward trending Sinclair Channel lies at an elevation of about 500 m, although local channel scour extends down as deep as 450 m in places.

Black marine shale of the Upper Cretaceous Colorado (LaBiche) Group lies at the surface of most of the upland, with possible exception of outliers of the younger Lea Park Formation shale in the highest parts of the upland to the south, and exposures of Lea Park Formation along the base of the May Hills Highland in the west, as shown in a series of geological cross-sections (Figures 6.5, 6.6, 6.7). The upland is presently covered by about 90 to 150 m of drift (Figure 6.4).

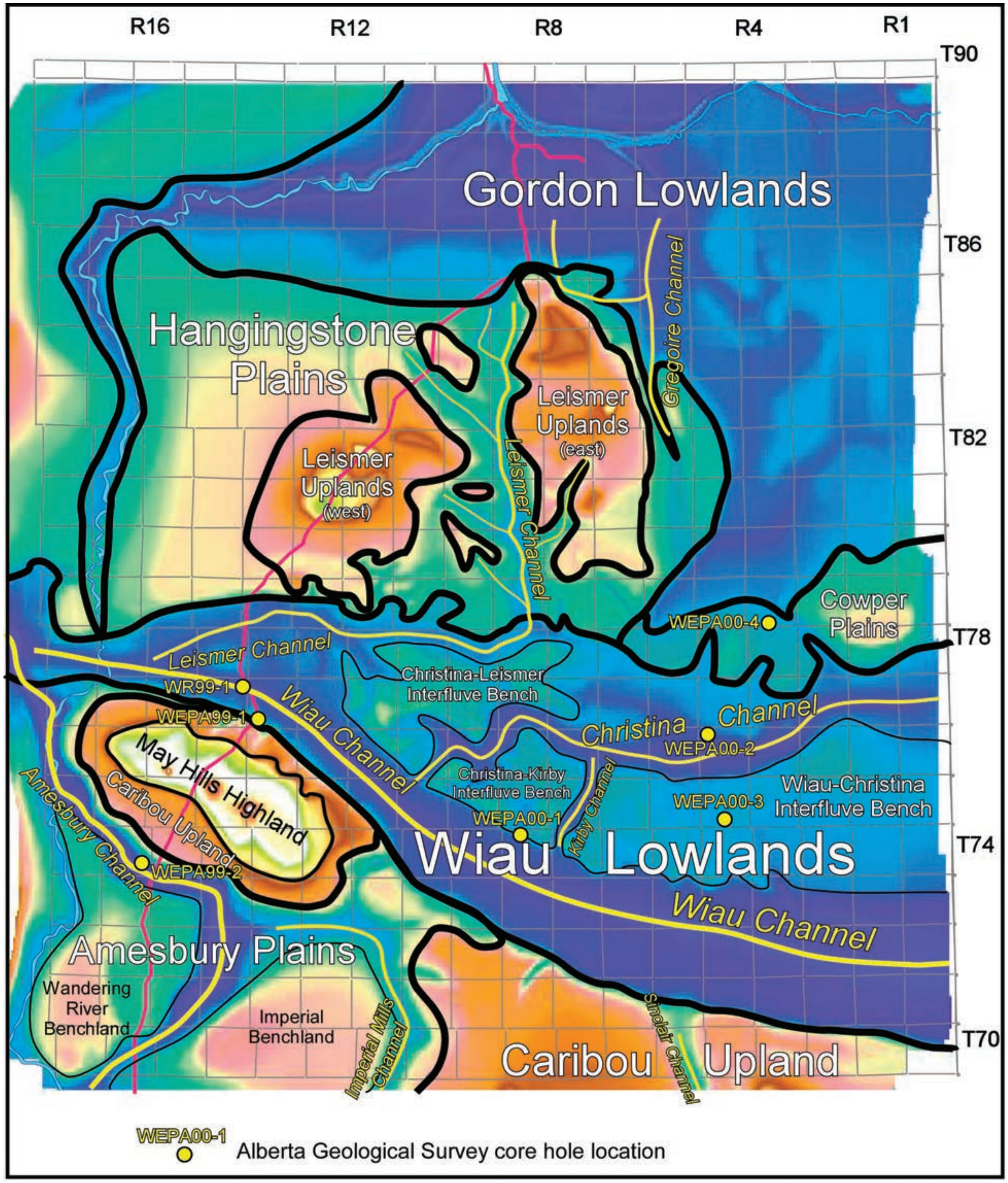


Figure 6.3. Major bedrock physiographic units.

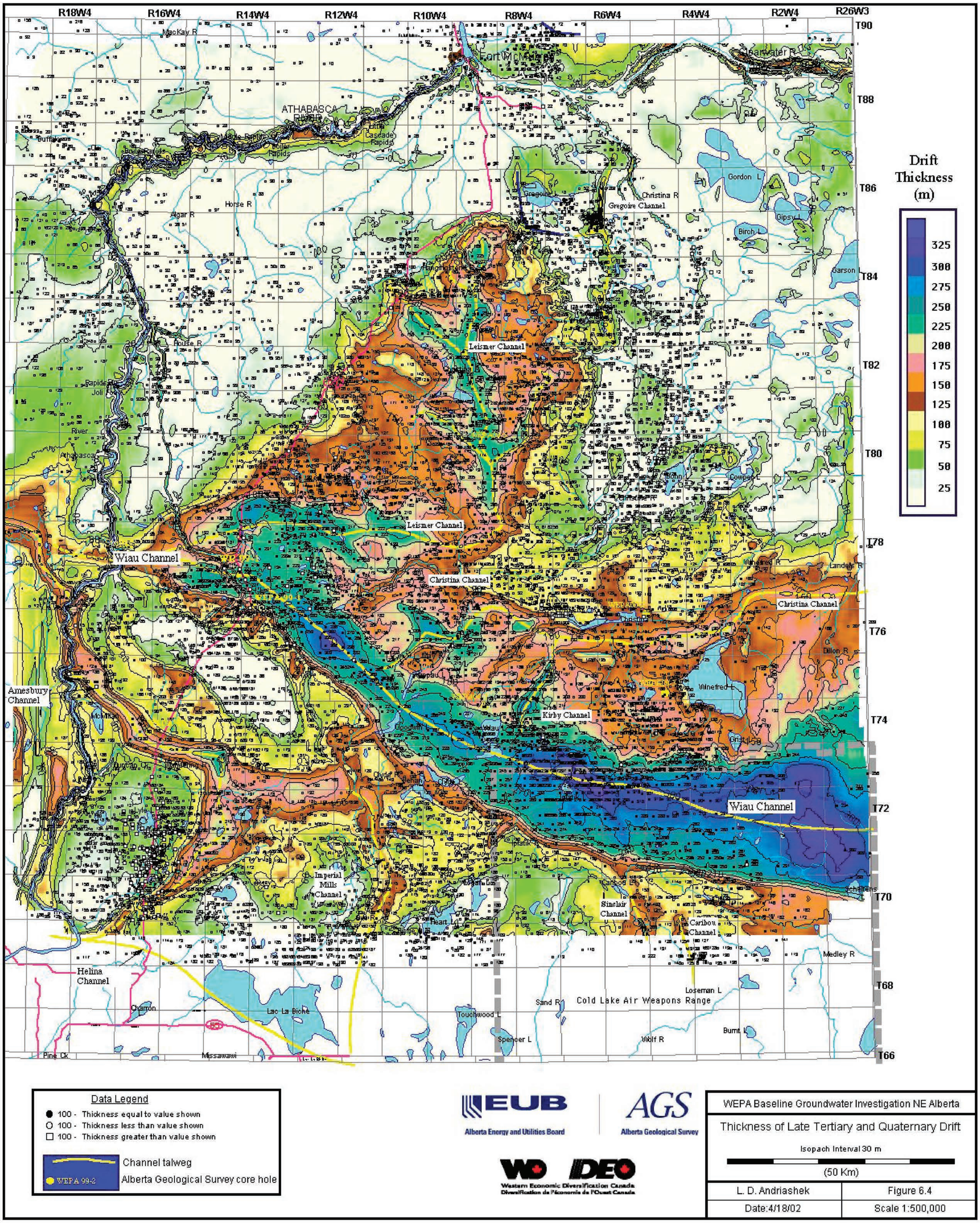

R18W4
R16W4
R14W4
R12W4
R10W4
R8W4
R6W4
R4W4
R2W4
R26W3
T90
T88
T86
T84
T82
T80
T78
T76
T74
T72
T70
T68
T66
Fort McMurray
ATHABASCA RIVER
Leismer Channel
Leismer Channel
Gregoire Channel
Christina R
Gordon L
Wiau Channel
Christina Channel
Christina Channel
Amesbury Channel
Kirby Channel
Winefred L
Wiau Channel
Imperial Mills Channel
Sinclair Channel
Caribou Channel
Helina Channel
Lac La Biche
Cold Lake Air Weapons Range
Drift Thickness (m)
325
300
275
250
225
200
175
150
125
100
75
50
25
Data Legend
100 - Thickness equal to value shown
100 - Thickness less than value shown
100 - Thickness greater than value shown
Channel talweg
WEPA 99-2
Alberta Geological Survey core hole
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Thickness of Late Tertiary and Quaternary Drift
Isopach Interval 30 m
(50 Km)
L. D. Andriashek
Figure 6.4
Date:4/18/02
Scale 1:500,000

Figure 6.5. Geological cross-section A-A'.

Figure 6.6. Geological cross-section B-B'.

Figure 6.7. Geological cross-section C-C'.

Figure 6.8. Geological cross-section D-D' showing stratigraphy of the drift and upper bedrock units along the Wiau Channel.

Figure 6.9. Geological cross-section E-E' (along Leismer Channel).

There is only a weak relationship between the boundaries between Caribou Upland bedrock physiographic unit and the Mostoos Upland, which forms the overlying surface physiographic unit (Figures 3.1 and 6.3).

6.2.3 Leismer Uplands

The Leismer Uplands lie at roughly the same elevation as the Caribou Uplands, but are located on the north, or opposite, side of the Wiau Lowlands (Figure 6.3). The uplands consist of a number of remnants of a formerly more extensive bedrock upland that was eroded and dissected by the Leismer channel and its tributaries (Figure 6.3). The Leismer bedrock upland underlies the present-day Crow Lake Upland physiographic unit, but a comparison of the boundaries shows that the geometries of the two are quite dissimilar – the Leismer Upland being significantly less extensive and lower in elevation than the Crow Lake Upland (Figures 3.1 and 6.3).

For purposes of discussion, the Leismer Uplands can be considered to consist of two major upland features, the Leismer Uplands West, and the Leismer Uplands East, which are separated by the Leismer Channel. The elevation of the western feature ranges from about 550 m to 630 m, with a maximum elevation of about 690 m in an isolated bedrock high in Tp 81, Rg 13 (Figure 6.1). The range in elevation of the eastern feature is less, varying between 530 m and 610 m. The Leismer Channel, and its tributaries, has eroded as much as 150 m into the pre-existing upland such that the channel talweg lies at an elevation as low as 490 to 500m.

Marine shale of the Upper Colorado (LaBiche) Group lies at the surface for most of the upland, with the possible exception of an outlier of Lea Park Formation siltstone and shale in the bedrock high in Tp 81, Rg 13 (Figure 6.10). In places, fluvial erosion within the Leismer Channel has down cut to intersect the top of the Lower Cretaceous Viking Sandstone (Figure 6.9).

Excluding the thick (>240 m) accumulations of drift above the Leismer Channel (half of which lies in the Hangingstone Plains and the other half in Wiau Lowlands physiographic units), drift thickness above the Leismer bedrock uplands averages about 100 m, and locally is as much as 150 m (Figure 6.4).

6.2.4 Amesbury Plains

Although the Amesbury Plains contains the most deeply incised bedrock channel in the study area, the herein named Amesbury Channel, the Plains are considered to occupy a position intermediary in elevation to the Caribou Uplands and the Wiau Lowlands, which lie to the north and east. Four physiographic elements comprise the Amesbury Plains: the Imperial and Wandering River benchlands, incised into which are the Amesbury and Imperial Mills bedrock channels (Figure 6.3).

The northward trending Amesbury Channel dissects the Amesbury Plains into two bedrock interfluves, the Wandering River Benchland and the Imperial Benchland. Both benchlands have an undulating bedrock topography in which the elevation differs by less than 60 m, ranging from about 500 to 560 m (Figure 6.1). The eastern boundary of the Imperial Benchland is defined by the Imperial Mills Channel, which lies at an elevation of about 480 to 500 m at the foot of the Caribou Uplands.

Unlike the relatively shallow Imperial Mills Channel, the Amesbury Channel is eroded more deeply into the surrounding bedrock, as much as 100 m in the narrow channel segment within Tp 74, Rg 17, producing much steeper channel walls (Figure 6.1). Elevations within the channel decrease in a northerly direction from about 440 m in the southern corner of the study area to about 370 m in Tp 78, Rg 18, where it, and the western end of the Wiau Channel, both converge.

Black marine shale of the Upper Colorado (LaBiche) Group is believed to form the bedrock surface throughout all of the Amesbury Plains (Figure 6.10). With the exception of the more than 180 m of drift infill within the Amesbury and Imperials Mills channels, the remainder of the Amesbury Plains is covered by about 30 to 60 m of drift (Figure 6.4).

6.2.5 Hangingstone Plains

The Hangingstone Plains lie at roughly the same elevation as the Amesbury Plains, but are located on the north, or opposite, side of the Wiau Lowlands. The physiographic unit surrounds the more prominent bedrock features of the Leismer Uplands, and includes only one subdivision, the Leismer Channel and its tributaries. Although data are sparse in the western part of the unit, the bedrock surface of the Hangingstone Plains is interpreted to slope gently toward the present-day Athabasca River (Figure 6.3). The bedrock surface has a steeper contact with the Gordon Lowlands along the eastern edge of the plains, where the topography drops deeply into the buried Gregoire Channel (Figure 6.1).

Elevation within the physiographic unit differs by less than 80 m, from a high of about 560 m at the contact with the Leismer Uplands, to a low of about 500 m along the talweg of the Leismer Channel. The northern and eastern boundary of the Hangingstone Plains roughly demarcates the north extent of the marine shale of the Colorado (LaBiche) Group. Sandstone, siltstone and shale of the Grand Rapids Formation outcrop north of the physiographic unit (Figure 6.10).

For much of the plains the thickness of drift cover is 30 m or less (Figure 6.4). The thickest accumulations of drift are found above the northern part of the buried Leismer Channel, and its tributaries, where as much 250 m of sediment are mapped.

6.2.6 Cowper Plains

The Cowper Plains form a relatively shallow, east-west physiographic divide between the Wiau Lowlands in the south and the Gordon Lowlands to the north. The western part of the plains is similar in elevation to, and can be considered to be the northern complement of the Wiau-Christina Interfluve Bench that lies on the opposite of the Christina Channel to the south (Figures 6.3 and 6.5). The eastern part of the plains lies at a higher elevation, more similar to that of the Hangingstone Plains. The flanks along the western part of the Cowper Plains appear to show erosion and incision by local drainage flowing both south into the Christina Channel, and north into the Gordon Lowlands. Headwater erosion and stream capture has breached the bedrock divide in Tp 77, Rg 2 to Tp 79, Rg 4, forming a shallow northwest-trending channel that transects the plains (Figure 6.1).

Regional differences in elevation within the plains are generally less than 60 to 70 m, ranging from a low of about 470 m in the channel in Tp 78 Rg 3, to a high of about 540 m directly east in Tp 79, Rg 2 (Figure 6.1). Marine shale of the Colorado (LaBiche) Group forms the bedrock surface of the plains. The Cowper Plains are covered by anywhere from 90 to 120 m of drift, with the thickest accumulations found above minor erosional features on the bedrock surface. Areas of thick drift also correspond to an accumulation of glacial sediment in a roughly east-west trending morainal ridge, directly south of Cowper and Bohns lakes (Figures 5.2 and 5.3).

6.2.7 Wiau Lowlands

The bedrock topography of the south-central part of the study area is defined by a broad lowland nestled between the bedrock highs of the Caribou and Leismer bedrock uplands, referred to as the Wiau Lowlands. The lowland extends in an east-west direction for a distance of about 175 km in the study area, widening from about 10 km in the west to more than 75 km at the Alberta-Saskatchewan political

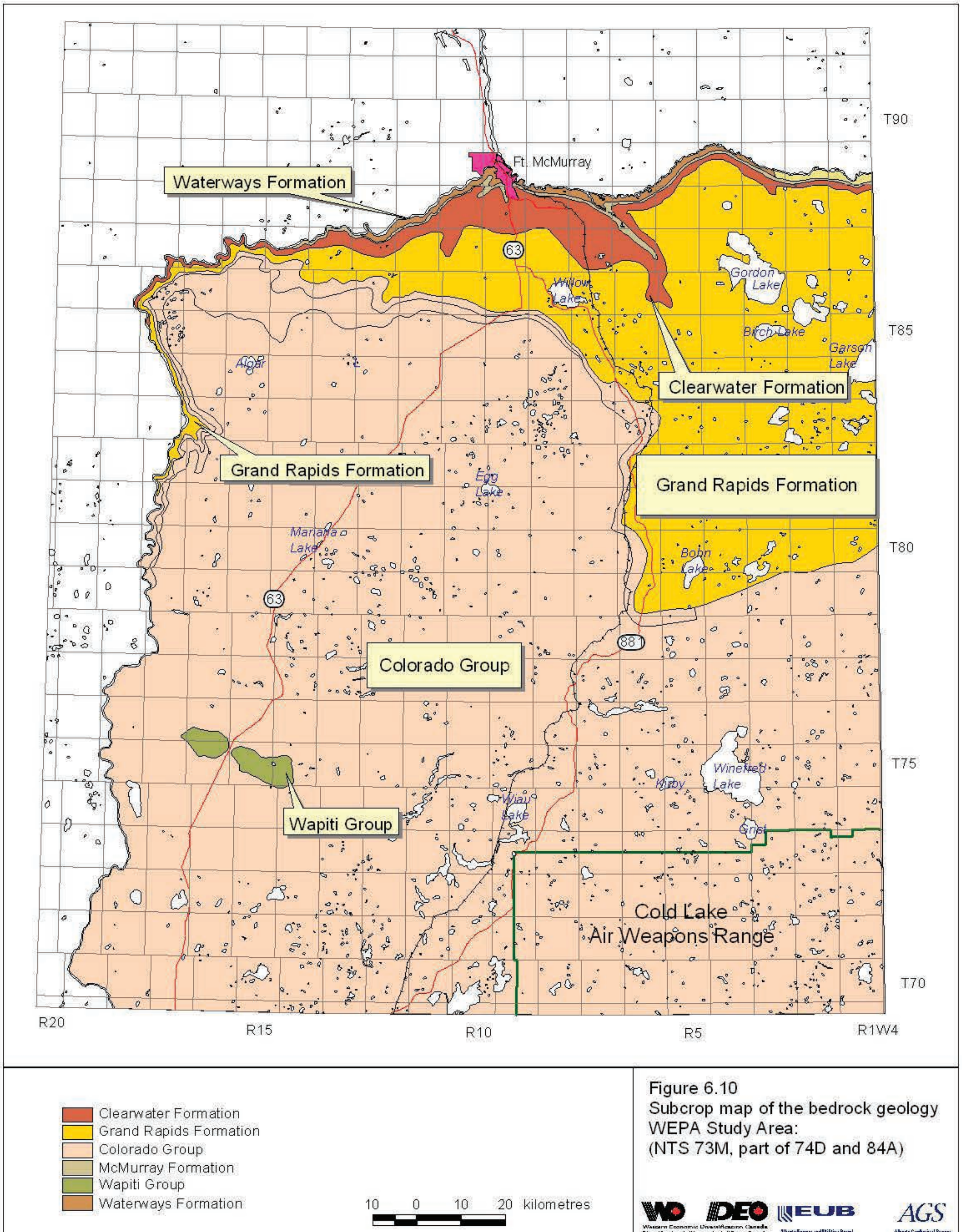


Figure 6.10
Subcrop map of the bedrock geology
WEPA Study Area:
(NTS 73M, part of 74D and 84A)

boundary (Figure 6.3). The difference of elevation within the lowland is about 100 m, ranging from a low of 380 m along segments of the buried Christina Channel, to a high of about 460 to 480 m at the base of the neighbouring uplands. A section across the Wiau Lowland shows an asymmetrical profile with the southern margin characterized by an abrupt contact with the relatively steep, northern slope of the Caribou Uplands, and the northern margin characterized by a gradual rise into the Hangingstone and Cowper plains (Figures 6.5 and 6.6).

The Wiau Lowlands physiographic unit includes a number of secondary physiographic elements: segments of four buried channels, the Wiau, Christina, Leismer and Kirby channels, and, the interfluve benches or terraces that separate these channels, referred to as the Wiau-Christina Interfluve Bench, the Christina-Kirby Interfluve Bench, and the Christina-Leismer Interfluve Bench (Figure 6.3). Although the Wiau Channel is considered to be the deepest of the four channels, with an elevation of about 390 m at the east end, segments of the Christina Channel in Tp 76, Rg 5, display evidence of local scour down to an elevation as low 375 m (Figures 6.1 and 6.5). The tops of the intervening interfluve benches are about 30 to 40 m higher than the channel floors, at an elevation of about 480 m. Opposing gradients, and the orthogonal nature of channel confluences, are indicative of a complex erosional history within the Wiau Lowland, which is discussed in more detail in the next section.

Two natural gas-bearing horizons have been intersected and eroded by buried channels in the Wiau Lowlands: the Viking Sandstone, which subcrops within the Wiau Channel, and the Grand Rapids Sandstone, the top of which subcrops beneath deeply-scoured segments of the Christina Channel. Elsewhere, black marine shale of the Lower Cretaceous Joli Fou Formation, or Lower Colorado Group form the bedrock surface (Figures 6.5 to 6.8, Figure 6.10).

The greatest accumulations of drift in the study area are found within the Wiau Lowlands, where in excess of 300 m have been mapped above the eastern segment of the Wiau Channel (Figure 6.4).

6.2.8 Gordon Lowlands

The lowest elements of the bedrock topography in the study area are found in the Gordon Lowlands, a low-relief, undulating to inclined bedrock landscape into which are incised by the present-day Athabasca and Clearwater rivers (Figure 6.3). In the west, where the unit has a gradational contact with the Hangingstone Plains, the 500 m contour level defines the upper part of the lowland. From here, the elevation decreases gradually northward to about 340 m along the Christina, Athabasca, and Clearwater river valleys (Figure 6.1). In the east, the lowland has a similar gradational contact with the Cowper Plains to the south, but has an abrupt contact with the steeply rising Leismer Uplands in Tp 84, Rg 6. This also coincides with the subcrop of the contact between the Colorado Group shale and the Grand Rapids sandstone (Figure 6.10). With the exception of the deeply eroded channels of the present-day rivers, buried Gregoire Channel is the most prominent bedrock feature in the Gordon Lowlands (Figure 6.3). As it is currently defined, the channel consists of two segments: a north-south trending segment located in Tps 82 to 87, Rg 6, and an orthogonal segment which trends in an east-west direction from Tp 85, Rg 6 to Tp 85, Rg 8, and from there, north to Tp 86, Rg 8 (Figure 6.1).

The easternmost arm of the channel has deeply eroded the bedrock surface to a depth as much as 150 m below the surrounding bedrock surface, such that in Tp 85, Rg 6 the elevation of the channel floor is about 285 m above sea level.

Grand Rapids Sandstone forms the bedrock surface for most of the lowlands, the exception being outcrops of oil sand of the Lower Cretaceous Manville Group, and carbonate of the Upper Devonian Waterways Formation, along the valley walls of the Athabasca and Clearwater rivers (Figure 6.10). For the most part, the thickness of drift in the Gordon Lowlands is less than 30 m, and in most places, less than 20 m. The exception is more than 180 m of drift that overlies the deepest parts of the Gregoire Channel (Figure 6.4).

6.3 Drift Thickness

A comparison of the surface and bedrock topography shows that the ranges in elevation of the two are similar, indicating that bedrock lies at, or near the present-day land surface in some areas. Examples of this include the May Hills bedrock highland, where the drift cover is only a few metres thick in places, and along the Athabasca, Clearwater, and Christina rivers in the northern part of the study area where bedrock is exposed in the valley walls. Although in some areas elements of the present-day topography are coincident with the underlying bedrock topography, in many places the two surfaces diverge, separated by thick drift. A subtraction of the bedrock surface from the surface topography yields an isopach map of drift thickness (Figure 6.4), which shows that as much as 325 m of sediment have accumulated above the talweg of the Wiau Channel, and at least 150 to 250 m above other bedrock channels such as the Christina, Leismer, Amesbury, Imperial Mills and Gregoire channels. The cover of drift in these channels is so thick that it has completely masked any surface expression of their surfaces.

In some cases, the cover of drift has more than just in filled the channels, it has accumulated to form a positive morainal landscape, the highest points of which lie roughly above the deepest parts of the underlying bedrock surface. Perhaps the best example of this mirror-image relationship is in the south-central part of the study area, where thick drift has accumulated directly above the Wiau Channel to form the topographically high Mostoos Upland physiographic unit (Figure 6.5). In fact, an approximate outline of the eastern part of the underlying Wiau Channel can be traced by the contours of the highest parts of the present-day surface, as shown in Figure 3.1. A similar example, though somewhat less pronounced, is the relationship between the bedrock topography and surface topography within the Crow Lake Upland physiographic unit. The Crow Lake Upland is dominantly a constructional landscape in which thick accumulations of drift have exaggerated the form of the underlying Leismer bedrock upland. This thick drift cover is greatest above the Leismer bedrock channel (and its tributaries), where, like the Wiau Channel, it has masked any expression of the underlying channel topography (Figure 6.9).

6.4 Buried Bedrock Channels

6.4.1 Introduction

Remnants of buried fluvial channels provide a historical record of the erosion that has occurred on the bedrock surface from the Late Cretaceous to the Late Pleistocene. To date, there have not been any techniques that establish the absolute dates or ages for these channels. Nevertheless, there are lines of evidence to determine the relative ages and sequences of erosive events.

Buried bedrock channels in the study area can be grouped into one of two relative-age categories – preglacial channels, and Quaternary-aged glacial and interglacial channels. Preglacial channels are considered to have formed prior to the onset of the first glaciation in the early Quaternary. They represent the regional, north and eastward drainage of the Western Canadian Sedimentary plains during the Late Cretaceous to early Quaternary period. These channels are interpreted to have their headwaters either in the Rocky Mountains or in the local bedrock plains that lie east of the mountains. Preglacial channels are characterized by the following:

- Buried preglacial channels are typically very wide, in some cases as much as 10 km wide, with shallow valley walls. Compared to glacial channels, preglacial channels exhibit very high width-to-depth ratios, as much as 250:1. Channel widths are so great, in fact, that these systems are commonly referred to as ‘buried preglacial valleys’, to denote their broad width and shallow slopes. The choice of terms may be semantics, but the term ‘channel’ is preferred to differentiate from valleys formed by other geological processes such as tectonics or subsidence.
- Longitudinal profiles of preglacial channels generally have very shallow gradients, inclined in a single direction; exceptions to this occur where channel piracy and stream capture divert drainage into adjacent systems, causing apparent reversals in gradient at the capture-end of the channel. Farvolden (1963) considered the uniformity of shallow gradients in preglacial channels to be evidence that erosion was more or less continuous since the end of Miocene time, and that the channels represent mature streams that drained mature landscapes. The reader is directed to the 1963 publication for additional insights regarding the sequential development of erosional features since late Oligocene time.
- The composition of the clasts in the fluvial sediments that lie on the channel floors consists of resistant rock types composed dominantly of light-coloured metaquartzite and sandstone, and dark-coloured chert derived from either Cordilleran rock sources, from local Cretaceous bedrock sources, or from recycled gravel that was deposited during an earlier stage in the erosion of the bedrock landscape. This petrologic composition gives the sand component a ‘salt-and-pepper’ appearance. Further, preglacial channel sediments are characterized not so much by the presence, but rather, by the absence of two distinctive rock types – granite and gneiss derived from the Canadian Shield, which lies to the north and east, downstream of the study area. The presence of Shield clasts in channel sediment can only be from a glacial source, from the northeast.
- Preglacial channels function as depositional basins for the accumulation of fluvial sediments on the channel floors, and later, infill with glacial sediments. A record of multiple glacial events is commonly recorded in the stratigraphy within buried preglacial channels, including re-occupation and local bedrock scour by subsequent glacial meltwater erosion.

Quaternary-aged bedrock channels include channels formed by glacial meltwater during any one of a number of glaciations, as well as by interglacial fluvial drainage systems that developed on the landscape in the period between major glaciations, similar to the drainage systems established on the present-day Alberta landscape. Quaternary-aged channels, and in particular, glacial meltwater channels, are characterized by the following:

- They are commonly formed by single-event, catastrophic releases of meltwater in a supraglacial or subglacial environment. Meltwater flow is either on the glacier surface and is confined by ice, or flow occurs beneath the glacier where the hydraulic head is determined, in part, by the weight of the glacier and differences in head of water within the glacier. As a consequence, drainage is not necessarily confined to lows in the underlying bedrock topography and channels can incise bedrock highs.
- Glacial channels are generally narrow and have relatively low width to depth ratios, in some cases as low as 5:1.
- Glacial channels commonly show lack of continuity at a regional scale, have abrupt truncations, and may exhibit concave-scoured longitudinal profiles.

- They commonly have thick in fills with glaciofluvial sediment which contain abundant granites and gneissic clasts from the Canadian Shield, and which are related to a single depositional event. Fluvial sediments can have a highly varied grain-size composition, with abrupt transitions in size from fine (silt, sand) to extremely coarse (1m boulders).

Aspects of the stratigraphy contained within each of the bedrock channels are discussed in more detail in Chapter 7.

6.4.2 Buried Preglacial Channels

6.4.2.1 Wiau Channel

The Wiau Channel is the most prominent bedrock feature in the study area. The channel is considered to be one of the widest, if not the largest, buried preglacial channels in the Plains region in North America. The Wiau channel was named, and first studied, by Gold (1983). Later, the Alberta Research Council constructed preliminary maps of the channel and surrounding bedrock topography as part of a preliminary groundwater resource evaluation (Stein and Andriashek, 1993).

The composition of the clasts in the fluvial sediments resting on the floor of the Wiau Channel are of Cordilleran origin (metaquartzite and chert), indicating that the Wiau channel was formed by preglacial drainage flowing eastward from the Rocky Mountains (see litholog for borehole WR99-1, Appendix 2-C). Eastward drainage is also supported by a relatively shallow eastward gradient of the channel floor (Figures 6.1, and Table 6.1). The channel extends for a distance of more than 195 km within the study area before it exits into Saskatchewan. As was discussed earlier, the thickest amount of drift in the study area occurs above the eastern segment of the Wiau Channel, where depth to bedrock (that is, drift thickness) exceeds 300 m. Actual incision into the bedrock by preglacial drainage is only about half of that depth, however, ranging between 150 to 175 m, as shown in cross-sections A-A' and B-B' (Figures 6.5 and 6.6).

There are also sections of the Wiau Channel that appear to show evidence of reoccupation and over-deepening of the bedrock channel floor by glacial meltwater erosion. The bedrock topography map (Figure 6.1) shows a relatively narrow (1 km) channel along the southern flank of the Wiau Channel in Tp 72, Rg 8 which, as Figure 6.11 illustrates, is interpreted to have been scoured by glacial meltwater subsequent to the advance of the first glaciation over the channel.

There are a number of other aspects regarding the geometry of the Wiau Channel that are worth discussing. At a first glance of the bedrock topography map of the area (Figure 6.1), it appears that the Amesbury Channel trends northward to join with the Wiau Channel in Tp 78, Rg 19, and that from there, the Wiau continues westward beyond the boundaries of the study area. Although the density of data in that area is poor, a close examination of the confluence of the two systems shows that the thalweg of the Amesbury Channel lies about 60 m deeper than that of the Wiau Channel, indicating that the Wiau Channel is, in fact, a hanging channel that was abandoned in favour of more recent drainage north and west along the Amesbury Channel. Thus, the Wiau Channel does not extend throughout all of central Alberta, as was once believed, but rather, has its boundaries entirely within the study area. Similar examples of stream piracy and channel abandonment were recognized in the mapping of the bedrock topography and buried channels in southern Alberta (Farvolden, 1963).

Secondly, in comparison with neighbouring preglacial channels such as the Helina and Beverly channels, which lie about 60 km to the south (Andriashek and Fenton, 1989), the Wiau Channel exhibits a

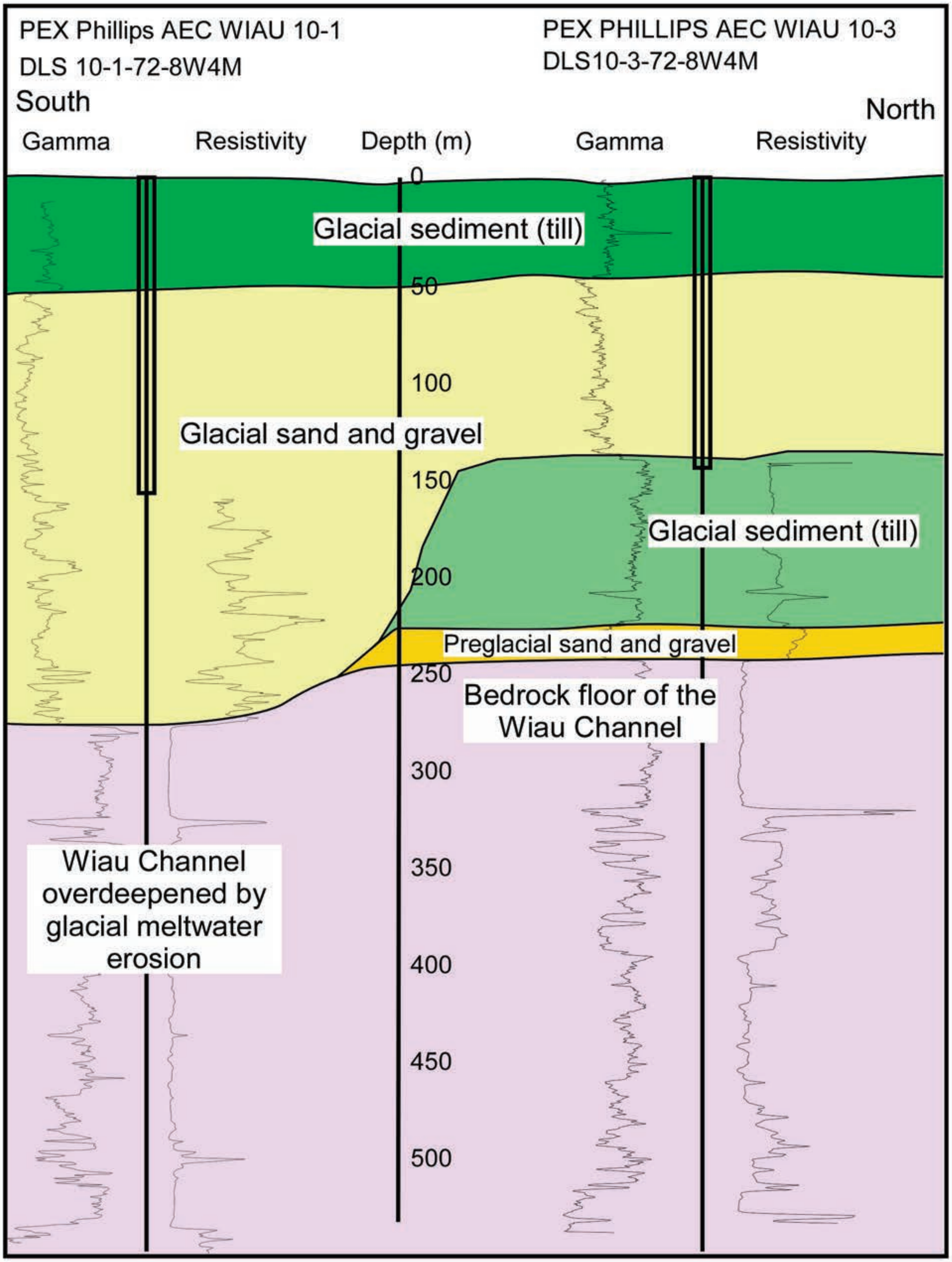


Figure 6.11. Reoccupation and overdeepening of preglacial bedrock channels by glacial meltwater, Wiau bedrock channel.

substantially greater width. Figure 6.1 shows that the channel broadens in an easterly direction, from about 10 km in Townships 75-76, Ranges 11-13, to as much as 25 to 30 km at the Alberta-Saskatchewan border. The reasons for the greater channel width in the east remain speculative, and there are little-to-no borehole data east of the study area to increase our understanding of the location and geometry of the Wiau Channel in Saskatchewan. One possible influence on the channel geometry is the effect that dissolution and collapse of the Prairie Formation evaporites, which underlies the eastern part of the channel, had on the topography of the overlying Cretaceous bedrock strata (Figure 10.3 in Mossop and Shetsen, 1994). Gradual subsidence of the overlying strata by salt dissolution during the Late Cretaceous-Tertiary interval may have enhanced the lateral migration and erosion of the bedrock surface in that area.

Thirdly, a series of sections across the Wiau Channel illustrate two other features of note:

- The floor of the channel has two topographical elements: a broad, generally level plain, extending in width as much as 20 km, into which is incised a deeper, narrower channel (3 km), which defines the talweg (Figure 6.5). Farvolden (1963) attributed a more deeply incised channel within a broad erosional plain to represent enhanced erosion during a stage of relatively rapid uplift of a landmass, which ended with the onset of the first glaciation.
- The channel margins exhibit cross-sectional asymmetry, with the southern margin being much steeper and higher than the northern margin (Figures 6.5, and 6.6). Asymmetrical profiles were also noted in other buried preglacial channels by Farvolden (1963, pg. 59) but have never been satisfactorily explained. In the case of the buried Beverly Channel in the Edmonton area for example (referred to as the North Saskatchewan Channel by Farvolden), it is the northern margin that rises steeply and southern more gradually, the opposite of that in the Wiau Channel.

6.4.2.2 Christina and Kirby Channels

The Christina Channel is the second largest bedrock channel within Wiau Lowlands. The channel lies about 20 km north of the Wiau Channel, and extends in an easterly direction for about 110 km before it exits the study area into Saskatchewan. Although the Christina Channel is considerably narrower than the Wiau Channel, ranging in width from about 5 to 8 km (Table 6.1), it is comparable in width to other preglacial channels south of the study area, such as the Beverly and Helina channels. As much as 300 m of drift lie above the deepest parts of the Christina Channel, though the average thickness is about 180 m (Figure 6.4).

Table 6.1. Dimensions and properties of buried bedrock channels

Name	Origin	Width (km) min – max	Depth to floor (m) min. – max.	Length (km)	Elevation of floor (m) min. – max.	Gradient & direction(s) m/km	Direction
Wiau	Preglacial	5 – 30	120 m – 340 m	195	385 – 435	0.25	east
Leismer	Preglacial	3 – 6	150 m – 250 m	145	435 – 500	0.45	south & west
Christina	Preglacial	1.5 – 8	140 m – 270 m	120	380 – 430	<0.1	east
Amesbury	Preglacial	3 – 10	150 m – 240 m	140	370 – 435	0.5	north
Imperial Mills	Preglacial	5 – 9	100 m – 190 m	80	480 – 490	<0.1	south & northwest
Kirby	Preglacial(?)	1.5 – 3	180 m – 270 m	20	400 – 435	?	north? south?
Gregoire	Glacial	0.8 – 1.5	60 m – 190 m	35	285 - 410	<0.1	north

It is inferred that the Christina Channel was originally of preglacial fluvial origin, although sediment from the deepest part of the channel has not been evaluated to confirm a preglacial petrological composition. The channel possibly reflects a diversion of the main Wiau Channel as the eastward-flowing preglacial fluvial system migrated northward. Apparent confluence of the two systems is indicated by the orthogonal junction of the western end of the Christina Channel with the Wiau Channel in Tp 75, Rg 11. Elsewhere, the two channels are separated by the Wiau-Christina, and Christina-Kirby bedrock interfluves. There is stratigraphical and morphological evidence that suggests the Christina Channel may have been re-occupied by glacial meltwater to account for the apparent scour and over deepening of the bedrock floor in a segment of the channel that lies in Tp 76, Rg 5 (Figures 6.1 and 6.5).

Of special note is the Kirby Channel, which breaches the bedrock bench and links the Christina Channel with the Wiau Channel in Tps 74 to 76, Rg 8 (Figure 6.1). The presence of this relatively small channel is based on limited data, and the origin is uncertain - it may represent headwall erosion and stream capture from the Wiau into the Christina system, or, it may represent a glacial meltwater channel that eroded through the underlying drift and into the bedrock surface. Aspects of the channel morphology are summarized in Table 6.1.

6.4.2.3 Leismer Channel

The Leismer Channel, previously referred to as the Conklin Channel (Stein and Andriashek, 1993), represents a relatively mature and well-established drainage network, which, on the basis of the numerous tributaries that feed the main channel, is inferred to have developed on the bedrock surface during preglacial time (Figure 6.1). However, sediments from the floor of the channel have not been evaluated to confirm a preglacial petrological composition. At least three tributaries of the main Leismer Channel have been mapped, but remain unnamed at this time.

The geometry of the Leismer Channel exhibits two fundamentally distinct forms: a north-south segment within the Hangingstone Plains, which extends south from Tp 85, Rg 9 to Tp 78, Rg 9; and, an east-west segment in the Wiau Lowlands, which extends west from Tp 78, Rg 9 to an apparent confluence with the Wiau Channel in Tp 78 Rg 16 (Figures 6.1 and 6.3). The gradient of the channel floor in the section of the Leismer Channel that lies within the Wiau Lowlands is to the west, indicating that final drainage was in a direction opposite to that within the Wiau Channel.

The width of the Leismer Channel has been estimated to range between 3 and 6 km, though this values increases to as much as 10 km where tributaries join the main channel, as in Tp 80, Rg 9 (Figure 6.1). As much as 250 m of drift have accumulated above the deepest parts of the channel.

6.4.2.4 Amesbury Channel

Although segments of the herein named Amesbury Channel were recognized in previous studies of the regional hydrogeology of northern Alberta (Alberta Environmental Protection, 1986 – Hydrogeological cross-section C-C'), the channel has only recently been studied and mapped in the study area (Figure 6.1).

The Amesbury bedrock channel is inferred to of preglacial origin on the basis of its size and relationship with neighbouring preglacial channels such as the Helina Channel, which directly south of the study area (Gold et al, 1985) and the Wiau Channel. There have not been any samples examined of the fluvial sediment that lies on the floor of the channel to determine the petrological composition and confirm a preglacial age.

The channel enters the study area in Tp 70, Rg 17, forming a broad meander within the Amesbury Plains before exiting the area in Tp 78, Rg 18 where it appears to join with the Wiau Channel (Figure 6.1). Physical aspects of the channel are summarized in table 6.1. A higher-level bedrock channel, which appears to be a remnant terrace of the Amesbury Channel, is mapped directly west of the main channel in Tp 71, Rg 17 (Figure 6.7). One feature worth highlighting is that unlike its neighbour, the Imperial Mills Channel, the Amesbury Channel is eroded much more deeply into the surrounding bedrock, as much as 100 m in the narrow, steep-walled segment of the channel in Tp 74, Rg 17 (Figure 6.1).

Elevations within the Amesbury Channel decrease from about 435 m in the southern segment to about 370 m in the northern segment, indicating that the last stage of drainage was to the northwest. As was discussed previously, the Amesbury Channel is about 50 to 60 m deeper than the Wiau Channel at the apparent junction of the two in Tp 78 Rg 18. This establishes that the Amesbury Channel post-dates the erosion of the Wiau Channel, and is, therefore, younger. Drainage north and westward along the Amesbury Channel also provides indirect evidence of a fundamental adjustment or shift in the regional gradient of the Western Canadian Sedimentary Basin, which caused a reversal in the regional drainage direction (Gold, 1983). The obvious spatial relationship with the present-day Athabasca River, which occupies segments of the Amesbury Channel in Tp 76, Rg 18, suggests that the Amesbury Channel may represent the drainage path of the ancestral Athabasca River.

There is stratigraphic evidence to show that glacial processes have modified the Amesbury Channel, or at least segments of the channel. AGS core hole WEPA99-2, located on the northern flank of the channel in Tp 74, Rg 17 (Appendix 2-B) shows that the coarse fluvial sediment which rests on the bedrock surface elsewhere along the channel, is absent at that location. Instead, glacial diamicton (till) rests directly on the bedrock, indicating that the basal fluvial sediment has been eroded by either glacial ice-scour, or, glacial meltwater, with subsequent infill of till.

Approximately 150 to 240 m of drift has in filled the channel (Figure 6.4).

6.4.2.5 Imperial Mills Channel

Descriptions of preglacial type sand deposits in lithologs of boreholes confirm that the Imperial Mills Channel is likely of preglacial age (Andriashek and Fenton, 1989). The Imperial Mills Channel is relatively shallow, with broad, gently sloping valley walls. The channel is eroded about 50 m into the local bedrock surface, the deepest parts of which lie at an elevation between 480 and 500 m, an elevation not too dissimilar to that segment of the Leismer Channel which lies within the Hangingstone Plains on the opposite side of the Wiau Channel (Figure 6.1). Other attributes of the channel are summarized in Table 6.1

The Imperial Mills Channel was originally interpreted to join the Wiau Channel to the north, and thought to have been formed by stream capture, which diverted flow south from the Wiau Channel into the Helina Channel (Andriashek and Fenton, 1989). However, the mapping conducted in this study indicates that the Imperial Mills Channel most likely does not merge with the Wiau Channel, but rather, trends in a more westerly direction, toward the Amesbury Channel (Figures 6.1 and 6.3). Unfortunately, there are very little data to accurately define the junction of the Imperial Mills and Amesbury channels, so it is uncertain if drainage was confluent, or if the Amesbury Channel truncates the Imperial Mills Channel, as depicted in Figure 6.1. If flow were confluent, then the geomorphic evidence (that is, the elevated position in the bedrock landscape, combined with the opposing gradients of the northern and southern segments of the channel) would indicate that the Imperial Mills Channel is the result of headwall erosion and stream capture of two preglacial tributary channels that merged to appear now as one. On the other hand, if the ends of the channel have been truncated by the Helina and Amesbury channels, then the elevated position of the Imperial Mills Channel on the bedrock landscape would indicate that it is an abandoned channel formed in the early stage in the history of erosion in the study area, even prior to erosion of the Wiau Channel.

6.4.3 Buried Glacial Channels

The presence of granite and gneiss rock-fragments in the fluvial sediments resting on the bedrock floor confirm that one of the bedrock channels in the study area, the buried Gregoire Channel (Figure 6.1), was eroded by glacial meltwater, possibly during the last glaciation during the Late Wisconsin. The Gregoire Channel is about 1 km wide and has been eroded as much as 150 into the local bedrock to form a deep trench along the contact between the Gordon Lowlands and the Leismer Uplands (Figure 6.12). It has the highest depth-to-width-ratio (~1:5) of any of the buried channels in the study area, as shown in Table 6.1. An absence of data prevents both ends of the channel from being accurately defined, but it is believed that the channel may terminate abruptly within the study area, the north end terminating at an elevation of about 360 to 370 m, and the south end terminating at an elevation of about 460 to 470 m (Figure 6.1).

Although the apparent northward gradient of the Gregoire Channel floor assumes drainage from south to north, this assumption may be incorrect - direction of flow may have been, in fact, from north to south, with water apparently flowing uphill away from a northern Laurentide glacier margin. This is not inconsistent of fluvial erosion by meltwater in contact with glacial ice - meltwater can flow either on the glacier surface and downcut through the ice to intersect the underlying bedrock floor, or, it can flow beneath the glacier under high hydrostatic head that enables it to flow ‘uphill’ and erode higher elements of the underlying bedrock landscape. There is morphological evidence in the Gregoire Channel to support this interpretation: a cross section along the channel talweg displays a “U” shaped longitudinal profile, showing as much as 100 m of over deepening by meltwater scour in the middle segment of the channel (Figure 6.1, Sec 29, Tp 85, Rg 6), indicating either supraglacial or subglacial fluvial erosion.

As Figures 6.1 and 6.3 illustrate, there is an east-west oriented bedrock channel located directly north of the Leismer Uplands, which appears to have an orthogonal junction with the Gregoire Channel in the west part of Tp 85, Rg 6. Data are inconclusive regarding the composition of the sediments in that unnamed channel, but if it proves to be of glacial origin, then this channel, and the Gregoire Channel, may be part of a glacial meltwater channel complex related to a single erosional event.

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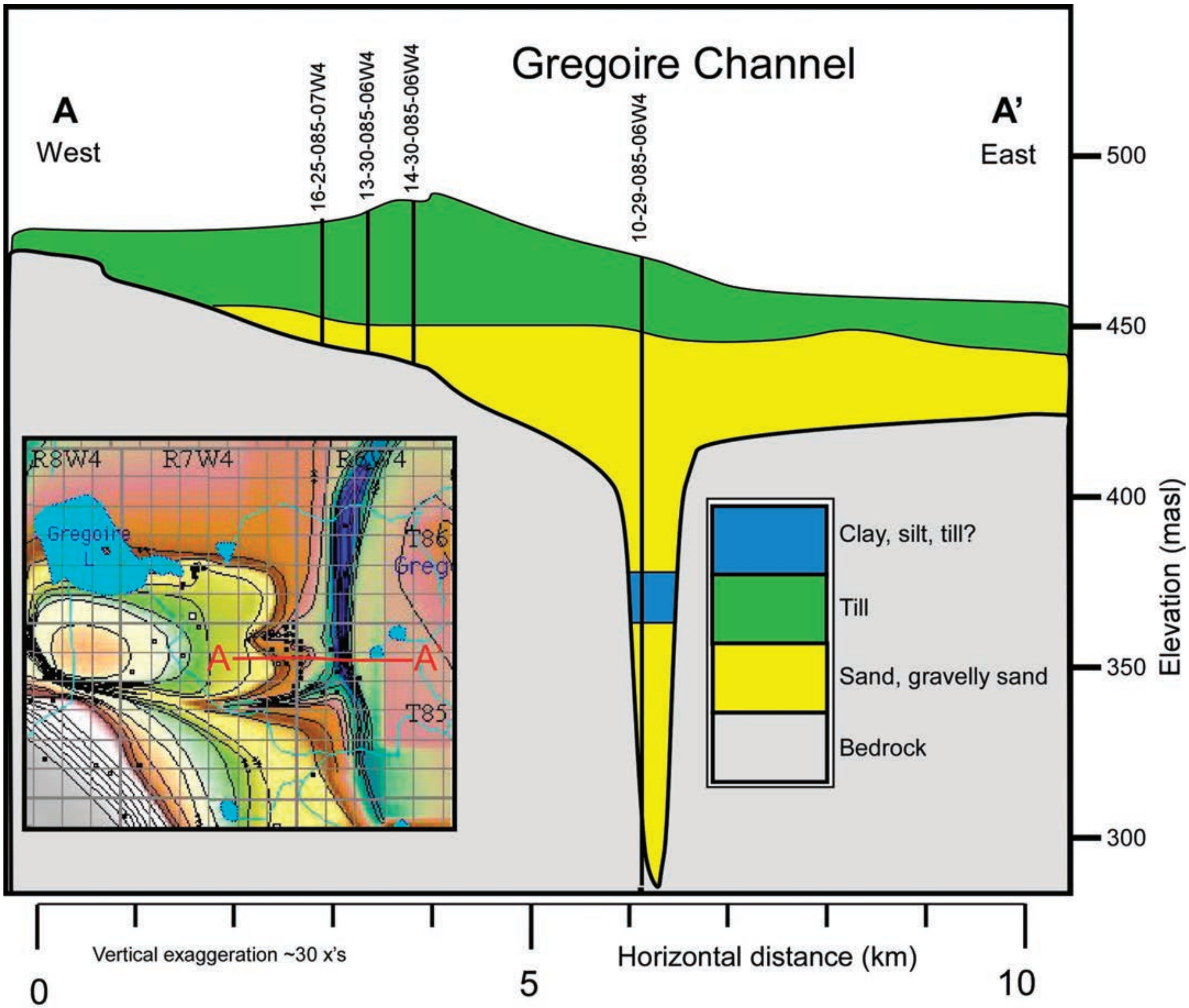

Figure 6.12. Deep incision of the bedrock surface by glacial meltwater, Gregoire Channel.

7 Geology of the Late Tertiary and Quaternary Drift Succession

7.1 Introduction

The north and central parts of Alberta contain some of the thickest deposits of heterogeneous, unconsolidated Tertiary and Quaternary sediment in the province, exceeding 300 m above segments of buried bedrock channels. Contained within this thick sedimentary sequence are extensive complexes of coarse, permeable stratified sediment found on the floors of bedrock channels and within the Quaternary glacial stratigraphic succession. These complexes are saturated with water and are favoured targets for groundwater exploration and development, particularly by the petroleum industry in its quest for large volumes of fresh water needed for steam enhanced recovery methods of bitumen. However, the occurrence and distribution of these aquifer systems is poorly known and incompletely mapped. Domestic well data are sparse and clustered in the sparsely settled areas, and generally consist only of driller's lithological descriptions. Petrophysical logs from the oil and gas wells are abundant, but the wells are usually completed with surface casings across the stratigraphic intervals, providing little to no information about the uppermost drift sequence.

Further complicating the predictive mapping of these aquifers is:

- the tendency of glacial genetic units to violate the law of original horizontality;
- the existence of unpredictable, vertically cross-cutting glacial sluiceways that can be infilled with sand, fine lacustrine clays, or younger glacial tills;
- the existence of glacially-thrusted terranes at depth and at surface;
- the recognition that a regional layer-cake concept oversimplifies the depositional architecture of these sediments, being more of a three-dimensional labyrinth, or a jigsaw-puzzle type.

Despite these complexities, a predictive stratigraphic model is emerging based on an understanding of the glacial history of the area. The key elements of this model are the recognition that:

- the region has been subject to multiple glacial events, and associated with each are nonstratified diamict units (till sheets) and stratified fluvial complexes deposited during advance and retreat phases of each glaciation;
- the distinct mineralogy of till sheets can be used to determine relative stratigraphic age and assist in regional correlations;
- that there is a cyclicity in the vertical facies associations; and
- the bedrock topography is a first-order control on the areal distribution of coarse-grained sediments.

This emerging glacio-stratigraphic model of the area can be used to predict the occurrence of aquifer-quality sediments for any depth and location, provided some key information is collected. The conceptual model also lets us place reasonable bounds on the predicted extent and connectivity of the aquifer-quality sediments in the subsurface.

7.2 Sources of Data for Stratigraphic Interpretations

Probably the biggest obstacle to interpreting the Quaternary stratigraphy is absence of high-quality subsurface data in the study area. Even though there are an abundance of oil and gas industry petrophysical logs, the upper part of the stratigraphic column is commonly not logged. There are few, if any, lithological descriptions of the material encountered, and those that are available, consist of generalized water-well drillers' field lithologs. Samples of Quaternary sediment are rarely collected. Fortunately, because of the thick drift in the region, there are numerous uncased portions of oil and gas exploration holes that record the lower half, or more, of the Quaternary units in the petrophysical logs. It is these borehole data, calibrated with key stratigraphic core holes drilled by the Alberta Geological Survey, which form the bulk of information used to construct the Quaternary stratigraphy in this area. The balance in developing the interpretive model is to maximize the information gleaned from oil and gas petrophysical logs, while at the same time collecting the key information to calibrate the log data with observed or measured values.

7.2.1 Methods of Investigation

7.2.1.1 Field Methods

Seven stratigraphic test hole sites were drilled by the AGS to assist the in the calibration of petrophysical logs and descriptive driller's records collected from the petroleum and water-well industries. A wet-rotary drill and continuous-core-recovery method was chosen to collect high-quality samples of the Quaternary sediment down to a depth of at least 200 m, or more (Figure 7.1). The coring process involves a 7.5 cm (3 inch) diameter, diamond-surfaced, tungsten-carbide bit (Figure 7.2) attached to a hollow drill stem in which a 3 m-long split core-barrel is recovered using wire-line methods. Samples of core were visually examined, described, and stored at AGS' Mineral Core Research Facility (MCRF) for further examination and sampling for laboratory analyses (Figure 7.3). The coring process was only marginally successful at collecting loose, unconsolidated sediment such as sand and gravel, thus those geological horizons are under-represented by core samples. Where drilling conditions necessitated the use of a tricone rock bit to penetrate through difficult horizons such as gravel and cobble beds, samples of those units were examined from cuttings that circulated up to the surface in the drill mud.

Field lithologs typically recorded information about the drill site, the drill-depth interval, amount of sample recovered in each interval, the dominant lithology, and other descriptive parameters such as colours of weathered and nonweathered horizons. One observation of particular interest recorded in the field lithologs was the presence or absence of hydrocarbon odour in samples of Quaternary sediment. This is an attribute of the drift that typically is not recorded in the central and southern parts of the province.

A suite of logs were run in each test hole to provide a down-hole record of the petrophysical properties of the sediment, and to permit correlations with petrophysical logs from near-by wells drilled by the petroleum industry. The log suite chosen to best characterize the properties of Quaternary sediments include the following: resistivity, self-potential, natural gamma, density, neutron and caliper. Petrophysical log traces were recorded in digital format using conventional LAS industry-standards (Log ASCII Standard).

7.2.1.2 Laboratory and Data Processing Methods

Fine-grained sediment, such as till, lacustrine silt and clay, and shale, were sampled at 1 m intervals and submitted to AGS' geological laboratory for in-house analyses, and preparation for analyses by external laboratories. Analyses typically performed by AGS' laboratory include grain-size determinations of the less-than-2mm-size fraction using the hydrometer and wet-sieve methods, and carbonate-content determinations of the silt-clay fraction using the Chittick gasometrical apparatus (Christiansen et al 1975, Christiansen 1992). The Chittick technique also provides information on the relative abundance of calcite and dolomite, which make up the total carbonate content of the samples. The results of AGS analyses are summarized in Appendix 4.

Figure 7.1. Wet-rotary coring rig.

Figure 7.2. Diamond-surfaced core bit for sampling Quaternary sediments.

Figure 7.3. Field logging of core samples.

Samples of fine-grained sediment were also submitted to Becquerel Laboratories Inc. for geochemical analysis, including gold plus 54 other elements. The results of those analyses, including a description of the analytical methods are included in Appendix 3.

Results from each test hole, including descriptions of lithology, grain-size distribution, matrix-carbonate content and petrophysical log traces are graphically portrayed in a series of strip-logs using LogPlot™ software from Rockware™ to facilitate hole-to-hole comparisons and assist in regional correlations. A legend of the symbols and patterns shown in the strip logs of the core holes is provided in Figure 7.4 Locations of the core holes are also shown in Figures 6.1 and 6.3.

7.3 Geology of AGS Core Holes

7.3.1 Core Hole WEPA99-1

Core hole WEPA99-1 is located within an upper terrace of the House River in the Stony Mountain Uplands, LSD 3, Sec 8, Tp 77, Rg 14W4M. The drill site is located in a sand and gravel quarry on the north side of the House River, along Provincial Highway 63. The site was selected to have greatest probability of intersecting the surface of the underlying Caribou bedrock upland, on the southern edge of the Wiau Channel (Figures 6.1 and 6.3). The hole was drilled in Quaternary sediment to 154.5 m, at which depth it encountered bedrock consisting of black mudstone and siltstone of the Colorado Group. Drilling continued in bedrock until the hole was terminated at a total depth of 167.3 m.

Detailed field descriptions of core samples from this hole are provided in Appendix 2-A, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.5. Some significant aspects of the geology within WEPA99-1 include the following:

- The upper 20 m or so consists of glaciofluvial outwash sand of the upper terrace of the House River.
- The till at 20 m shows progressively increasing amounts of clay in the matrix with depth, including more shale clasts in the pebble fraction. Clay and shale enrichment is interpreted to represent glacial erosion and incorporation of bedrock material. At about 50 m, the texture of the till changes abruptly to more sand and less clay. This is reflected in both the resistivity and gamma logs, and in the percentages of matrix clay and sand (Figure 7.5 and Table A4-1, Appendix 4). A faint hydrocarbon odour was detected in freshly exposed core from a depth of about 48 m.
- At a depth of 62 m there is a sharp contact between unoxidized till above, and highly weathered oxidized till below (Figure 7.6). The oxidized profile on the surface of this lower till extends for a depth of about 5 m where it is visible only as iron-stain along fractures (Figure 7.6). This sharp unconformable contact is also reflected to lesser degree on the resistivity log, and is well defined by an increase of percent of matrix carbonate in the oxidized till. Geochemistry values of the tills from this depth show a corresponding increase in calcium and magnesium in the till below the buried oxidized horizon (Table A3-3). As well, arsenic values increase dramatically in the buried weathered, oxidized profile, and become progressively higher toward the contact with the bedrock shale (Figure 7.7).
- The till between 95 m to 154.5 m contains abundant clasts of shale and soft siltstone of the local bedrock. This imparts an overall more clayey composition to the till, as reflected by the lower resistivity and higher gamma values at that depth, shown in Figure 7.5.
- The bedrock at depth 155 m consists of Colorado Group black marine mudstone and siltstone, containing numerous calcareous Inoaceramus fossil shells (Figure 7.9). Contact between the bedrock and overlying Quaternary sediments is well defined by an increase in gamma ray values, and somewhat surprisingly, by an increase, rather than decrease, in resistivity.

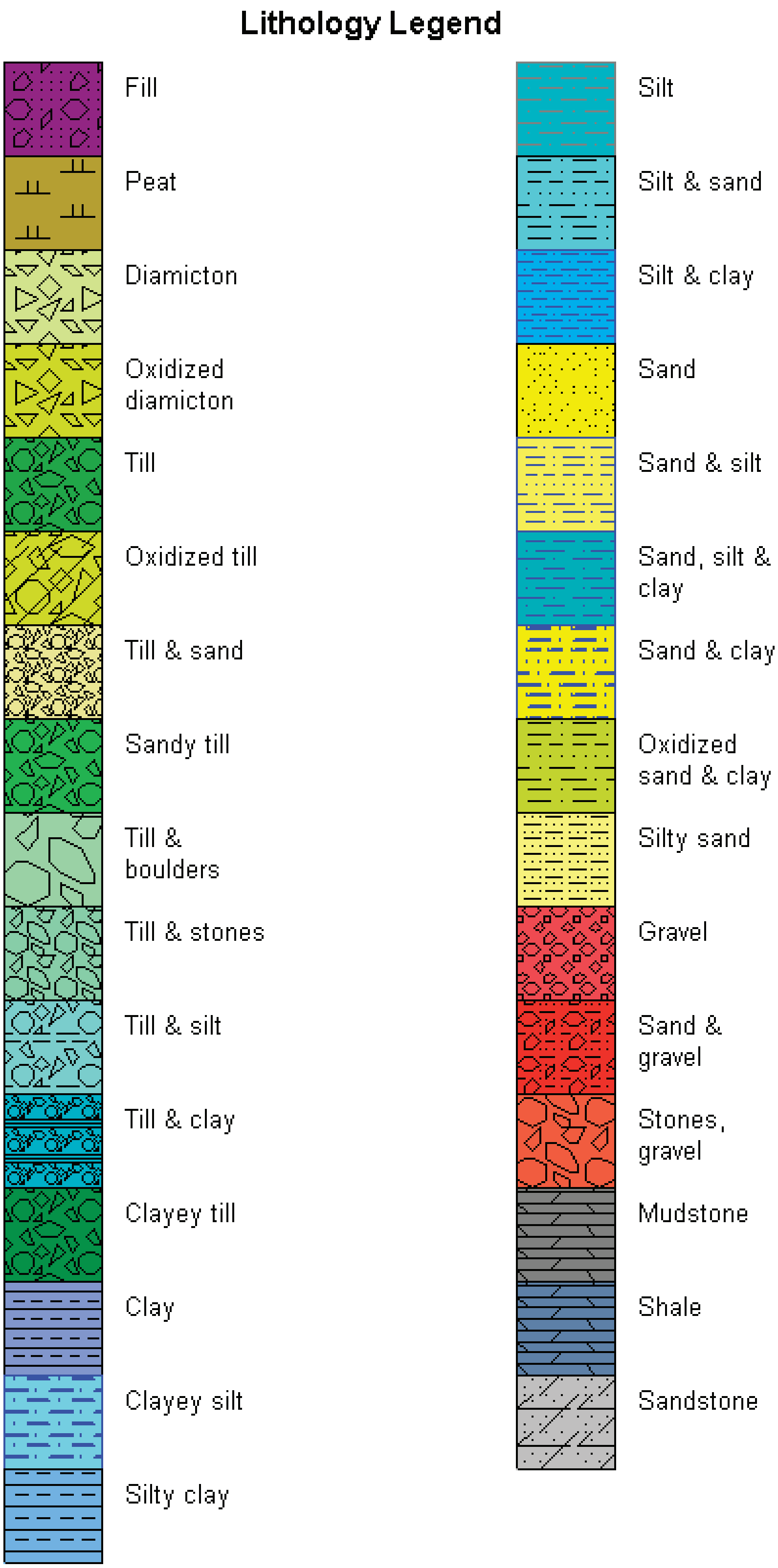

Figure 7.4. Strip-log lithology legend.

Well Name: WEPA99-1
Location (DLS): 03-08-77-14W4M
Latitude: 55.6517371°
Longitude: 112.1468557°
Surveyed Ground Level: 660.92 masl

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Alberta Geological Survey

Figure 7.5. Lithological and petrophysical log properties of Quaternary units, core hole WEPA99-1.

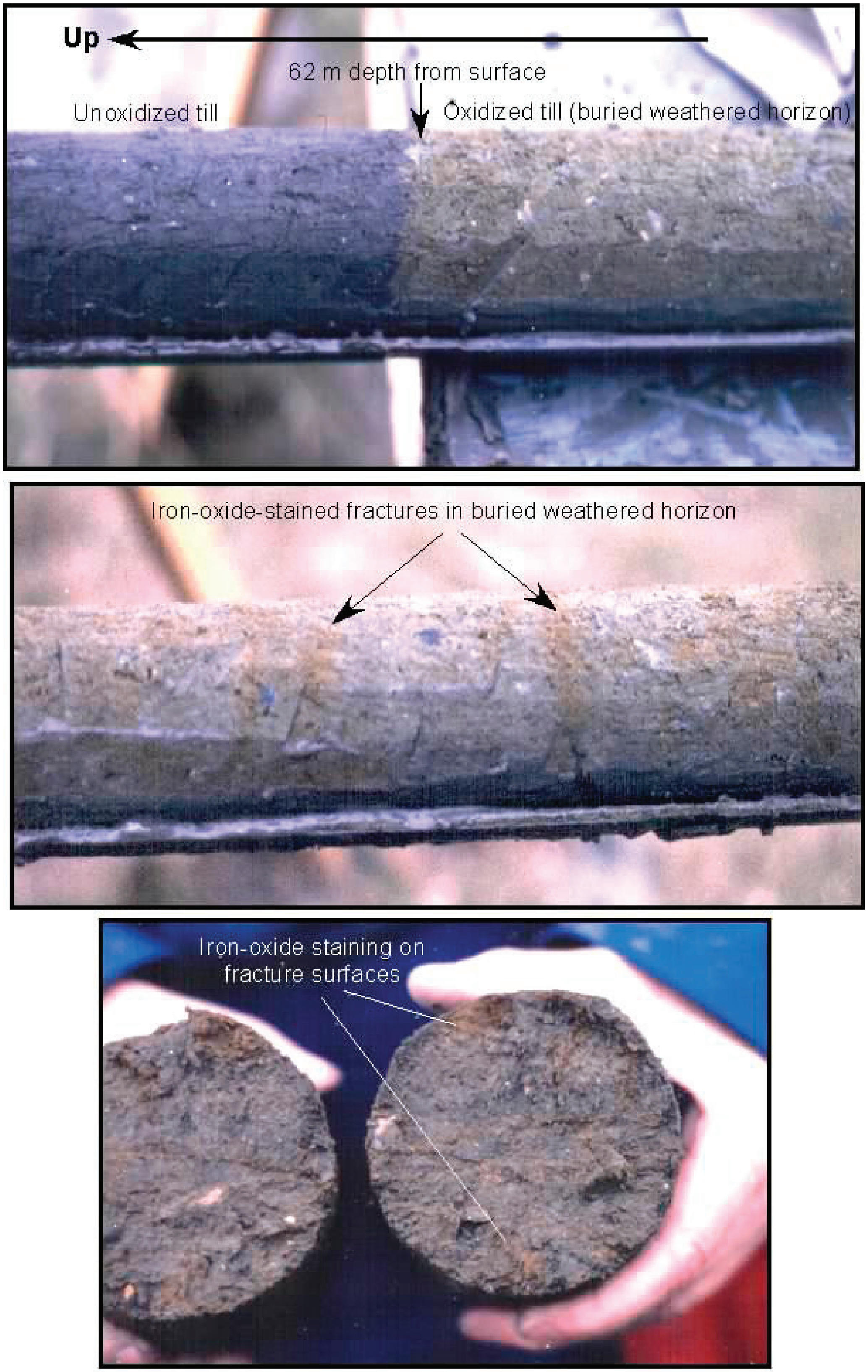


Figure 7.6. Buried weathered and oxidized till at 62 m depth, WEPA99-1.

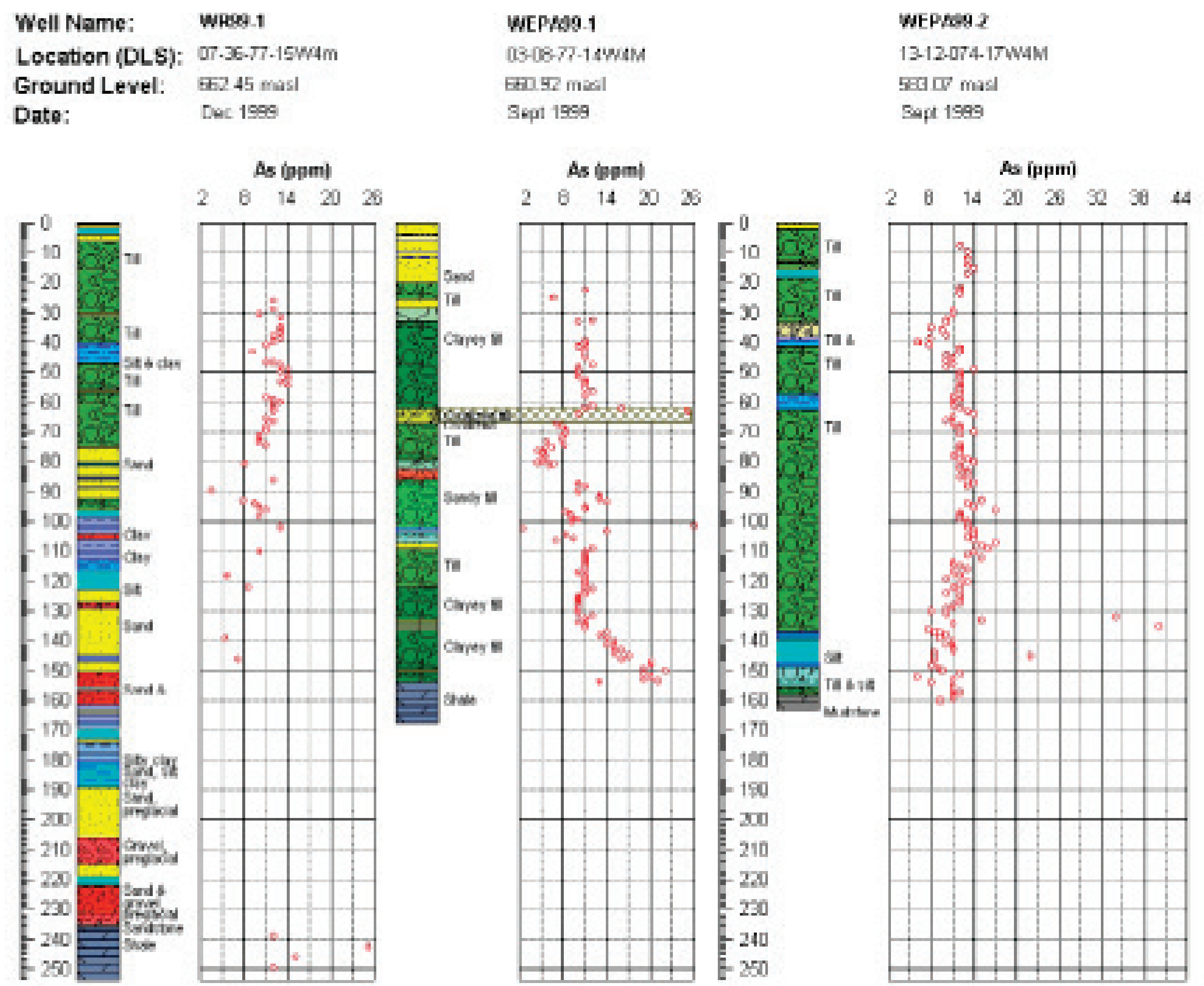


Figure 7.7. Variations in arsenic concentrations in glacial sediments, core holes WR99-1, WEPA 99-2.

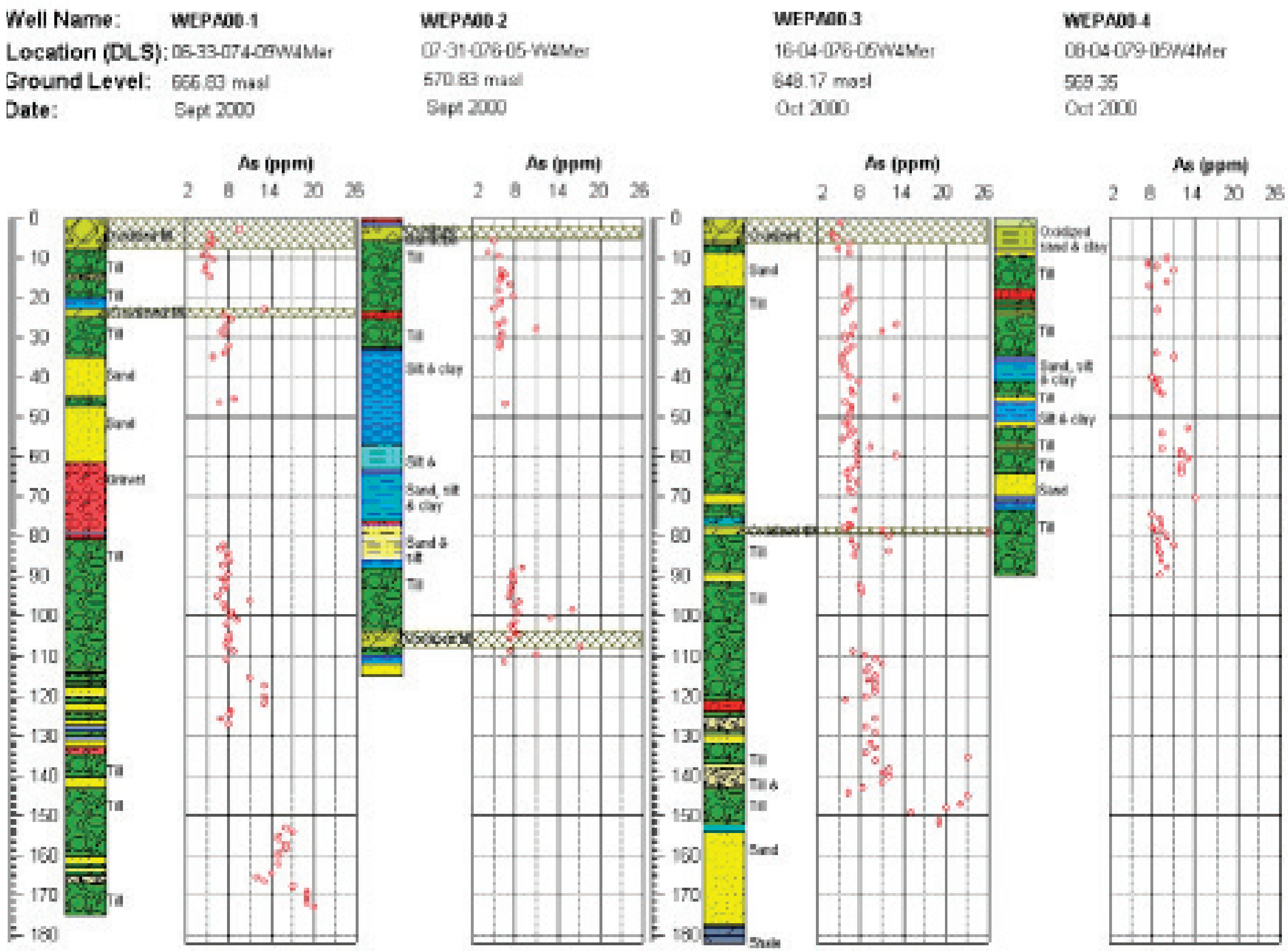


Figure 7.8. Variations in arsenic concentrations in glacial sediments, core holes WEPA00-1 to WEPA00-4.

Figure 7.9. Inoaceramus fossils in marine shale of the Colorado Group, WEPA99-1.

In terms of till lithostratigraphy, the upper 62 m of low carbonate till in core hole WEPA99-1 is correlative with the Grand Centre till found in the Cold Lake area to the southeast (Figure 7.10). On the basis of the weathered profile and relatively high-carbonate content, the till in the 62 to 109 m interval is correlative with the oxidized high carbonate Marie Creek till found in the Cold Lake area. The lower carbonate till below this interval is tentatively correlated with the Bonnyville till, which is also mapped in the Cold Lake area.

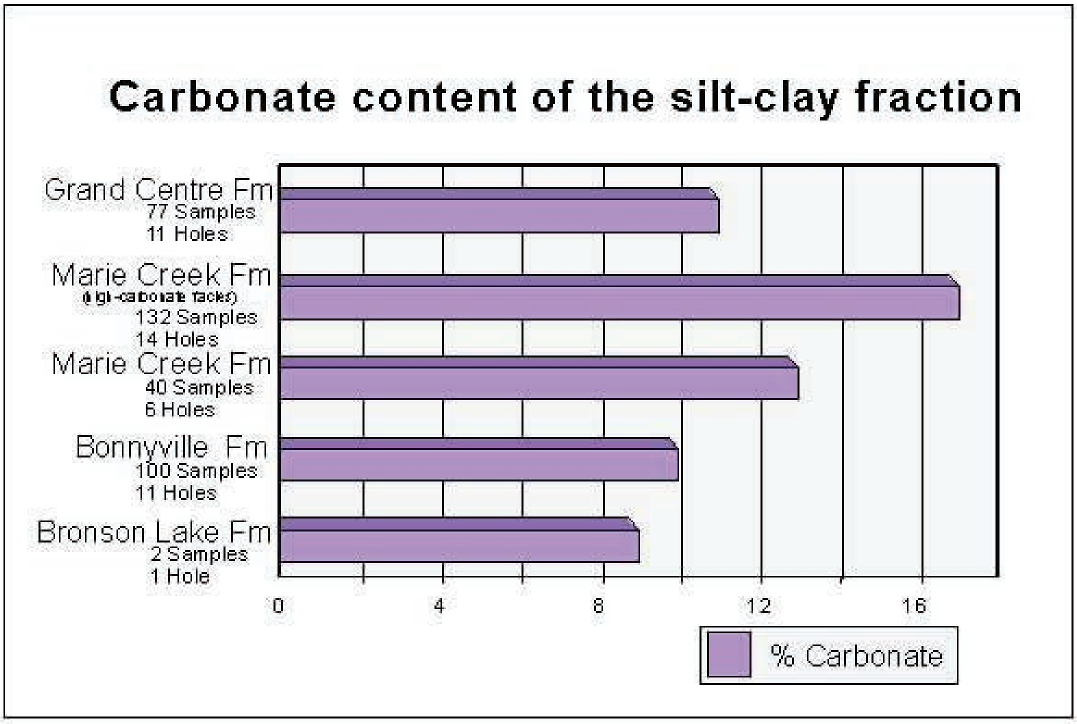
7.3.2 Core Hole WEPA99-2

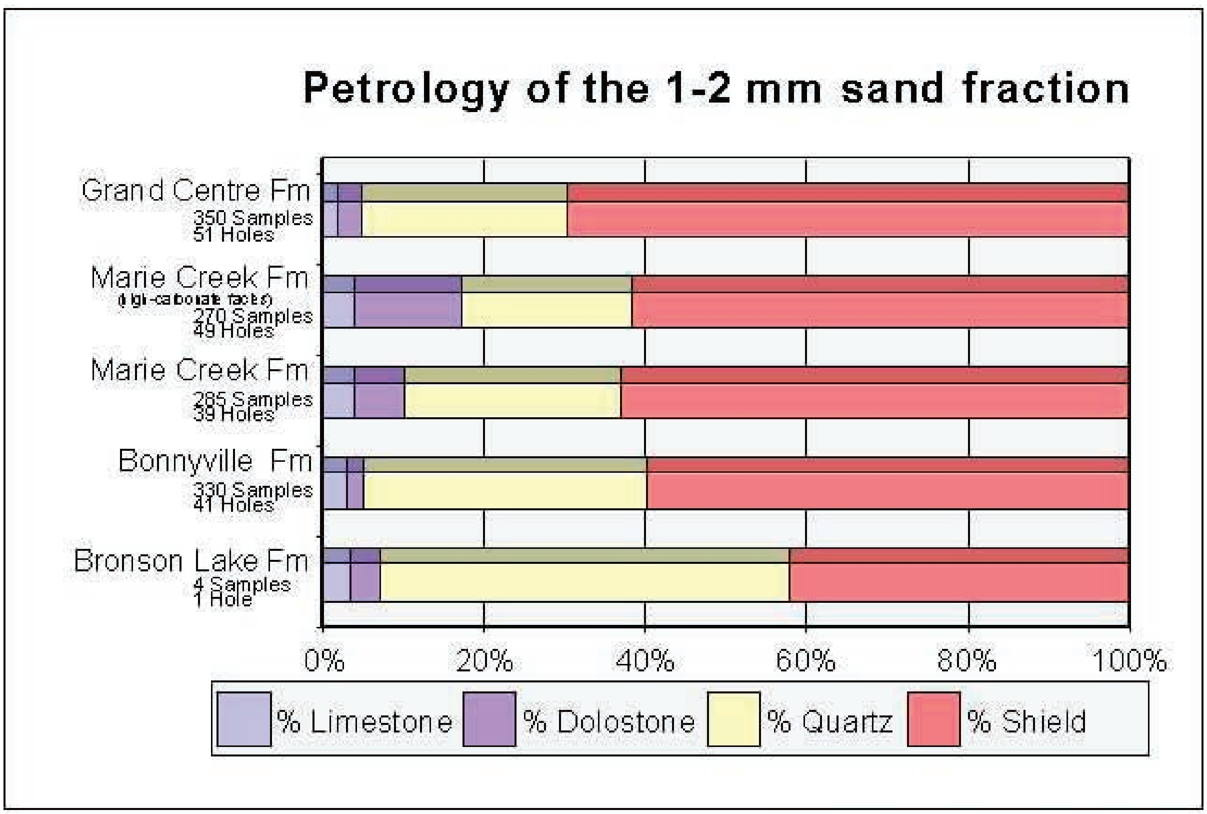
Core hole WEPA99-2 is located on a low-relief, undulating morainal landscape within in the Lac La Biche Plain in LSD 13, Sec 12, Tp 74, Rg 17W4M. On the basis of water-well log information in the area, and in the absence of a bedrock topography map, the thickness of drift at the site was expected to be relatively thin, less than 50 m. However, as Figures 6.1 and 6.3 show, the information from the core hole established that the site is located almost directly above the talweg of a previously unmapped bedrock channel, the buried Amesbury Channel, where drift thickness exceeds 150 m. The hole was drilled in Quaternary sediment with a conventional water-well drill rig to about 158 m, at which depth it encountered bedrock consisting of black mudstone of the Colorado Group. The hole terminated in bedrock only a few metres deeper at a depth of about 160.5 m, after it was deemed unsafe to drill farther because of the potential for escape of formation gas. A result of the shallow depth of penetration into bedrock is that there is a higher probability in situ bedrock was not reached at this site, and that the 2 m of bedrock material at the base of the hole may be an erratic of glacially displaced bedrock. It was the depth-to-bedrock and drift thickness information collected from this core hole that helped establish the location and characteristics of the buried Amesbury bedrock channel.

Detailed field descriptions of core samples from this hole are provided in Appendix 2-B, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.11. Some significant aspects of the geology within core hole WEPA99-2 include the following:

- Almost the entire 159 m of Quaternary succession at this site consists of till, with the exception of about 4 m of silt and clay at a depth of about 60 m, and about 18 m of silt at a depth of 137 m (Figure 7.11). Coarse-grained sediment (sand, gravel) resting on the bedrock floor of the Amesbury Channel, as interpreted later from petrophysical logs of nearby gas wells, is conspicuously absent.
- No buried weathered or oxidized horizons were encountered at this site.
- A relatively high carbonate interval of till and sand at a depth between 30 m and 58 m is tentatively correlated with the high carbonate till at a depth of 62 m in WEPA99-1.
- Arsenic values at a depth of about 130 m to 145 m are as high as 40 parts per million in samples of till, which is interbedded with, or includes lenses of silt (Table A3-4, Appendix 3, and Figure 7.7).

In terms of till lithostratigraphy, the relatively high carbonate till between 30 and 58 m is correlated with the Marie Creek till mapped in the Cold Lake area to the southeast (Figure 7.10). The correlation is considered highly tentative primarily because the contrast in carbonate values between the tills at this site is not strong. The till above 30 m is tentatively correlated with the Grand Centre till, and the low-carbonate till that lies below the lacustrine clay at 62 m is correlated with the Bonnyville till in the Cold Lake area (Andriashek and Fenton, 1989).





(modified from Andriashek and Fenton, 1989)

Figure 7.10. Petrological characteristics of tills in the Cold Lake area.

Figure 7.11. Lithological and petrophysical log properties of Quaternary units, core hole WEPA99-2.

7.3.3 Core Hole WR99-2

Core hole WR99-2 is located on an organic covered, undulating morainal landscape within the Stony Mountain Uplands in LSD 7, Sec 36, Tp 77, Rg 15W4M. The hole was drilled by the Alberta Geological Survey's mineral's program to determine the mineralogical composition of the Quaternary sediments in the area. This groundwater project was coordinated with their investigation to maximize the amount of information that could be collected from the core hole.

The site location was chosen to have the greatest probability of intersecting the talweg of the buried Wiau Channel, and to calibrate the sediments that were recorded in petrophysical logs from nearby oil and gas wells with detailed lithological descriptions and analyses of samples. Of particular interest was an examination of the petrological composition of the fluvial sediments on the bedrock floor to verify a preglacial source and age. The anticipated great depth to bedrock (>200 m), and the high potential for intersecting natural gas migrated from subcrops of gas-bearing horizons such as the Viking Formation, necessitated the use of oil-field drilling equipment and drill rigs equipped with some form of well blow-out prevention device to ensure safety of the operation. As a consequence, the upper 20 m of the hole was protected with steel casing, which prevented electrical logs from being run in this interval. As well, coring operations began below the 20 m casing depth, and representative samples are not available for the upper part of the succession. The drilling operator provided descriptions of the geological sediment in this upper 20 m interval, as AGS staff members were not on site while casing was installed. This type of coring program is estimated to have cost almost four times that of a normal coring operation using a conventional water-well drill rig.

Total depth of investigation in this core hole was 253.7 m, of which the upper 235.3 m is Quaternary and late Tertiary sediment (drift), and the lower 18.4 m is bedrock of the Lower Colorado Group. The drift-bedrock contact is defined by approximately 1 m of Viking Formation sandstone, which overlies about 17 m of Joli Fou Formation shale. Two water-well piezometers where installed at this site: one at a depth of 8 m to serve as a water-table well, and one completed at a depth of 230 m within the lowermost sand and gravel unit in the hole.

Detailed field descriptions of core samples from this hole are provided in Appendix 2-C, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.12. Some significant aspects of the geology within core hole WR99-1 include the following:

- Glacial diamicton (till) comprises only about one-third (~ 75 m) of the stratigraphic succession, that being the uppermost third of the column. The bottom two-thirds of the succession (~160 m) is comprised of two fining-upwards sequences each of which grades from gravel to silt and clay. These are interpreted to be of fluvial origin.
- The composition of pebbles in the lower fining-upward cycle, as determined by field observations of cuttings and validated by microscopic examination of selected samples, shows a clast petrology indicative of a source from the Cordilleran Mountains and local bedrock, that is, metaquartzite and black chert. This differs from the sand and gravel in the upper fining-upwards cycle which contains abundant granite and gneissic clasts brought into the area by Laurentide glaciers from the Canadian Shield. This validates the initial assumption that the bottom-most fluvial sediments in the Wiau Channel are of preglacial origin and age. The preglacial sand and gravel deposits on the floor of the Wiau Channel are thus correlative with Empress Formation Unit 1 preglacial sand and gravel mapped in buried channels within the Cold Lake area to the south (Andriashek and Fenton, 1989). On the basis of stratigraphic position, the silt and clay in the interval between 161 m and 191 m, which lies above basal preglacial gravel, is interpreted to be Empress Formation Unit 2 silt and clay. However,

Figure 7.12. Lithological and petrophysical log properties of Quaternary units, core hole WR99-1.

the presence of granite rock fragments in the sand fraction from this horizon, as described in the lithologs, indicates a glaciofluvial source. Thus, there remains some uncertainty regarding the origin and age of the silt and clay that rests above the preglacial sand and gravel at this site.

- There is also some uncertainty regarding the origin of the clay in the interval between 100 m and 122 m. Lithologs of core at 105 m (Appendix 2-C) describe the clay as black, highly broken, and deformed with slickensides, which possibly represents a block of glacially displaced shale. However, logs of the core at about 114 m describe the silt and clay as rhythmically bedded and containing one or two pebbles, typical of a glaciolacustrine deposit. For purposes of stratigraphic correlations, all of the silt and clay in this interval is considered to be glaciolacustrine sediment. A change in the drill method at a depth of about 162 m, from core barrel to tricone rock bit, resulted in poor sample recovery and poor descriptions of the silt and clay in the interval from about 165 to 190 m.
- There are no mineralogical or petrological indicators to suggest that more than one till is present at the site. Carbonate values of the till are low, indicating that the till is most likely the upper Grand Centre till encountered in the upper part of core hole WEPA99-1, although the till at WR99-1 appears much less clayey than the upper till at WEPA99-1 (Figures 7.5 and 7.12).

7.3.4 Core Hole WEPA00-1

Core hole WEPA00-1 is located on low to moderate relief, hummocky moraine on the higher reaches of the Mostoos Upland, in LSD 6, Sec 33, Tp 74, Rg 9W4M. The hole was drilled to establish the stratigraphic succession along the northern margin of the Wiau Channel and to calibrate petrophysical logs from numerous gas wells in the area. Of particular interest was the need to characterize the nature and origin of the clay-rich sediment at a depth of about 140 to 150 m, which typically has as a distinctive low resistivity and a high gamma value on the petrophysical logs.

Although existing borehole information indicated that the depth to bedrock was more than 200 m in the area, core hole WEPA00-1 was drilled only to a total depth of 173.5 m, terminating in Quaternary sediment. The reason for prematurely ending the hole in drift rather than bedrock was the increased risk of encountering natural gas (as either in situ gas in bedrock strata, or migrated-gas in Quaternary strata,) beyond this depth, and the prohibitive cost of using an oil and gas drill rig needed to mitigate the risk.

A nest of four water-well piezometers was installed at this site to provide information on vertical gradients, as well as other hydrogeological parameters. Wells were completed in sand at depths of 15 m (water-table well), 41 m, 76 m, and 120 m.

Detailed field descriptions of core samples from this hole are provided in Appendix 2-D, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.13. Some significant aspects of the geology within core hole WEPA00-1 include the following:

- The succession of the 174 m of drift drilled at this site consists of about 35 m of till overlying about 45 m of sand and gravel, which overlies more than 94 m of till with interbeds of sand (Figure 7.13).
- The upper 20 m of till are characterized by a higher matrix carbonate content compared to values for the till below. The carbonate values decrease abruptly beneath a 2 m-thick silt and clay bed which rests on top of a buried, weakly-oxidized till. Oxidation of this till is expressed primarily as rust-coloured iron-stain along fractures and joints.
- Odours of hydrocarbon (similar to bitumen odour), and a faint ‘rotten egg’ smell (H_2S), were noted in core recovered from a depth of about 32 m, and hydrocarbon odour was evident in varying concentrations down to a depth of about 108 m (Figure 7.13). None of the cores of till showed any evidence of free hydrocarbon, or clasts and inclusions of hydrocarbon-bearing rocks such as bitumen saturated sandstone.

Well Name:	WEPA00-1
Location (DLS):	06-33-074-09W4Mer
Latitude:	55.4513762°
Longitude:	111.3298897°
Surveyed Ground Level:	666.83 masl

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Figure 7.13. Lithological and petrophysical log properties of Quaternary units, core hole WEPA00-1.

In addition to hydrocarbon odour, a dark oily emulsion was evident on the surface of the drill fluid in the circulation tank when the core bit reached a depth of about 32.5 m (Figure 7.14). This emulsion persisted on the surface of the drill-mud tank over a four-day period until the hole was abandoned. Also observed were bubbles rising up the borehole when the drill operations ceased momentarily at a depth of about 78 m in sand and gravel. The driller indicated the rig was not experiencing any problems with the seals on the mud pumps, which could be introducing air into the drill fluid. Bubbles were also observed coming up in the borehole when coring at a depth of about 153 m. At a depth of about 35 m a decision was made to sample a section of till from the next core run which, on the basis of the previous run, was expected to have the most concentrated hydrocarbon odour. However, the lithology changed from till to sand at about 35.5 , and the next encounter of sediment with odour was the relatively thin till bed between 45 and 47 m, at which depth a 15 cm thick sample of core was extracted and sealed in a glass vessel. The results of the hydrocarbon analysis (Table 7.1) confirm the field observations that hydrocarbons are present in the till, and also that the composition is similar to bitumen from Cretaceous-age oil sands deposits in northeastern Alberta. As significant as are the till intervals which do show traces of hydrocarbon odours, it is worth noting that the till in the lower part of the core hole showed no traces of odour. As a final comment, observations in the field show that none of the water samples from water-well piezometers completed at depths of 15, 41, 76, and 120 m, had any visible traces of hydrocarbon. That is, a hydrocarbon odour was not detected, nor was an iridescent sheen visible on the surface of water samples. Water samples were not submitted for laboratory analysis of hydrocarbon to confirm this, however. The apparent absence of hydrocarbons in the samples of groundwater from sand bodies indicates that the source of hydrocarbon odour and emulsions of oily material are most likely derived from till.

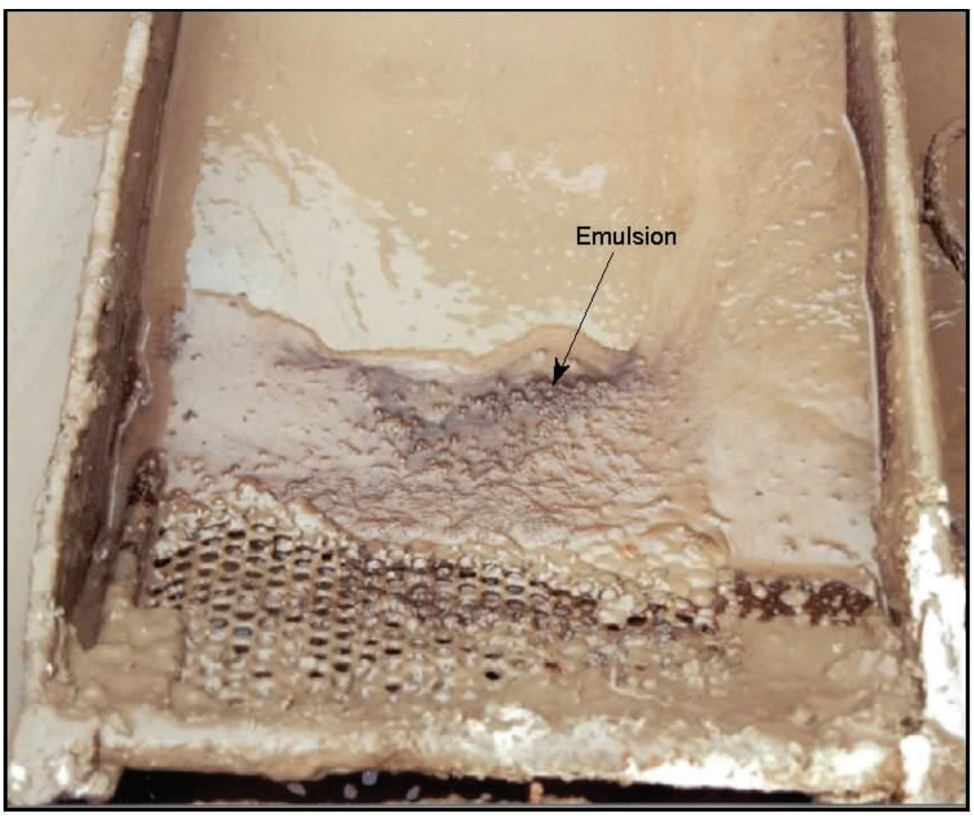


Figure 7.14. Hydrocarbon emulsion on surface of drilling mud tank, WEPA00-1. The emulsion was first observed when drilling in till at a depth of about 32.5 m, and was visible in the drill mud over the next four days, until the hole was abandoned at a depth of 173.5 m.

Table. 7.1. Analysis of hydrocarbon in till, core hole WEPA00-1.

Carbon Number	Total Sample dry wt. (mg/kg)	Saturates Fraction dry wt. (mg/kg)	Aromatics Fraction dry wt. (mg/kg)	Detec-tion limit	Carbon Number	Total Sample dry wt. (mg/kg)	Saturates Fraction dry wt. (mg/kg)	Aromatics Fraction dry wt. (mg/kg)	Detection limit
C11	<1	1	<1	1	C36	32	15	13	1
C12	<1	2	<1	1	C37	31	14	13	1
C13	2	3	<1	1	C38	25	14	11	1
C14	5	5	<1	1	C39	37	11	13	1
C15	7	6	1	1	C40	25	13	13	1
C16	13	12	2	1	C41	30	13	10	1
C17	17	12	3	1	C42	17	10	13	1
C18	24	18	3	1	C43	28	9	10	1
C19	29	22	4	1	C44	28	11	12	1
C20	29	21	6	1	C45	22	6	10	1
C21	31	23	6	1	C46	22	8	10	1
C22	33	20	6	1	C47	16	10	10	1
C23	30	25	8	1	C48	27	8	10	1
C24	31	22	8	1	C49	22	7	10	1
C25	32	22	9	1	C50	22	7	7	1
C26	33	21	10	1	C51	16	5	10	2
C27	34	22	11	1	C52	21	7	10	2
C28	28	18	9	1	C53	22	6	8	2
C29	36	22	12	1	C54	16	5	8	2
C30	37	26	15	1	C55	16	5	13	2
C31	44	21	13	1	C56	16	4	8	2
C32	35	19	13	1	C57	22	6	8	2
C33	28	15	11	1	C58	17	6	8	2
C34	34	17	16	1	C59	23	4	10	2
C35	39	20	13	1	C60+	619	74	238	20
					Total	1803	693	665	

C11 - C60+ Hydrocarbon Characterization			
Fraction	Concentration dry wt. (mg/kg)	% of Total	
Total Saturates/Aliphatics (C11-C60+)	693	38.4	
Total Aromatics (C11-C60+)	665	36.9	
Polars and Asphaltenes (by difference)	445	24.7	
Total Extractable hydrocarbons (C11-C60+)	1803	100.0	

C60 Hydrocarbon Analysis Calibration Check			
Carbon Number	Actual mg/L	Recovered mg/L	% Recovery
C12	20	21	105
C14	30	32	107
C16	40	42	105
C18	50	53	106
C20	60	64	107
C22	80	85	106
C24	100	105	105
C26	120	127	106
C28	120	126	105
C30	100	106	106
C32	80	84	105
C36	60	64	107
C40	50	52	104
C44	40	42	105
C50	30	32	107
C60	20	21	105

- The core samples confirm that the low-resistivity, high-gamma signature at a depth of about 145 to 150 m in nearby petrophysical logs represents clay-rich till, and not glaciolacustrine silt and clay, as once believed. An interesting aspect of this clay-rich till is that in addition to the till matrix being more enriched in silt and clay, and depleted in sand (Figure 7.13), the till is also enriched in large pebbles (2-3 cm) of shale and siltstone, which also imparts overall higher clay content to the bulk texture of the till (Appendix 2-D). This clay (shale)-rich unit is well defined on many of the petrophysical logs above the Wiau Lowlands, and is a good marker horizon for stratigraphic correlations.
- Relatively high arsenic values (13 to 20 parts per million) are recorded for samples from the oxidized till profile at about 23 m, and from the clay (shale)-rich till at about 153 m (Table A4-4, Appendix 4 and, Figure 7.8). It is inferred that these high values are attributed to the accumulation of arsenic adsorbed on ferromagnesium colloids staining fractures in buried weathered horizons in till, and, to the enrichment of bedrock material (black marine shale of the Colorado Group), which naturally contains arsenic (L. Andriashek, 2000).

On the basis of high carbonate values, the upper 20 m of till is locally correlated with the high-carbonate till buried at a depth of about 62 m in core hole WEPA99-1, and regionally correlated with the Marie Creek till south in the Cold Lake region (Figure 7.10). On the basis of low carbonate content and a buried oxidized horizon, the till at a depth of about 23 m is correlated with the Bonnyville till, which is also mapped south of the study area (Andriashek and Fenton, 1989). The presence of the high-carbonate Marie Creek till at the top of the hole indicates that the uppermost low carbonate Grand Centre till, which lies at the surface in the Cold Lake area, is absent at this site. The clay-rich (shale-rich) till at a depth of about 150 m is tentatively correlated with the clay-rich Bronson till found in buried channels in the Cold Lake area (Andriashek and Fenton, 1989).

7.3.5 Core Hole WEPA00-2

Core hole WEPA00-2 is located in a gravel pit on the north flank of an ice-contact glacial meltwater-channel complex directly east of Christina Lake in LSD 7, Sec 31, Tp 76, Rg 5 W4M. The hole was drilled to establish the stratigraphic succession above the buried Christina Channel, and to calibrate the numerous petrophysical logs from oil and gas, and water-well industry activities in support of oils sands development in the area.

WEPA00-2 was drilled, cored and logged to a depth of about 115 m, and was terminated while still in Quaternary sediment, primarily because of the risk of encountering natural gas in bedrock formations, or gas that migrated into the Quaternary sediments from bedrock horizons below (Figure 7.15).

Detailed field descriptions of core samples from this hole are provided in Appendix 2-E, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.15. Some significant aspects of the geology within core hole WEPA00-2 include the following:

- The succession of the 115 m of drift drilled at this site can be summarized as about 34 m of till overlying about 54 m of stratified sediment, mostly silt and clay, which overlies about 22 m of till, and lastly, about 3 m of sand.
- The till in the upper 34 m of the hole has apparent higher carbonate content than the till below 88 m. The carbonate values of the upper till are comparable to that of the high-carbonate tills in core holes WEPA99-1 and WEPA00-1, which are correlated to the Marie Creek till in the Cold Lake area.

Well Name: WEPA00-2
Location (DLS): 07-31-076-05W4Mer
Latitude: 55.6275339°
Longitude: 110.7614465°
Surveyed Ground Level: 570.83 masl

Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
Alberta Energy and Utilities Board
Alberta Geological Survey

Figure 7.15. Lithological and petrophysical log properties of Quaternary units, core hole WEPA00-2.

- The thick sequence of silt, clay, and sand at 34 to 88 m displays deformed, rhythmitic bedding and inclusions of silt lenses or laminae that appear to be rip-up clasts (Appendix 2-E). Thin beds of till (0.2 – 0.35m) within the sand, silt, and clay succession between 83 and 88 m are inferred to be deposited in an ice-proximal, proglacial lacustrine environment.
- Fine sand and silt partings in the till at a depth of about 95 to 104 m appear to cause an increase in the amount of sand within the matrix, even though the petrophysical logs at this depth indicate lower resistivity and higher gamma values, characteristic of more clayey sediment. This change in the properties of grain-size is also reflected in the carbonate values, which decrease abruptly below 95 m (Figure 7.15).
- A buried oxidized profile is present within the till at a depth of about 104 to 108 m. The significance of this oxidized horizon with respect to demarcating a weathered surface of an older regional till is not evident, as there does not appear to be a corresponding change in any of the other parameters such as carbonate content, grain size, or petrophysical log character in this interval. As in other buried oxidized profiles, arsenic values in this oxidized horizon are also relatively high (Table A4-5, Appendix 4, and Figure 7.8).
- A weak hydrocarbon odour was detected in the till at a depth of about 25 m, directly below a bed of gravel.

In terms of till lithostratigraphy, three tills can be differentiated at this site: a high-carbonate sandy till from surface to a depth of 33 m, which is tentatively correlated with the Marie Creek till in Cold Lake (Figure 7.10); a moderately high carbonate silty till from 88 to 94 m, somewhat similar in character to the upper till; and, a sandy, low carbonate till from 94 to 110 m in which a 4 m thick oxidized profile is present in the middle of the interval.

7.3.6 Core Hole WEPA00-3

Core hole WEPA00-3 is located directly west of Winefred Lake on a moderate-relief hummocky morainal landscape, in LSD 16, Sec 4, Tp, 76, Rg 5 W4M. The borehole is situated above the interfluve bench that separates the Wiau and Christina channels in the Wiau Lowlands bedrock physiographic unit (Figures 6.1 and 6.3). The hole was drilled to establish the lithostratigraphical framework above the bedrock bench, and to determine the petrological composition of the fluvial sediments that rest on the bedrock floor (as determined from petrophysical logs in the area) as to whether the sand is of glacial or preglacial age and origin.

Core hole WEPA00-3 was drilled to a depth of 182 m and terminated after sampling a few metres into the top of shale of the Colorado Group. The contact between Quaternary sediments and the bedrock surface was intersected at a depth of about 177.5 m (Figure 7.16). Coring operations ceased at a depth of about 156 m after encountering difficult drilling conditions due to rocks and boulders. The remainder of the hole was logged from descriptions of drill cuttings from a tricone rock bit. A nest of three water-well piezometers was installed at this site, in sand beds at 17 m (water-table well), 79 m, and 158 m.

Detailed field descriptions of core samples from this hole are provided in Appendix 2-F, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.16. Some significant aspects of the geology within core hole WEPA00-3 include the following:

- From top down, the succession of Quaternary sediment (drift) at this site consists of about 10 m of till, about 8 m of sand, as much as 136 m of till with minor beds of sand and gravel, and lastly, about 24 m of sand.

Well Name: WEPA00-3
Location (DLS): 16-04-075-05W4Mer
Latitude: 55.4730401°
Longitude: 110.7072983°
Surveyed Ground Level: 648.17 masl

Figure 7.16. Lithological and petrophysical log properties of Quaternary geological units, core hole WEPA00-3.

- The field descriptions of the petrology of the sand at the bottom of the hole highlight the presence of abundant granite and gneiss from the Canadian Shield, confirming that at this site the origin of the fluvial sediment on the bedrock floor is of a glacial source (Appendix 2-E).
- There are a number of properties that differentiate the upper 78 m of till from the remainder of the till below, the main of which is the higher carbonate content, particularly dolomite, in the upper 78 m, as shown in Figure 7.16. Further, the contact is also well defined by a 1.5 to 2 m thick oxidized horizon on the surface of the low carbonate till. This contact is also well expressed on the petrophysical logs, the lower till showing a higher resistivity, lower gamma, and in particular, higher neutron value. Lastly, the contact is also marked by an increase in the percent sand, and a decrease in percent clay in the lower till.
- The resistivity of the upper 78 m of till shows progressively decreasing values with depth, indicating possible enrichment of the till matrix with clay. The grain-size analyses support this interpretation, showing a particularly clay-rich zone near the base of the till unit from about 58 m to 75 m (Figure 7.16). This enrichment of finer-textured material with depth is repeated to a lesser degree in the bottom part of the lower till where an increase in the silt content appears to be expressed as a higher value in the gamma log, and lower value in the resistivity log at the 135 to 150 m depth interval.
- The geochemistry data shows significantly elevated values for arsenic for samples from the buried oxidized till at 79 m, similar to elevated values in buried oxidized tills in other core holes (Table 4-6, Appendix 4, and Figure 7.8). Arsenic values are also relatively higher below 110 m, and in particular, at a depth between 143 m and 151 m where the lithologs describe abundant shale clasts in the till. High arsenic at this depth may be reflecting naturally high concentrations that are found in shale of the local bedrock.
- Weak odours of hydrocarbon were detected in samples of till in numerous intervals within the core hole. Odours were first detected at a depth of about 18 m, and persisted in core samples down to a depth of about 50 m. Hydrocarbon odours were not detected again until a depth of about 92 m, approximately 14 m below the top of the buried oxidized horizon. Odours were detected intermittently from 92 m to down to about 125 m, and none below that depth, specifically none in the samples of shale at the bottom of the core hole. As in all of the other core samples of till in which hydrocarbon odours were detected, there was no visible evidence of free hydrocarbon in the till, nor clasts and inclusions of hydrocarbon-bearing rock fragments.

In terms of till lithostratigraphy, three tills can be differentiated:

- a high-carbonate till that extends from surface down to 78 m, which is correlated with the Marie Creek till in the Cold Lake area (Figure 7.10);
- a middle low-carbonate till, that extends from 78 m to 125 m, the surface of which has an oxidized weathered profile, and is correlated with the Bonnyville till in the Cold Lake region;
- a lower, clay-rich, low-carbonate till containing numerous shale pebbles, which is tentatively correlated with the Bronson till in the Cold Lake area (Andriashek and Fenton, 1989).

7.3.7 Core Hole WEPA00-4

Core hole WEPA00-4 is located on a high-relief morainal ridge situated south of Cowper and Bohn lakes in LSD 8, Sec 4, Tp 79, Rg 4, W4M. The site was chosen to determine the nature of the drift stratigraphy and to establish if a west-east oriented complex of high relief landforms in the area (Figure 5.3), is a bedrock high, or an accumulation of thick moraine.

Core hole WEPA00-4 was drilled to a depth of 90 m, and terminated in drift sediments. Detailed field descriptions of core samples from this hole are provided in Appendix 2-G, analytical laboratory results are captured in Appendices 3 and 4, and the lithology is summarized graphically in Figure 7.17. Some significant aspects of the geology within core hole WEPA00-4 include the following:

- The hole established that at this site the high-relief landform is composed of thick drift, and not thin drift draped on a bedrock topographic high. The borehole data supports other observations of thick drift in high outcrops along recently constructed roads in the area.
- The Quaternary succession can be summarized as till with beds of gravel, sand, silt, and clay to 45 m, bedded sand, silt and clay to 53 m, till to 64 m, sand to 70 m and till below that to 90 m (Figure 7.17). Carbonate values for the upper 45 m of till and stratified sediment are generally higher than values for the till in the bottom 37 m of the hole.
- Arsenic values in the till increase slightly at a corresponding depth (~60 m) where abundant shale clasts are present in the till (Figure 7.8).
- No hydrocarbon odours or buried oxidized profiles were recorded from the core samples.

In terms of till lithostratigraphy, the upper 10 m of sediment are very tentatively correlated with the Grand Centre till to the south. The next 35 m of till are tentatively correlated with the high carbonate till found in WEPA00-3 and WEPA99-1, which is regionally correlative with the Marie Creek till in the Cold Lake area (Figure 7.10). Both correlations are highly speculative primarily because the carbonate values are not as contrasting as in the tills in core hole WEPA00-3 to the south. It is possible that the second till at this site is, in fact, more correlative with the uppermost till in the eastern part of the province, the Grand Centre till. On the basis of the very low carbonate content, the till in the bottom 37 m of the hole is correlated with the till at a depth of 78 m in core hole WEPA00-3, which is regionally correlated with the Bonnyville till in the Cold Lake area to the south.

7.4 Constructing the Drift Hydrostratigraphy

The object of most stratigraphic investigations of drift in the study area is to locate buried aquifers for the purposes of extracting water. As such, the natural focus is to identify, correlate, and map the buried permeable units, such as preglacial and glacial sand and gravel, in order to quantify groundwater resources. This exercise, while successful at a local scale, can prove flawed when attempting to map buried glacial aquifers at a regional scale. As mentioned previously, there is a tendency of glacial units to violate the law of original horizontality. Glacial meltwater can flow on, within, or beneath the ice surface, and under high hydraulic head. Fluvial sediments can therefore be draped on apparent topographic highs. Subsequent catastrophic glacial meltwater releases can lead to the existence of unpredictable, vertically cross-cutting glacial sluiceways that can be in filled with sand and gravel that is superposed on older meltwater deposits. Differentiation of these fluvial deposits on the basis of mineralogy or clast petrology proves difficult to impossible because the source rock for the coarse clast component is essentially the same for each Laurentide glacial event.

The reconstruction of the drift stratigraphy in this study area is based on the premise that in northeast Alberta multiple and episodic glaciations have occurred during the Quaternary. This is a valid assumption in that at least three, and possibly four, glacial events are recorded in the stratigraphic sequence of the Cold Lake area, located directly south of, and down-glacier, of the study area (Table 7.2). The underlying model is a variant of a genetic-stratigraphic model that relates local groups of sediments to larger, regional scale genetically related strata (Bleuer 1999). The model considers glacial advances analogous

Figure 7.17. Lithological and petrophysical log properties of Quaternary geological units, core hole WEPA00-4.

Table 7.2. Table of Quaternary stratigraphic units in eastern Alberta, Cold Lake area (from Andriashek and Fenton, 1989).

TIME UNITS			ATHABASCA OIL SANDS AREA	SASKATOON AREA SASKATCHEWAN	
			STRATIGRAPHIC UNITS		
HOLOCENE			SURFICIAL STRATIFIED SEDIMENT		
QUATERNARY	LATE PLEISTOCENE	LATE WISCONSIN	GRAND CENTRE FM	SASKATOON GROUP	BATTLEFORD FM
		MIDDLE WISCONSIN	SAND RIVER FM Stratified Sediments		
		EARLY WISCONSIN	MARIE CREEK FM		FLORAL FM UPPER TILL
		SANGAMON	ETHEL LAKE FM Stratified Sediments		RIDDELL MEMBER
	EARLY AND MIDDLE PLEISTOCENE	ILLINOIAN			FLORAL FM LOWER TILL
		PRE-ILLINOIAN	BONNYVILLE FM	SUTHERLAND GROUP	WARMAN FM
			MURIEL LAKE FM Stratified Sediments		DUNDURN FM
			BRONSON LAKE FM		MENNON FM
TERTIARY	PLIOCENE		EMPRESS FM UNIT 3 stratified Sediments EMPRESS FM UNIT 2 stratified Sediments EMPRESSFM UNIT 1 stratified Sediments	EMPRESS GROUP	

to marine transgressions, or “flooding events”, but involving water in the solid state (ice) rather than liquid. Associated with each glaciation, or ‘transgression”, are regionally extensive deposits that record the flooding event. In the case of continental glaciers, the diamicts, or tills, represent the sedimentary record of these events, and are considered as a primary sequence boundary (Bleuer 1999). Tills of these glacial events thus stratigraphically bound stratified fluvial or lacustrine sediments that are deposited in the advance or retreat phase of a glacial event. The challenge in mapping the Quaternary sediments in northeast Alberta is being able to differentiate and classify the tills and associated stratified sediments of multiple glacial events in a stratigraphic succession that is more than 300 metres thick. It is only after the glacial genetic stratigraphy is defined, that the task of correlating and mapping aquifer units can be successfully undertaken.

The following discusses some of the guiding principles in the interpretation of the glacio-genetic sequences in the study area.

7.4.1 Cyclicity in Petrophysical Log Responses of Multiple Till Units

The base of each till sheet, irrespective of age or source, appears to be enriched with fine-grained material, which results from the glacial comminution and incorporation of the underlying local bedrock. In the study area the local bedrock is dominantly black marine shale of the Colorado Group, and incorporation of bedrock material can consist of clay enrichment in the till matrix, or as discrete slabs of intact, but displaced shale. This enrichment with clay can be expressed in grain-size analyses or from petrophysical logs. The net effect is that there is cyclicity in the grain-size distribution within the stacked sequence of till sheets, with the base of each till sheet, or cycle, showing enrichment with clay. These can, in fact, be considered as the ‘hot shales’ of a marine transgression (e.g., Galloway, 1989).

Figure 7.18 illustrates this cyclicity in the logs of the Quaternary drift from three oil and gas boreholes. Major till sheets can be differentiated by the coarsening upward trend of the resistivity curve. The contact between two till units is most striking in places where one till directly overlies another, as in the Amoco Kirby 10-19 well. Figure 7.18 also demonstrates that even though till units 2 and 3 directly overlie coarse fluvial sediment, the composition of the base of the till is more fine-grained, reflecting enrichment with clay from the underlying shale. While recognition of this cyclicity permits the first-order differentiation of till sheets, there generally is insufficient information to permit correlation from hole to hole, other than by stratigraphic position. None-the less, in the absence of any additional information, a first-order stratigraphic framework can be constructed from cycle patterns on the logs.

7.4.2 Differentiation and Correlation by Till Mineralogy and Geochemistry

The petrological composition of a till deposit is very much influenced by the petrology of the underlying rock units exposed up-ice at the time of glaciation. At the gross scale, there is a petrologic differentiation within the entire glacial drift sequence that reflects the nature and degree of exposure of the underlying rock types traversed by each successive glacier. Schreiner (1990), proposed a model in which each glacial advance strips off the younger bedrock geological units, and exposes the underlying, older units (presumably partially stripping off previously deposited tills as well). Applying this concept to northwest Alberta, the earliest and oldest glaciation would strip off Upper Cretaceous shale and sandstone rock units. Tills associated with this glaciation would therefore be enriched with sedimentary rock material, primarily clay from the regionally extensive shale of the Colorado Group. The next glaciation would strip off the now-more-exposed underlying Paleozoic carbonate rock units, and the resulting tills down-ice would be enriched with carbonate material. Lastly, the youngest glaciations would erode the now-more-exposed Precambrian rocks of the Canadian Shield, and the tills would show enrichment with Shield petrology and mineralogy.

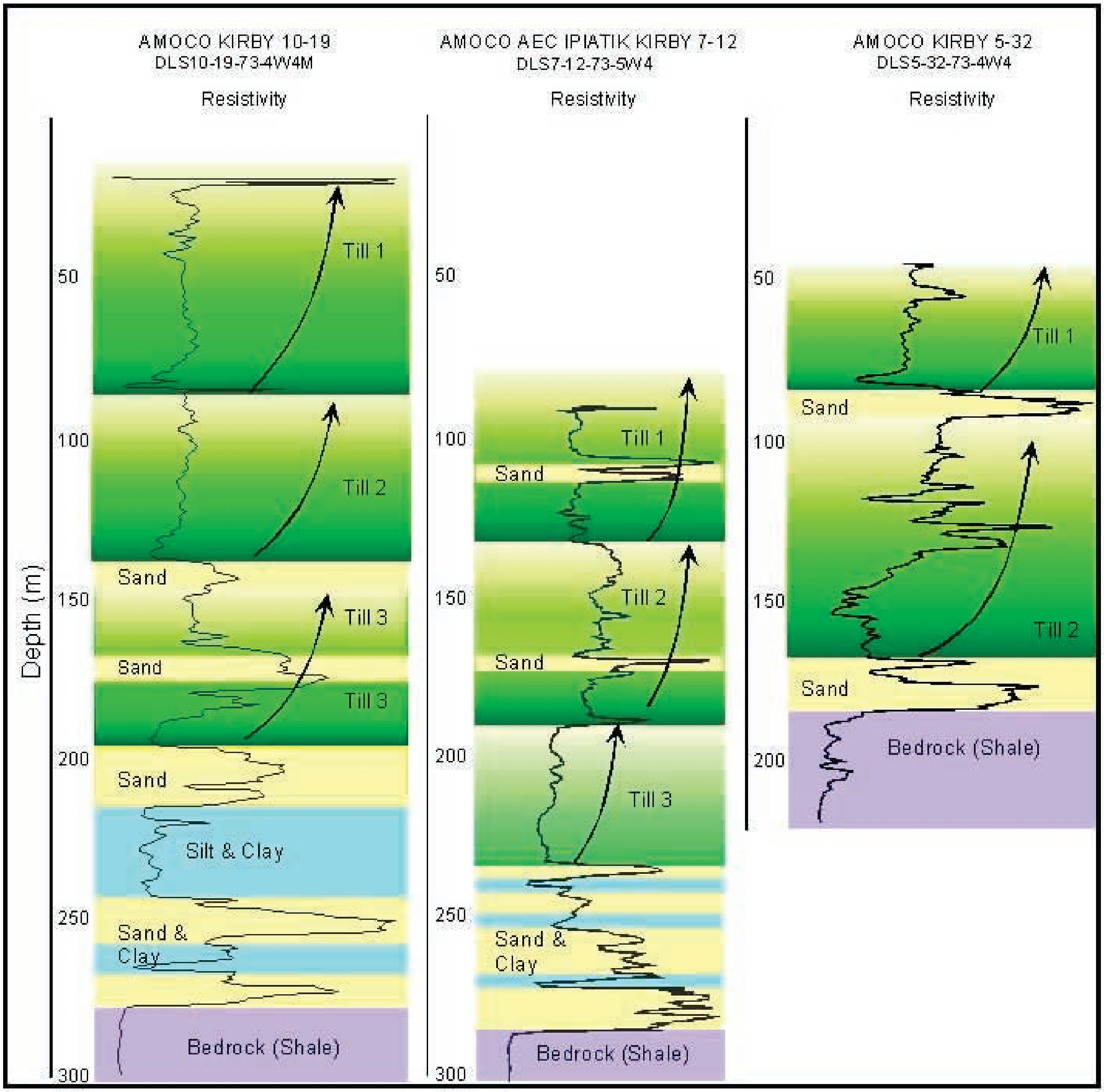


Figure 7.18. Differentiation of tills from cyclic patterns in petrophysical logs.

Enrichment of underlying bedrock material can be expressed as differences in grain-size distribution, in petrological composition of the coarse clast fraction (pebbles, granules, coarse sand), or in the mineralogical composition of silt and clay fractions of the till matrix. For example, the mirroring of the underlying bedrock units in the Quaternary stratigraphic record is well documented in the petrology of the coarse sand fraction of tills in the Cold Lake region, south of the study area (Andriashek and Fenton 1989). The uppermost Grand Centre till of the Cold Lake area is enriched with Precambrian Shield rock fragments, the middle Marie Creek till is enriched with Paleozoic carbonate fragments, mostly dolostone, and lower most Bonnyville and Bronson tills are enriched with either quartz, or shale fragments, likely from Cretaceous rock units (Figure 7.10).

Other petrological methods, such as the Chittick method, involve gasometrical techniques to determine the amount of carbonate minerals in the till matrix (Christiansen et al 1975, Christiansen 1992, Andriashek and Fenton 1989). This provides an indirect method of differentiating tills by provenance, specifically Paleozoic carbonates. While both matrix carbonate and coarse-sand count methods have proved successful, they require relatively large sample sizes which can be difficult to collect from rotary chip cuttings, they are operator dependent and labour intensive, as in the case of coarse sand petrology counts, or, they require specialized laboratory equipment and procedures not commonly found in industry. More recently, geochemical analysis of gold plus 54 other elements is being conducted on the silt-clay fraction of glacial sediments as a means to characterize and correlate tills. Figure 7.19 demonstrates the application of both the Chittick gasometrical method and aspects of the geochemistry to differentiate tills from core hole WEPA99-1. Although the petrophysical logs demonstrate at least five coarsening cycles, the relative amounts of matrix carbonate, and the abundance of calcium and magnesium (which most probably are reflections of the abundance of limestone and dolostone in the till matrix), permit the grouping of the five cycles into three major till units, with the middle unit having a significantly greater amount of carbonate compared to the tills above and below. Although calcium and magnesium appear to be effective parameters for differentiating tills, there may very well be other associations of differentiating geochemical parameters. A rigorous analysis of the geochemistry data remains to be done on the data collected on this, and past studies in the area.

Figure 7.20 illustrates how both electric log response and till petrology assist in the correlation of tills sampled from two core holes in the study area. Three clearly defined log cycles are evident in borehole WEPA00-3, but the geochemistry indicates that these are not the same three major log cycles in WEPA99-1. However, magnesium concentrations indicate the high carbonate till found in WEPA99-1 can also be recognized in WEPA00-3. The bottom-most cycle in WEPA00-3 appears to be a different, and older, till unit. It is also noteworthy that in some cases sand and gravel deposits are nested within till units, while others lie at the contact of major till units. The correlation and depiction of these sand and gravel units on a regional map would be fundamentally different as a result of the interpretation of the till contacts.

7.4.3 Buried Weathered Profile – Interglacial Event Markers

Each major glaciation was followed by a prolonged interglacial, during which time a weathered profile developed on the surface of the exposed till. In the analogy to marine regressions, Bleuer (1999) considers the development of paleosols equivalent to the onlap of the ‘atmospheric sea’. Where preserved, these weathered, oxidized profiles serve as stratigraphic markers, and are especially useful in establishing the unconformable contact between different tills. They also help confirm that major till units are of distinctly different glacial events, and not simply litho-petrological facies of a single event.

At least three weathered stratigraphic horizons were intersected by core holes drilled in this study. Figure 7.20 shows buried oxidized profiles recognized in core from two of the seven rotary core holes. In core

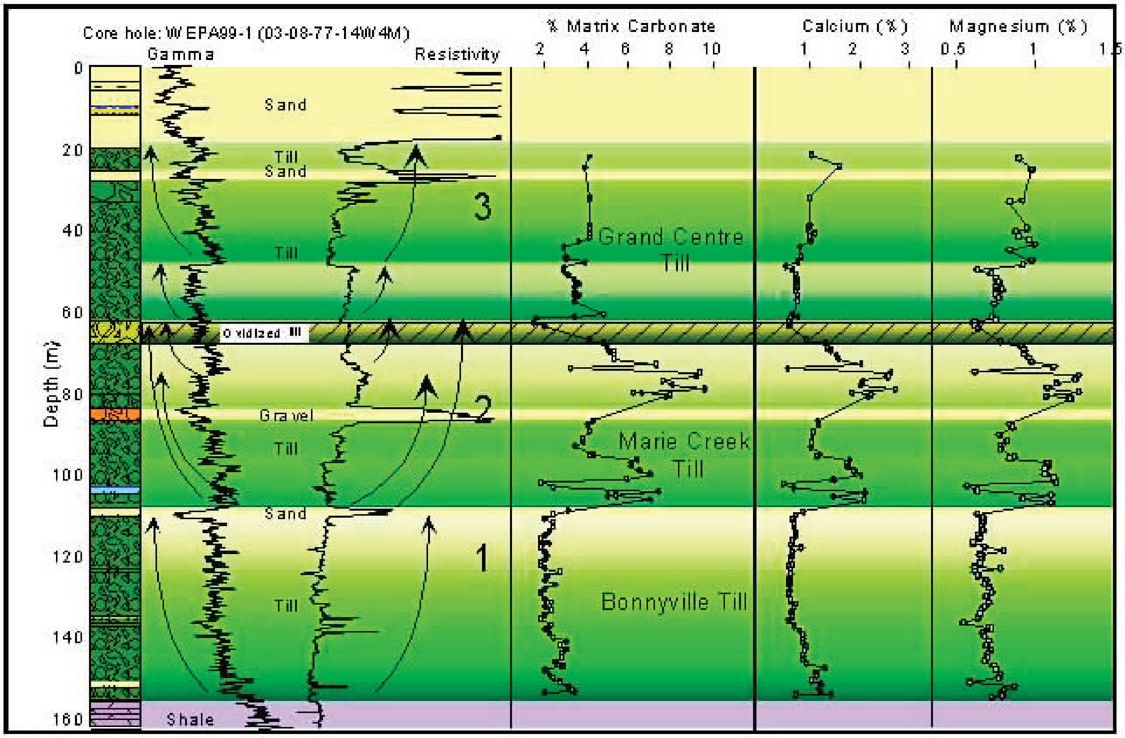


Figure 7.19. Differentiation of tills at core hole WEPA99-1, based on cyclicity in log traces, matrix carbonate content and geochemical properties.

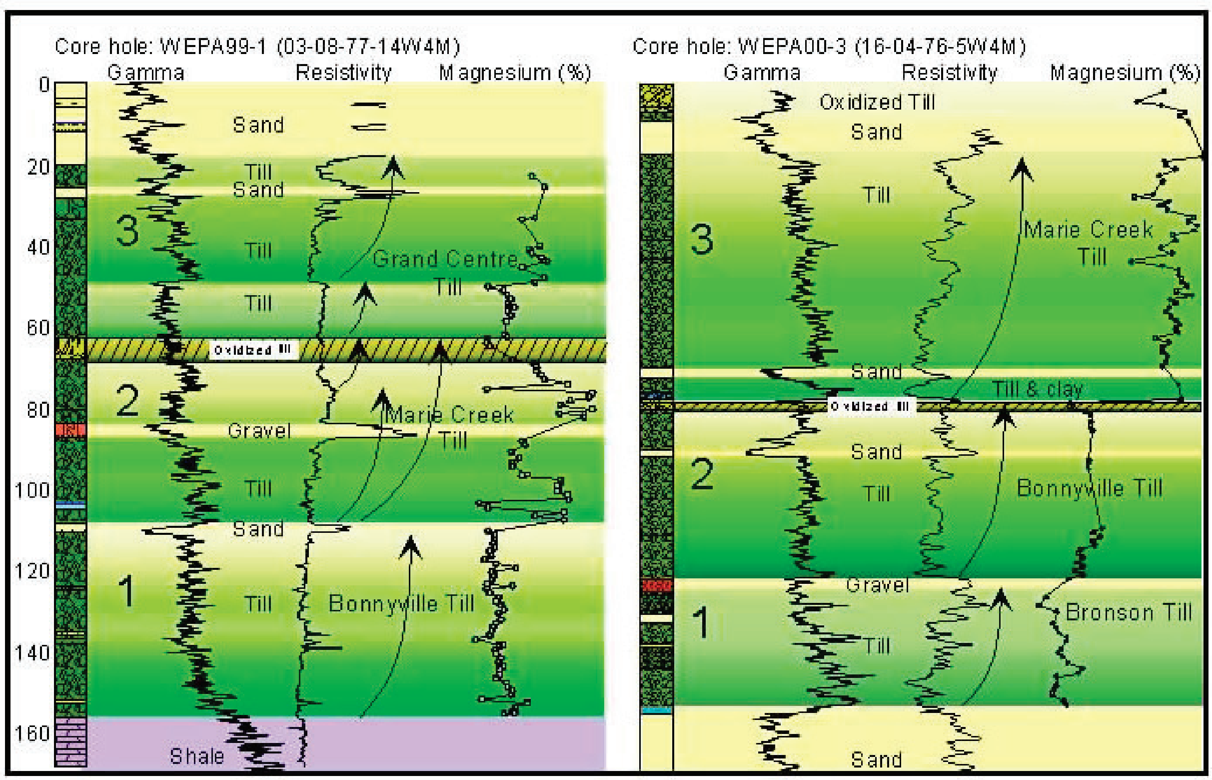


Figure 7.20. Correlation of tills on the basis of log response, geochemistry, and weathered unconformities.

hole WEPA99-1 the top of the high carbonate till (unit 2 – Marie Creek till) is strongly weathered to a depth of at least five metres, whereas in core hole WEPA00-3 a one-to-two metre thick horizon is oxidized on the surface of the underlying low carbonate till (unit 2 – Bonnyville till). In both cases the weathered profiles further support the differentiation and correlation that was based initially on log responses and mineralogical properties. The buried weathered horizon encountered at great depth in core hole WEPA00-2 is somewhat of an enigma in that it occurs in the middle of an apparent single till unit. There does not appear to be a corresponding change in any of the other parameters such as carbonate content, grain size, or petrophysical log character in this interval. As in other buried oxidized profiles, arsenic values in the oxidized horizon in WEPA00-2 are also relatively high. The horizon might demarcate the boundary between the Bonnyville and Bronson tills, but this remains speculative.

In the ideal case, weathered profiles would be considered the primary stratigraphic marker on which to base a glacio-genetic stratigraphic framework. There are a number of reasons why this is neither possible, nor feasible. Firstly, weathered surfaces are generally not widespread, either because surfaces were not uniformly oxidized everywhere, or, more likely, because weathered horizons are not well preserved due to fluvial or glacial erosion during successive glacial events. Second, where present, weathered horizons can only be recognized from high quality, expensive data-collection methods, such as core. In very few cases is this quality of data available. Tills, on the other hand, represent a depositional event, and have a much higher preservation potential. Furthermore, borehole logs are relatively abundant in the study area and permit more regional correlations. For these reasons, interpretations of till log cycles provide a better subsurface method on which to develop a working stratigraphic framework.

The significance of buried weathered profiles to hydrostratigraphy is twofold. First, these horizons can be potential zones of hydrogeochemical anomalies resulting from the precipitation and concentration of dissolved minerals along joint and fracture faces. Second, weathered profiles establish a major hiatus in the depositional environment. Sand and gravel units resting on top of weathered tills are deposited subaerially, and therefore likely to be more extensive than sand and gravel beds deposited syngenetically with tills.

7.5 Regional Correlation of the Drift Stratigraphy

The calibration of numerous petrophysical logs from the petroleum industry with data from the seven AGS core holes permits a first-order attempt at constructing a regional correlation of the late Tertiary and Quaternary stratigraphic succession within the more than 300 m of drift in the study area. Given the inherent heterogeneity of sediments deposited in glacial environments, and the abrupt changes in sediment properties over short distances, the amount of data and resources required to resolve local-scale variations in the Quaternary stratigraphy are beyond the scope of this project. None-the-less a conceptual architecture of the Quaternary drift has been constructed, adopting the stratigraphic model developed by the Alberta Geological Survey for the Sand River map area NTS/73L (Table 7.2). The proposed framework provides the basis for further stratigraphic interpretations following completion of this initial baseline study.

Five cross-sections have been constructed to illustrate the drift stratigraphy in the study area: three north-south cross-sections, referred to as A-A’, B-B’, and C-C’ (Figures 6.5, 6.6, 6.7), and two sections along the talweg of buried channels: D-D’ along the Wiau Channel (Figure 6.8) and E-E’ along the Leismer Channel (Figure 6.9). Although it may seem contrary, there is generally a higher confidence of the correlations of the lower half of the drift succession than in the upper part, primarily because the availability of petrophysical log data decreases near the top as a result of wells being cased off and not logged. Further, the data from seven core holes are insufficient to permit, with confidence, the calibration and correlation of all of the logs in the study area. As a result, only the lowermost of the drift units can be mapped with some confidence in the subsurface – the remainders are depicted only in cross-section form. A description of each of the units, from bottom of section upwards, follows.

7.5.1 Tertiary-Quaternary Stratigraphy - Empress Formation

The Empress Formation constitutes the lowermost of the drift units resting on the bedrock surface. The formation was formally assigned “Group” status by Whitaker and Christiansen (1972) to include the “stratified gravel, sand, silt, and clay of fluvial, lacustrine, and colluvial origin that overlies Cretaceous and nonmarine Tertiary bedrock, and underlies glacial till of Quaternary age in southern Saskatchewan and adjoining areas of Alberta.” Andriashek and Fenton (1989) later suggested adopting the formation-name, rather than group-name, to describe the same stratigraphic interval in the Sand River (Cold Lake) map area.

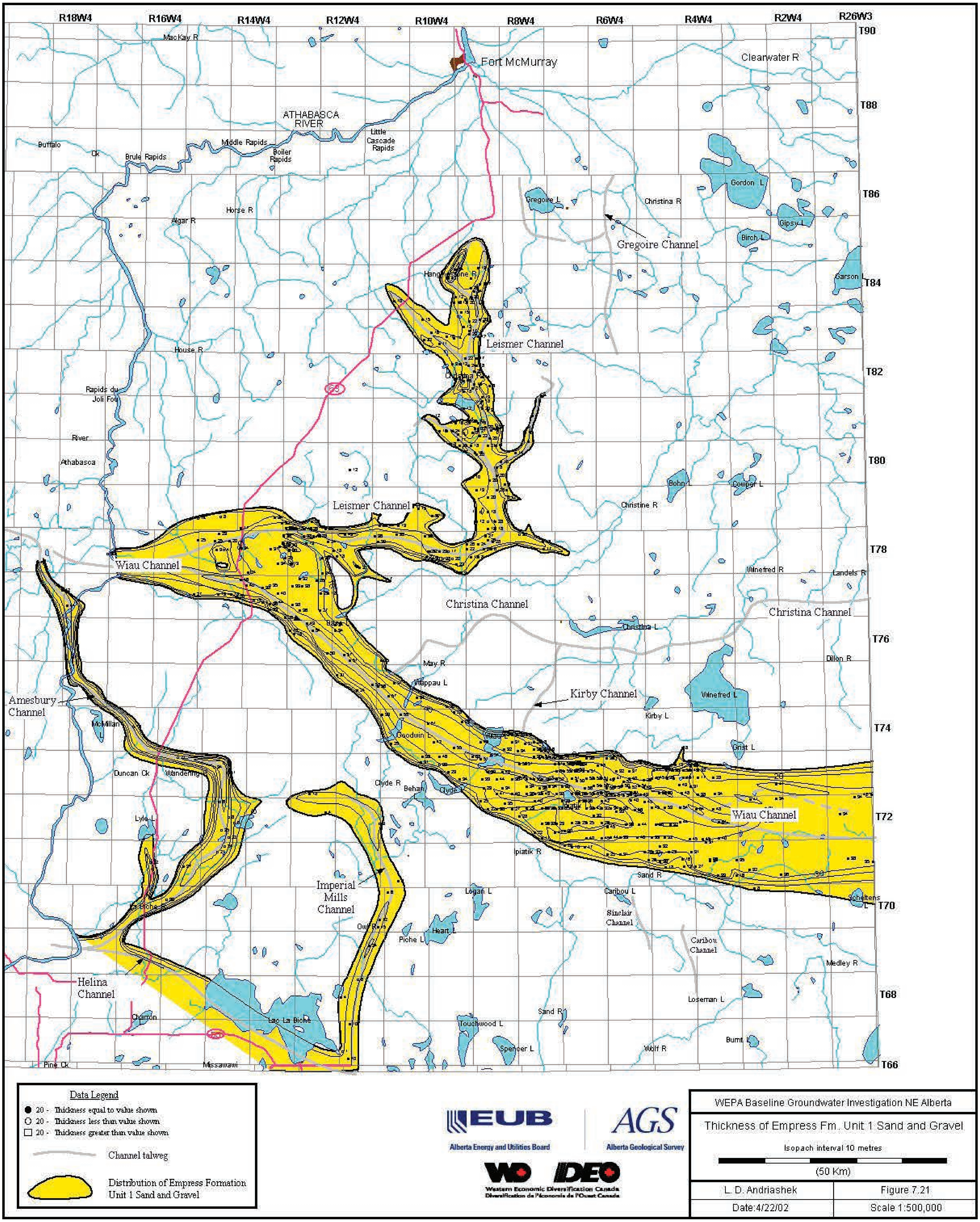
It is important to keep-in-mind that term “Empress Formation” is a lithostratigraphic mapping term to describe all stratified sediments that rest on bedrock, and that are covered by the first occurrence of glacial till in the area. As a consequence, stratified sediments of different petrology, origin, and age, can all be included as part of the Empress Formation, provided they meet the defining stratigraphic requirements. That being said, the Empress Formation in eastern Alberta can be divided into three units on the basis of lithological and petrological properties, stratigraphic position, and mappable extent. From bottom to top these are referred to as: Unit 1 preglacial sand and gravel; Unit 2 silt and clay; and, Unit 3 glacial sand and gravel.

7.5.1.1 Empress Formation Unit 1 - Preglacial Sand and Gravel

Empress Formation Unit 1 sand and gravel is composed of light-coloured metaquartzite, dark-coloured chert, and other resistant rock types derived from the Rocky Mountains and local bedrock. The sediment was deposited by eastward-flowing rivers on the Alberta bedrock surface prior to the advent of the first Laurentide glaciation. Hence, granite and gneiss rock-fragments, which were transported into Alberta by glaciers flowing from the Canadian Shield, are conspicuously absent in this unit. Unit 1 sand and gravel deposits, therefore, can only be differentiated from stratigraphically younger glacial sand and gravel if information on clasts petrology enables the distinction to be made, or, where a lithological distinct unit, such as regionally extensive silt and clay, separates the two. Where neither of these conditions can be met, sand and gravel resting on the bedrock floor can only be classified as Empress Formation of undifferentiated age and origin.

Extensive and continuous deposits of Empress Unit 1 sand and gravel are mapped on the floors of preglacial channels, including the Wiau, Leismer, Amesbury, and Imperial Mills channels (Figure 7.21). However, a preglacial composition has been verified only in samples from the Wiau Channel – assignment of a preglacial age to the sand and gravel that rests on the floors of the other channels is only inferred by stratigraphic position and channel morphology. Although the Christina Channel is also believed to have been eroded by preglacial drainage, there is some uncertainty regarding the age and origin of the fluvial sediments that rest on the channel floor throughout. For this reason, Christina Channel sand and gravel is classed as undifferentiated Empress Formation deposits. Petrophysical log traces show that finer-textured fluvial sediment also occur as beds within Unit 1 sand and gravel. These fine-grained beds are widespread and mappable within the eastern segment of the Wiau Channel (Figure 6.8), and within the northern segment of the Leismer Channel that lies in the Hangingstone Plains bedrock physiographic unit (Figure 6.9).

More than 70 m of Empress Formation Unit 1 have been mapped in the study area, the thickest deposits of which occur along the talweg of the Wiau and Amesbury channels (Figures 6.5, 6.7, and 7.21).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Brule Rapids
Middle Rapids
Boiler Rapids
Little Cascade Rapids
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Sand R
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Spencer L
Wolf R
Burnt L
Pine Ck
Missawawi
Data Legend
20 - Thickness equal to value shown
20 - Thickness less than value shown
20 - Thickness greater than value shown
Channel talweg
Distribution of Empress Formation Unit 1 Sand and Gravel
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Thickness of Empress Fm. Unit 1 Sand and Gravel
Isopach interval 10 metres
(50 Km)
L. D. Andriashek
Figure 7.21
Date:4/22/02
Scale 1:500,000

Variations in thickness within the Wiau Channel have an apparent linear form, likely reflecting channel scour and infill as the paleoriver migrated across the broad bedrock lowland. Unit 1 deposits within the Leismer Channel are generally less than 30 m thick, the exception being at the extreme north end of the channel in Tp 84, Rg 10 where in excess of 50 m of channel sediment are mapped. Sediments inferred to be Unit 1 also lie on the floors of the tributaries of the main Leismer Channel.

Structure contours on the surface of Unit 1 indicate a range in elevation of about 110 m, from a low of about 420 m on the eastern segment of the Wiau Channel, to a high of about 530 m in the extreme north end of the Leismer Channel (Figure 7.22). The gradient of the surface of the deposits reflects that of the underlying bedrock channel surface – that is, deposits within the Leismer Channel have an apparent surface gradient to the south and west, the deposits in the Wiau channel have an apparent gradient to the east, and the deposits in the Amesbury Channel slope to the north and west. Cross-section D-D' (Figure 6.9) also shows that Empress unit 1 sediments within the Leismer Channel are stratigraphically equivalent and correlative with sediments within the western end of the Wiau Channel, indicating confluence of drainage between these two channel systems. The same cannot be said about the stratigraphical relationship between Unit 1 deposits in the Amesbury Channel, which lie at an elevation of about 420 m, and those in the western end of the Wiau Channel, which are estimated to lie at an elevation of about 470 m (Figure 7.22). This disjunction demonstrates that drainage within the two systems likely was not confluent, and that deposition of Unit 1 in the Amesbury Channel most likely followed that in the Wiau Channel.

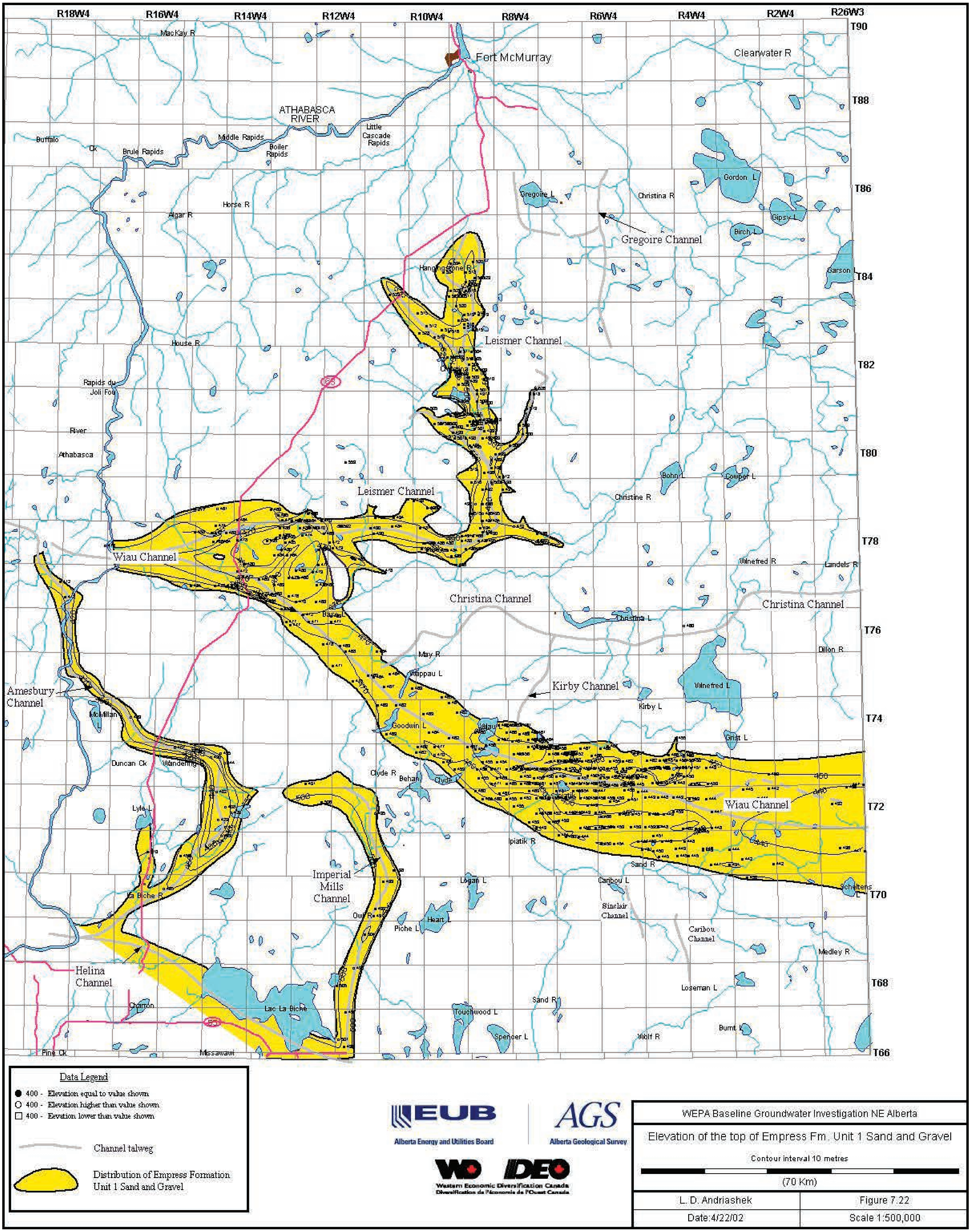
Probably the most striking aspect regarding the distribution of Unit 1 is the great lateral and continuous extent of the preglacial sand and gravel within the Wiau Channel. Figure 7.21 shows that Unit 1 extends for almost 30 km across the channel at the eastern end of the study area, making this one of the most widespread and thick buried fluvial deposits of Tertiary/Quaternary age in the Western Canadian Sedimentary Basin.

7.5.1.2 Empress Formation Unit 2 Silt and Clay

Empress Formation Unit 1 deposits characteristically fine upwards into silt and clay of undifferentiated fluvial and lacustrine origin, referred to as Empress Formation Unit 2 silt and clay. Andriashek and Fenton (1989) interpret these fine-grained sediments to represent the influence of the first glaciation in the region, which blocked the regionally eastward drainage in the channels causing suspended sediment to be deposited in the ponded water. Samples of Empress Unit 2 silt and clay were encountered and logged in only one core hole, WR99-1, in the interval from about 161 m to 191 m (Figure 7.12). The unit was described as sand, silt, and clay from small rotary-drill chip-samples using a tricone rock bit, and is well recorded on the petrophysical logs.

Extensive and continuous deposits of Empress Formation Unit 2 silt and clay are mapped primarily in the eastern two-thirds of the Wiau Channel (Figures 6.5, 6.6, 6.8, and 7.23). They have not been recognized in the Amesbury or Christina channels, and are mapped only sporadically within the Imperial Mills Channel. Until such time as samples of the Quaternary are collected from the Leismer Channel, it is uncertain if a clay-rich unit that lies above Unit 1 sand and gravel in the Leismer Channel consists of till, as currently interpreted on cross-section E-E' (Figure 6.9), or silt and clay. If the latter, then the clayey sediment in the Leismer Channel may be correlative with silt and clay of Empress Unit 2, and the extent of the Unit 2 may be greater than that shown in Figure 7.23.

Coincidentally, the thickest deposits of Unit 2 silt and clay are mapped in core hole WR99-1, in the western end of the Wiau Channel. However, as discussed previously, there is some ambiguity regarding the origin of the thick fluvial sediment above the preglacial sand and gravel at this site. The top of Unit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Leismer Channel
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Athabasca
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Caribou Channel
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Helina Channel
Medley R
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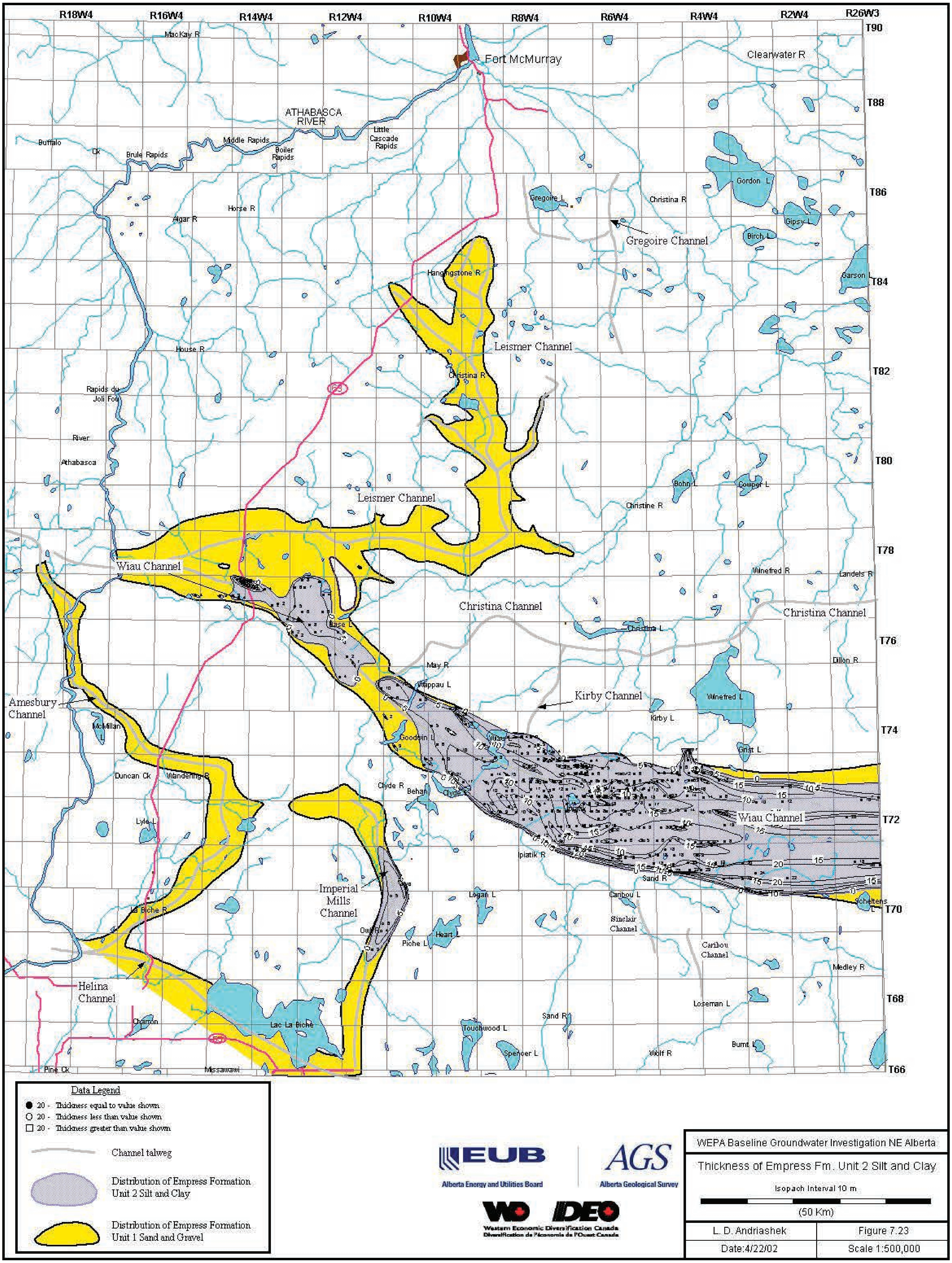
Sand R
Loseman L
Touchwood L
Spencer L
Wolf R
Burnt L
Pine Ck
Missawawi
Data Legend
400 - Elevation equal to value shown
400 - Elevation higher than value shown
400 - Elevation lower than value shown
Channel talweg
Distribution of Empress Formation Unit 1 Sand and Gravel
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Elevation of the top of Empress Fm. Unit 1 Sand and Gravel
Contour interval 10 metres
(70 Km)
L. D. Andriashek
Figure 7.22
Date:4/22/02
Scale 1:500,000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Fort McMurray
Clearwater R
MacKay R
ATHABASCA RIVER
Little Cascade Rapids
Middle Rapids
Boiler Rapids
Brule Rapids
Buffalo
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Gregoire L
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Birch L
Gregoire Channel
Hangingstone R
Garson L
Leismer Channel
House R
Christina R
Rapids du Joli Fou
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Athabasca
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Winefred L
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Amesbury Channel
McMillan L
Goodwin L
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Wandering R
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Wiau Channel
Lyle L
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Imperial Mills Channel
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Caribou Channel
Medley R
Helina Channel
Charron
Lac La Biche
Sand R
Loseman L
Touchwood L
Spencer L
Wolf R
Burnt L
Pine Ck
Missawawi
Data Legend
20 - Thickness equal to value shown
20 - Thickness less than value shown
20 - Thickness greater than value shown
Channel talweg
Distribution of Empress Formation Unit 2 Silt and Clay
Distribution of Empress Formation Unit 1 Sand and Gravel
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Thickness of Empress Fm. Unit 2 Silt and Clay
Isopach Interval 10 m
(50 Km)
L. D. Andriashek
Figure 7.23
Date:4/22/02
Scale 1:500,000

2 lies about 20 m higher at WR99-1 than elsewhere in the Wiau Channel, indicating that the sequence may represent deposits of a later glaciofluvial event, which down cut and superposed younger sediments, including silt and clay. Other thick deposits (>25 m) of Unit 2 silt and clay are mapped in the extreme east end of the Wiau Channel in Tp 71, Rg, 1(Figure 7.23). Elsewhere, Unit 2 ranges in thickness generally between 10 m and 15 m.

The top of Unit 2 silt and clay shows relatively little change in elevation, which is expected for fluvial or lacustrine sediments that are deposited in a broad depositional basin. The surface elevation is highest in the western part of the Wiau Channel, between 485 and 490 m, and decreases gradually to a low of about 455 m to 460 m in the east (Figure 7.24). For most of the channel, however, the elevation varies by only 10 m or so, ranging between 460 and 470 m.

7.5.1.3 Empress Formation Unit 3 Glacial Sand and Gravel

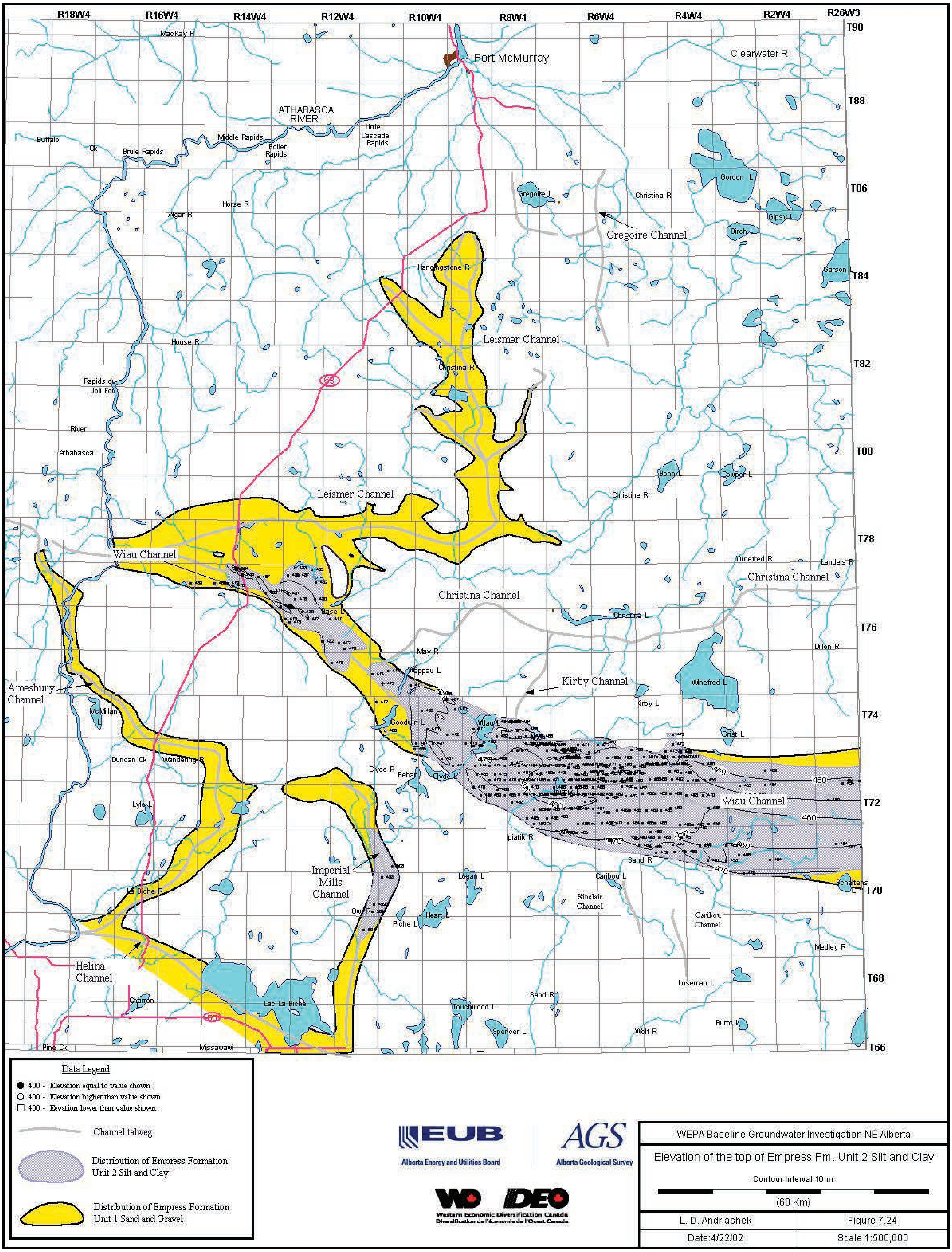
Empress Formation Unit 3 glacial sand and gravel is the youngest of the units in the Empress Formation, and constitutes the first deposit of glacial origin in the study area. As discussed previously, Empress Unit 3 deposits are characterized by an abundance of granite and gneiss rock fragments derived from the Canadian Shield, which differentiates them from the metaquartzite-chert sand and gravel of Unit 1. In almost all cases, however, information that permits this petrological differentiation is absent from bore holes in the study area. Thus, Units 1 and 3 can only be differentiated from petrophysical logs, and only where intervening silt and clay deposits of Unit 2 are present. For this reason, the distribution of Unit 3 glacial sand and gravel, as shown in Figure 7.25, is confined to the same areal boundaries that define the extent of Empress Unit 2 silt and clay. Glacial sand and gravel of Unit 3 may have greater extent than shown, but if they are in direct contact with Unit1 sand and gravel, the two cannot be differentiated.

Empress Formation Unit 3 sand and gravel are mapped in two settings: within the Wiau Channel, where petrophysical logs and a few lithologs indicate that glacial sand and gravel overlies Empress Unit 2, (Figures 6.5, 6.6, and 6.8), and within the buried Gregoire Channel, where samples confirm that glacial sand and gravel rest directly on the bedrock channel floor (Figures 6.5 and 7.25). Empress Unit 3 deposits exhibit a wide range in thickness, as much as 40 m in the western end of the Wiau, to in excess of 70 m in the Gregoire Channel. A number of sites of thick (>20 m) Unit 3 deposits have correspondingly higher elevations than Unit 3 in surrounding areas, indicating that at these locations stratigraphically higher glaciofluvial sediments may be superposed on Empress sediments. Examples of this include the area west of Wiau Lake in Tp 73, Rg 9, and in the western segment of the Wiau Channel in Tp 77, Rgs 13 to 15 (Figure 7.26). The quasi-linear trend of the structure contours on the surface of Unit 3 in the Wiau Lowland, as depicted in Figure 7.26, lend credence to a scour-and-fill glaciofluvial depositional model. Unit 3 deposits in the Gregoire Channel are interpreted to have in filled the channel during a single depositional event following the catastrophic erosion of the bedrock channel by subglacial meltwater.

7.5.1.4 Undifferentiated Empress Formation Channel Deposits

There are parts of the study area where the petrology and origin of the fluvial sediments resting on the floors of bedrock channels is unknown, and where the sedimentary succession of those fluvial sediments consists of only one sediment type, generally coarse-grained sediment (sand, sand and gravel). Until such time as the petrology of the sediment can determined to establish the source and age, deposits of this type cannot be classed into any of the three units of the Empress Formation but rather, are grouped under the general heading of Undifferentiated Empress Formation.

The sediments within the Christina Channel currently fall under the category of Undifferentiated Empress Formation sediments (Figure 7.27). For the most part the sediment within the Christina Channel appears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Gregoire Channel
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Gipsy L
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Horse R
Algar R
Hangingstone R
Garson L
Leismer Channel
House R
Christina R
Rapids du Joli Fou
River
Athabasca
Bohn L
Cowper L
Christine R
Leismer Channel
Wiau Channel
Winefred R
Landels R
Christina Channel
Christina Channel
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Christina L
Dillon R
May R
Kirby Channel
Amesbury Channel
Winefred L
Kirby L
McMillan
Goodwin L
Wiau L
Grist L
Duncan Ck
Wandering R
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Wiau Channel
Lyle L
Ipiatik R
Sand R
Imperial Mills Channel
Logan L
Caribou L
Sinclair Channel
Scheltens L
La Biche R
Owl R
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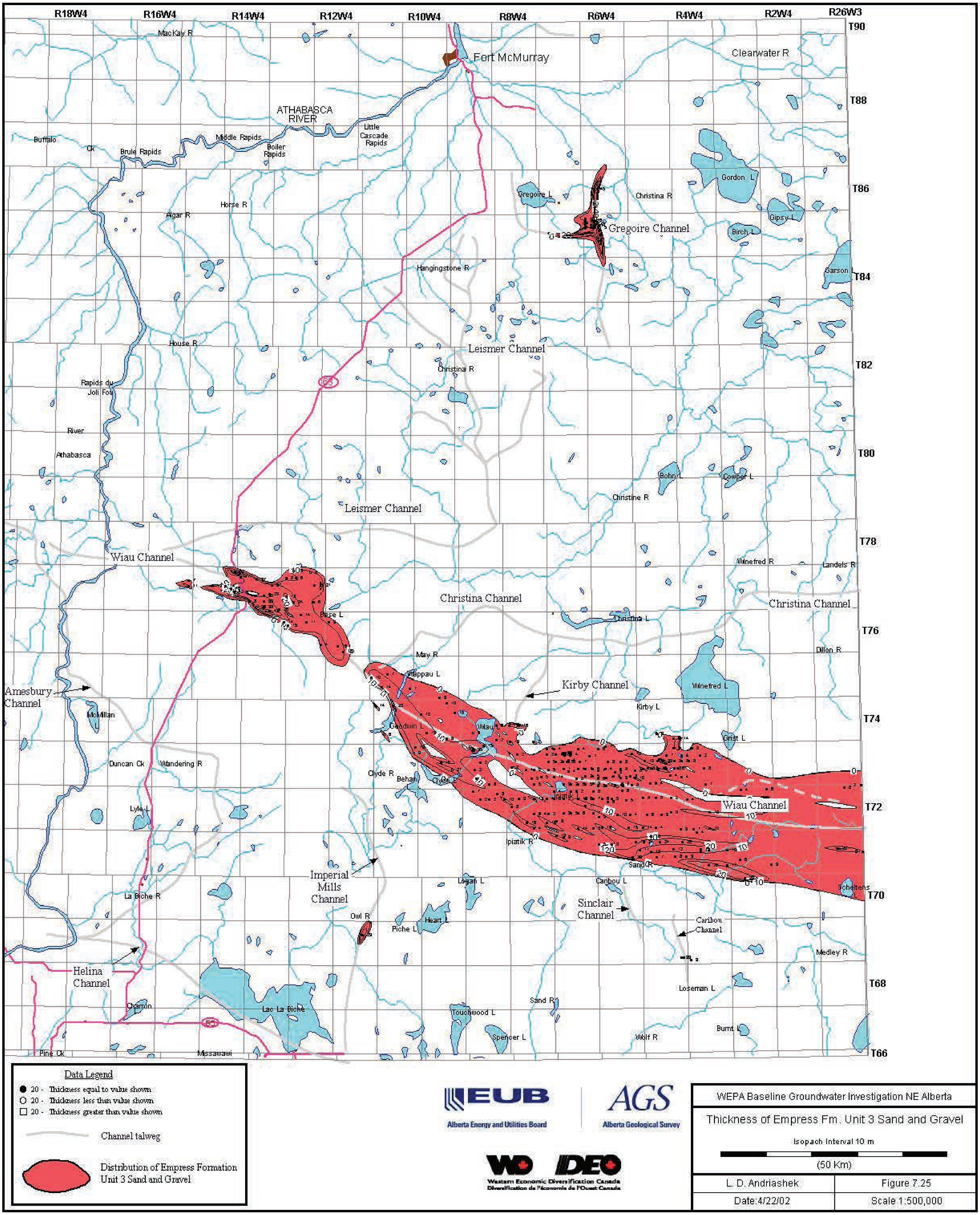
Heart L
Caribou Channel
Medley R
Helina Channel
Loseman L
Charron
Lac La Biche
Sand R
Touchwood L
Spencer L
Wolf R
Burnt L
Pine Ck
Missawawi
Data Legend
400 - Elevation equal to value shown
400 - Elevation higher than value shown
400 - Elevation lower than value shown
Channel talweg
Distribution of Empress Formation Unit 2 Silt and Clay
Distribution of Empress Formation Unit 1 Sand and Gravel
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Elevation of the top of Empress Fm. Unit 2 Silt and Clay
Contour Interval 10 m
(60 Km)
L. D. Andriashek
Figure 7.24
Date:4/22/02
Scale 1:500,000



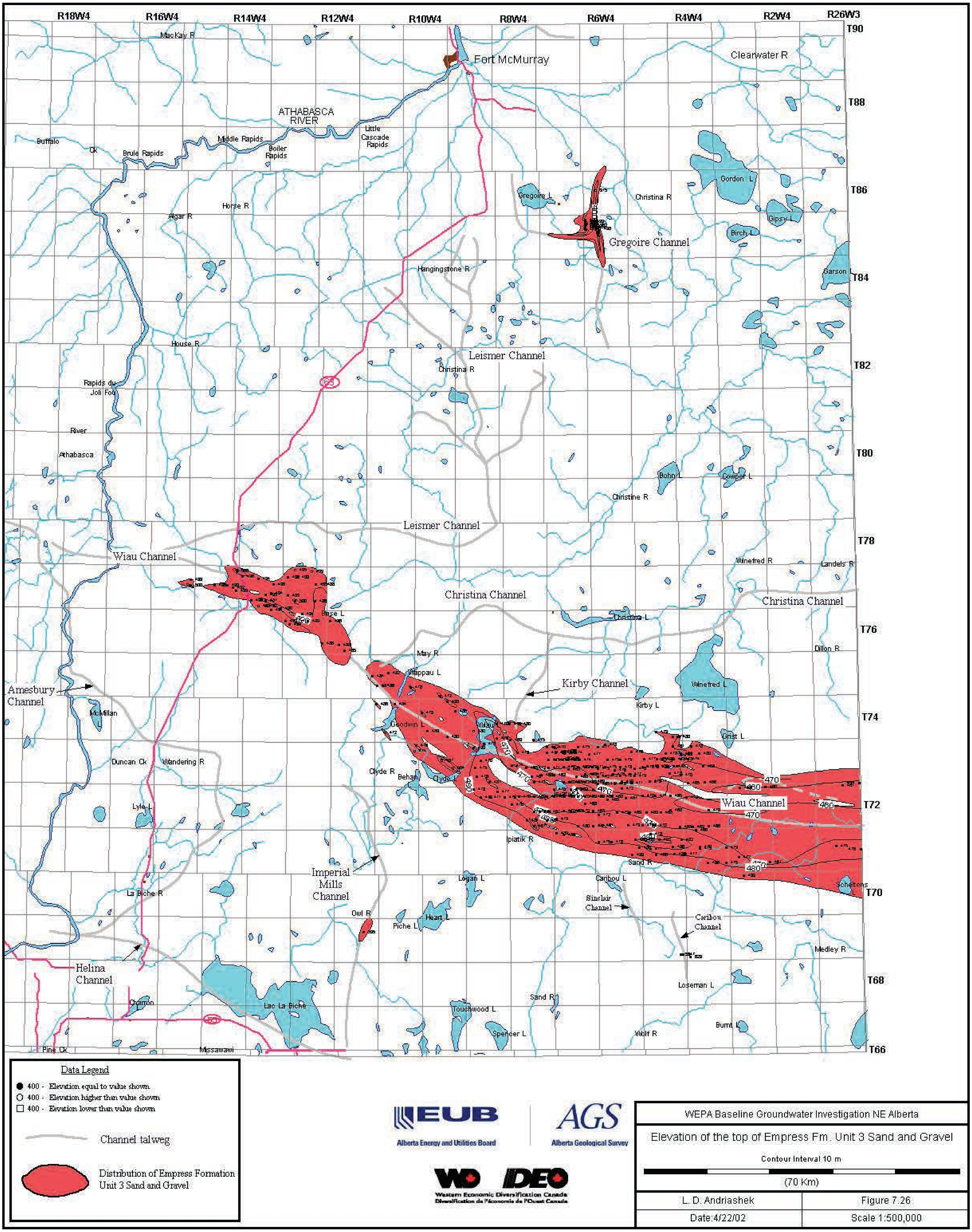
WEPA Baseline Groundwater Investigation NE Alberta

Thickness of Empress Fm. Unit 3 Sand and Gravel

Isopach Interval 10 m

(50 Km)

L. D. Andriashek	Figure 7.25
Date:4/22/02	Scale 1:500,000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Fort McMurray
Clearwater R
MacKay R
ATHABASCA RIVER
Little Cascade Rapids
Middle Rapids
Boiler Rapids
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Gregoire L
Christina R
Gordon L
Gipsy L
Birch L
Gregoire Channel
Hangingstone R
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Leismer Channel
Christina R
Rapids du Joli Fou
River
Athabasca
Bohn L
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Winefred R
Landels R
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Dillon R
Amesbury Channel
Kirby Channel
Winefred L
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Imperial Mills Channel
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Caribou Channel
Medley R
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Charron
Lac La Biche
Touchwood L
Sand R
Loseman L
Spencer L
Wolf R
Burnt L
Pine Ck
Missawawi
Data Legend
400 - Elevation equal to value shown
400 - Elevation higher than value shown
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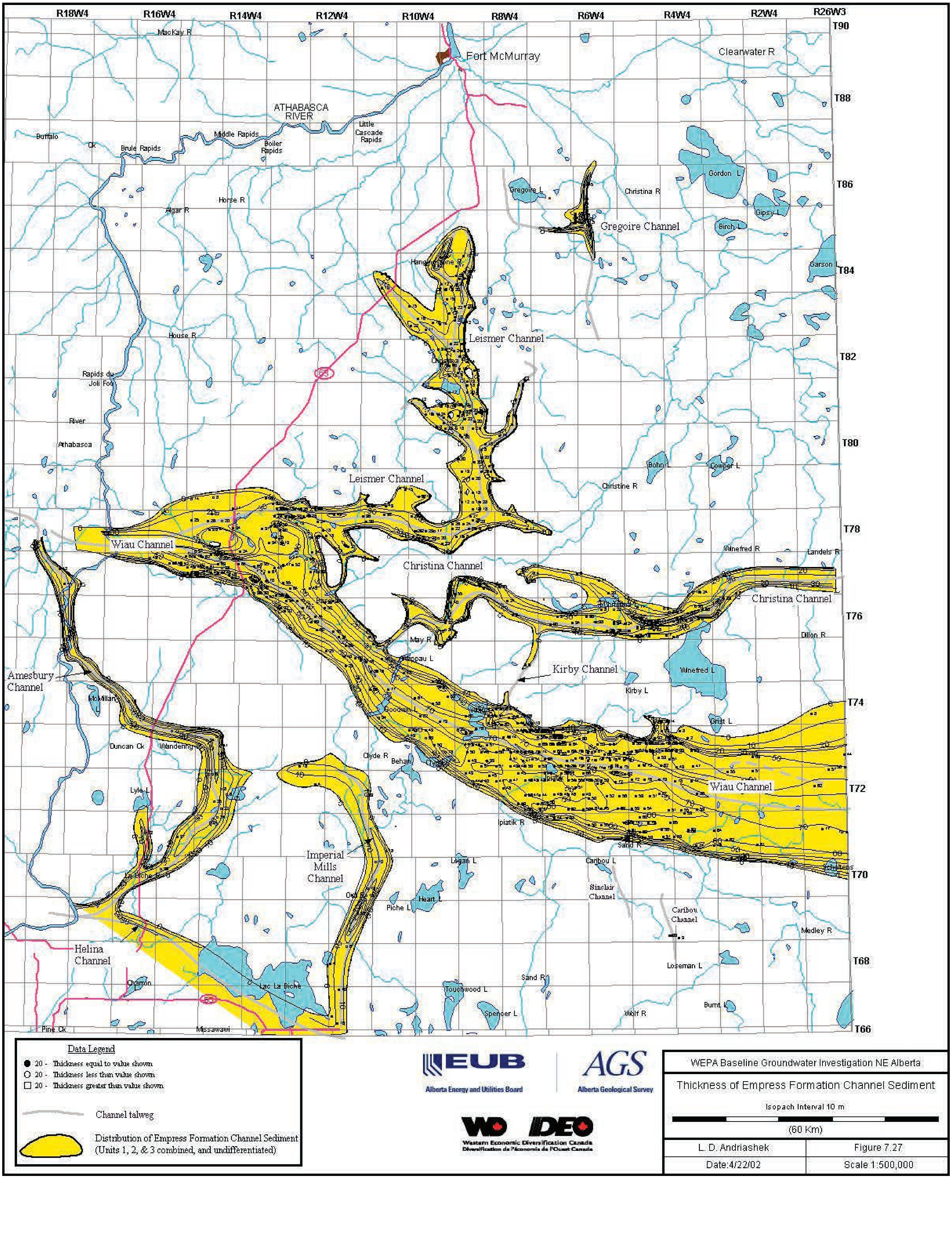
Channel talweg
Distribution of Empress Formation Unit 3 Sand and Gravel
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Elevation of the top of Empress Fm. Unit 3 Sand and Gravel
Contour Interval 10 m
(70 Km)
L. D. Andriashek
Figure 7.26
Date:4/22/02
Scale 1:500,000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Caribou Channel
Lac La Biche
Data Legend
20 - Thickness equal to value shown
20 - Thickness less than value shown
20 - Thickness greater than value shown
Channel talweg
Distribution of Empress Formation Channel Sediment (Units 1, 2, & 3 combined, and undifferentiated)
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Thickness of Empress Formation Channel Sediment
Isopach Interval 10 m
(60 Km)
L. D. Andriashek
Figure 7.27
Date:4/22/02
Scale 1:500,000

to be sand, or sand and gravel, but not necessarily of the same age and source. Although the channel is inferred to be of preglacial age, formed by the same processes that created the Wiau Channel, elements of the channel floor exhibit over-deepening by scour, which may be attributed to down-cutting by glacial meltwater at a later time. If so, then sediments that rest on the floor of the Christina Channel may be of multiple origins. Figures 6.5 and 7.27 shows that more than 90 m of sediment have in filled an apparent over-deepened scour that lies in the segment of the Christina Channel defined by Tp 76, Rgs 4 and 5. A similar over-deepening of the channel occurs in Tp 77 Rg 9, where 70 m of sediment are mapped. At least 20 to 30 m of sediment are mapped elsewhere in the channel. Structure contours on the surface of the Christina Channel sediments are depicted in Figure 7.28.

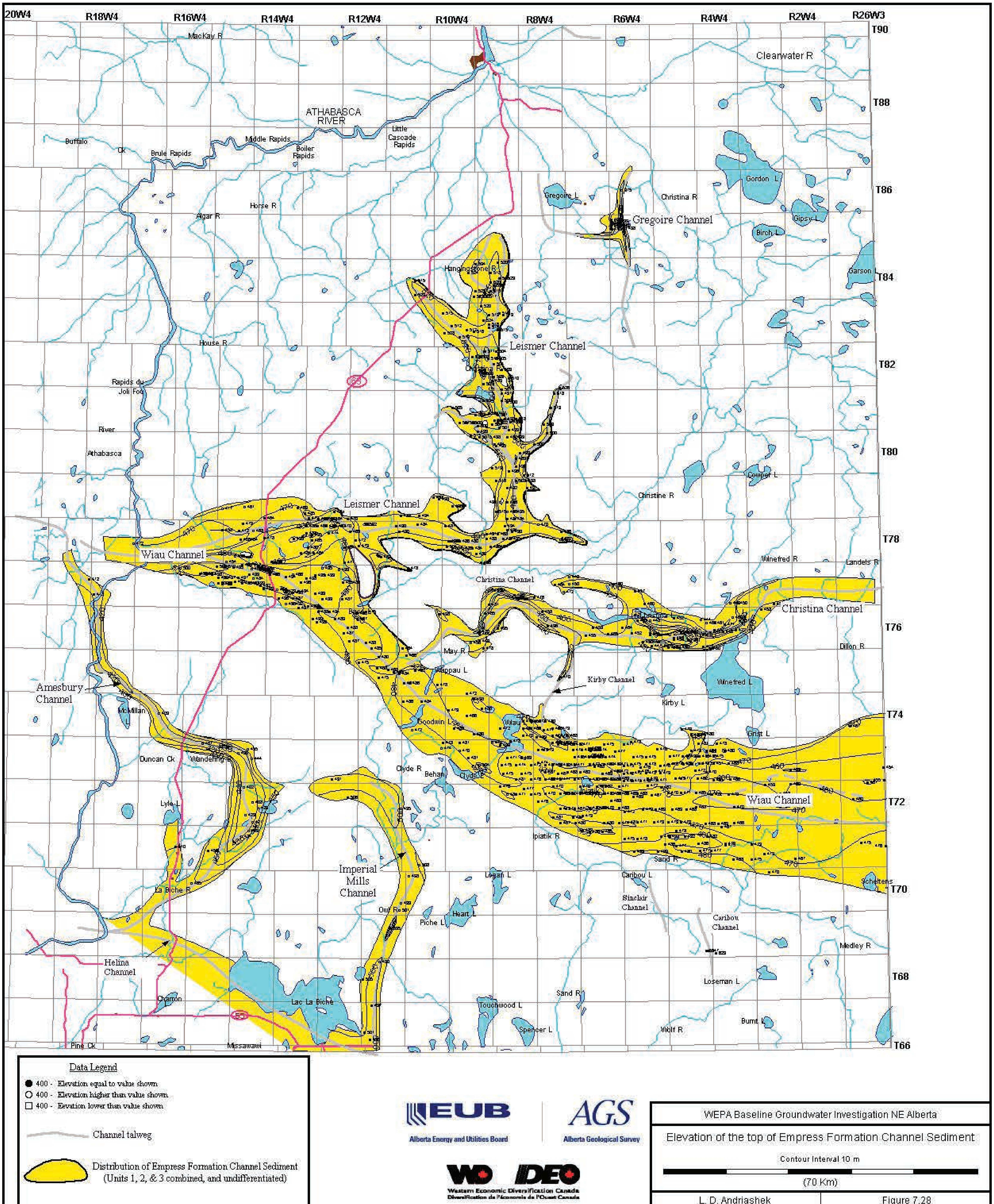
Figure 7.27 shows the distribution and combined thickness of all three units of the Empress Formation, which essentially represents all stratified sediment resting on the floors of bedrock channels. It illustrates that there are substantial areas along the talweg of Wiau Channel where the cumulative thickness of preglacial and glacial sand and gravel, and fluvial or lacustrine silt and clay, is as much as 70 to 80 m. Structure contours on the surface of the combined units are also shown in Figure 7.28.

7.5.1.5 Empress Formation on the Interfluve of Bedrock Channels

The bedrock interfluves between the major channels within the Wiau Lowland are mantled by thick deposits of sand and gravel that lie at an elevation generally higher than the uppermost fluvial sediments within the buried channels (Figures 6.5, 6.6, and 7.29). In the initial work on the regional Quaternary stratigraphy of the area, Stein and Andriashek (1993) speculated on the origin and concluded that, in absence of petrological information, it was reasonable to assume the interfluve sediments were likely to be of preglacial age and composition, representing higher-level terrace lag deposits of the Wiau-Christina fluvial system. However, field descriptions and examination of recent core samples from AGS borehole WEPA00-3 in Tp 75, Rg 5 (Appendix 2-F) show that at least at that location, the sand and gravel resting on bedrock interfluve is of glacial composition and origin.

Figure 7.29 shows that interfluve deposits are mapped in five geographic areas: in the interfluve between the Wiau and Christina channels, both east and west of the Kirby Channel; in the interfluve between the Christina and Leismer channels; as terrace bench deposits on the north side of the Leismer Channel; within three poorly-defined channels on the north side of the Christina Channel; and, within a poorly-defined channel that parallels the south side Wiau Channel beneath Clyde Lake in Tps 72-73, Rgs 9-10. Interfluve deposits are as thick as 40 m directly west of Winefred Lake, but elsewhere generally range between 10 and 20 m. Structure contours on the surface of interfluve deposits indicate that they generally lie at an elevation above 480 m, which is the upper limit for the elevation of Empress Unit 3 deposits in the Wiau Channel. Interfluve deposits that have an anomalously great thickness and high elevation, such as in Tp 76, Rg 3 (Figures 7.29 and 7.30) likely represent areas where younger deposits have been superposed on the bedrock surface by later glaciofluvial scour-and-infill events.

The current assessment of the distribution, thickness, and elevation of the tops of all of the Empress Formation channel and interfluve deposits is depicted in Figures 7.31 and 7.32. In total, the Empress Formation within the study area is considered to constitute one of the largest, if not the largest, bodies of coarse-grained sediment that lies on the bedrock surface anywhere within the Western Canadian Sedimentary Basin. In this regard, it has enormous potential to be one of the major aquifers above the oil sands in northern Alberta.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Little Cascade Rapids
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Touchwood L
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Burnt L
Pine Ck
Missawawi
Data Legend
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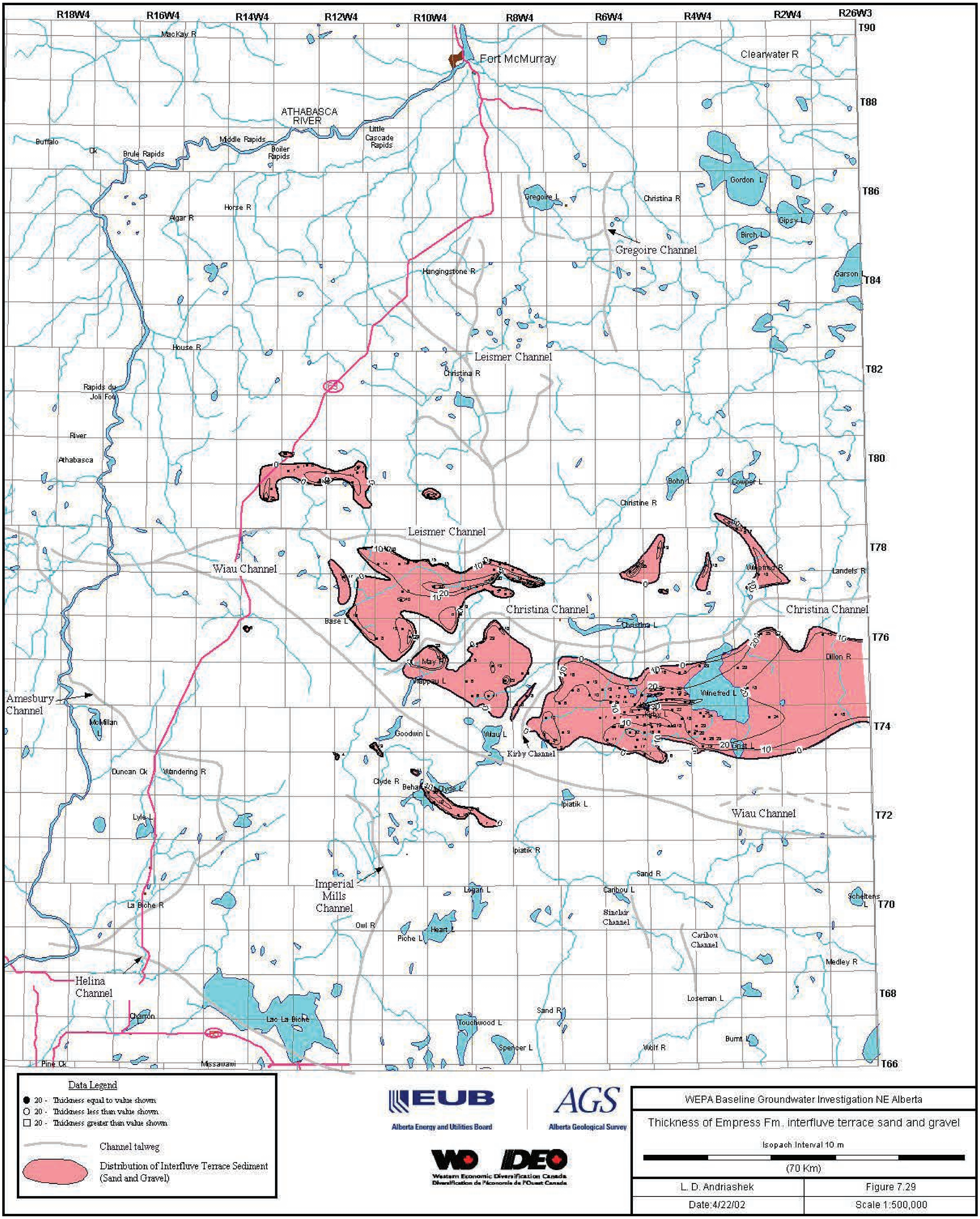
400 - Elevation higher than value shown
400 - Elevation lower than value shown
Channel talweg
Distribution of Empress Formation Channel Sediment (Units 1, 2, & 3 combined, and undifferentiated)
EUB Alberta Energy and Utilities Board
AGS Alberta Geological Survey
WD DEO Western Economic Diversification Canada Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Elevation of the top of Empress Formation Channel Sediment
Contour Interval 10 m
(70 Km)
L. D. Andriashek
Figure 7.28
Date:4/22/02
Scale 1:500,000



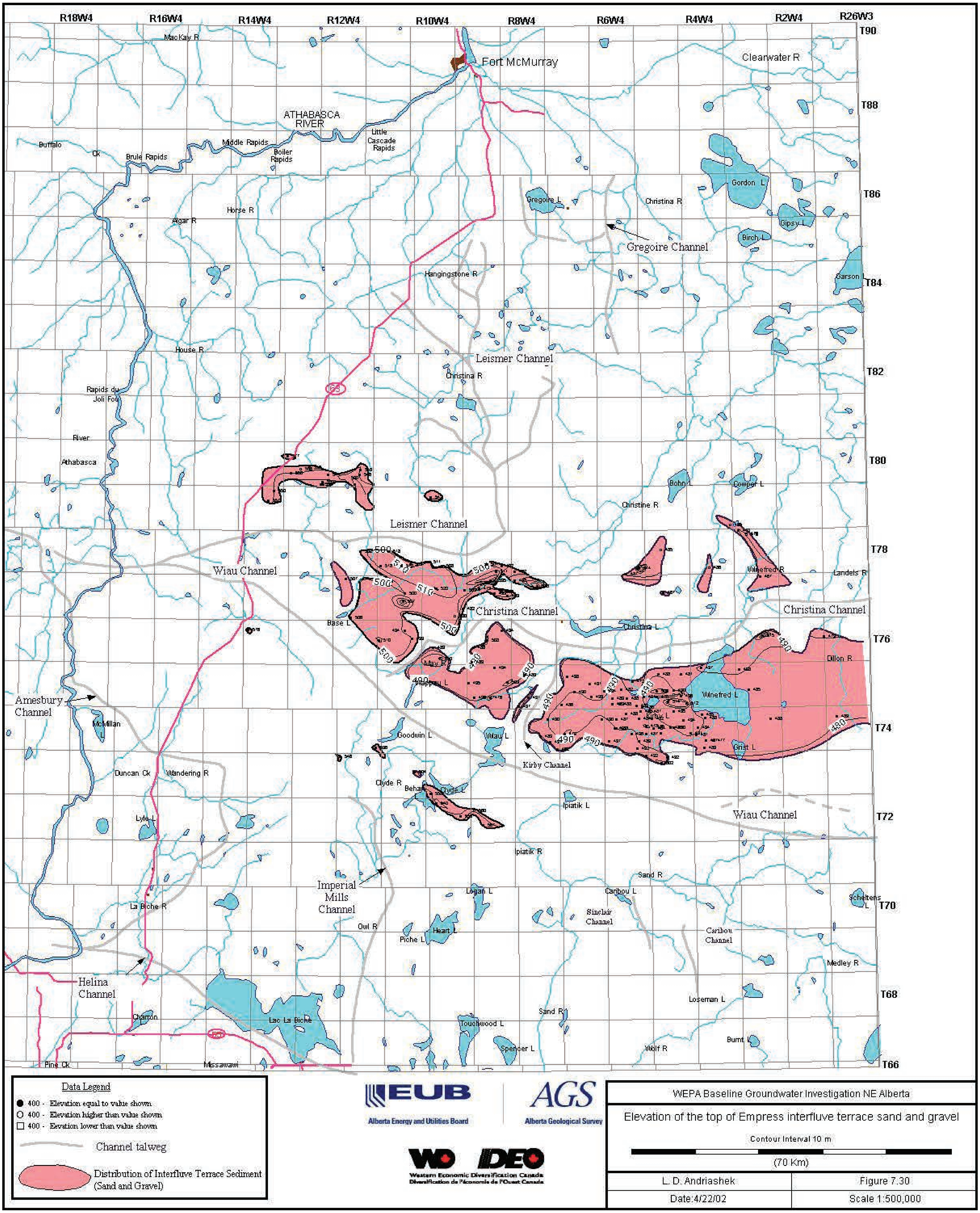
WEPA Baseline Groundwater Investigation NE Alberta

Thickness of Empress Fm. interfluve terrace sand and gravel

Isopach Interval 10 m

(70 Km)

L. D. Andriashek	Figure 7.29
Date:4/22/02	Scale 1:500,000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Touchwood L
Spencer L
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Data Legend
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Channel talweg
Distribution of Interfluve Terrace Sediment (Sand and Gravel)
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Elevation of the top of Empress interfluve terrace sand and gravel
Contour Interval 10 m
(70 Km)
L. D. Andriashek
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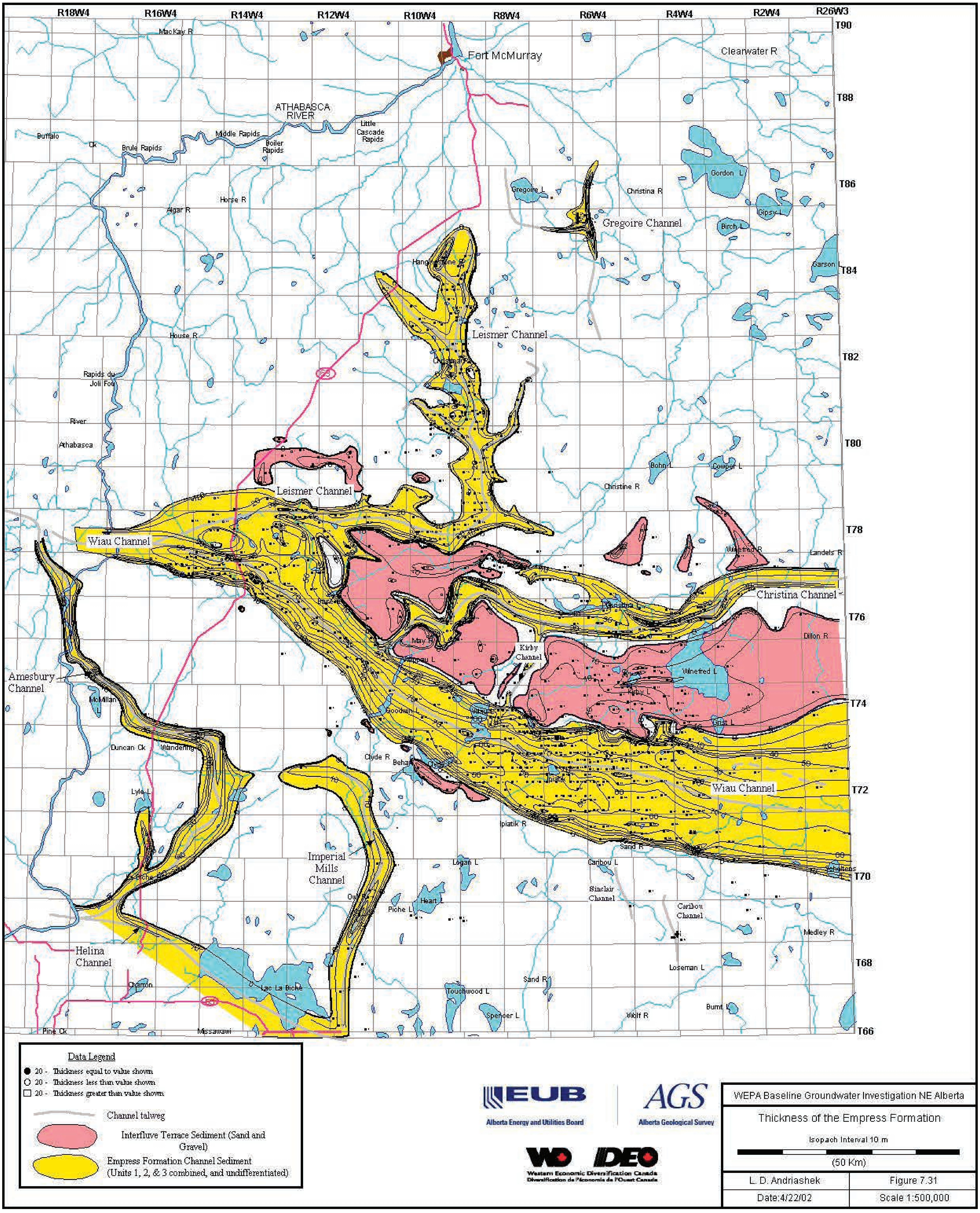
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Data Legend
20 - Thickness equal to value shown
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Channel talweg
Interfluve Terrace Sediment (Sand and Gravel)
Empress Formation Channel Sediment (Units 1, 2, & 3 combined, and undifferentiated)
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey
WD
DEO
Western Economic Diversification Canada
Diversification de l'économie de l'Ouest Canada
WEPA Baseline Groundwater Investigation NE Alberta
Thickness of the Empress Formation
Isopach Interval 10 m
(50 Km)
L. D. Andriashek
Figure 7.31
Date:4/22/02
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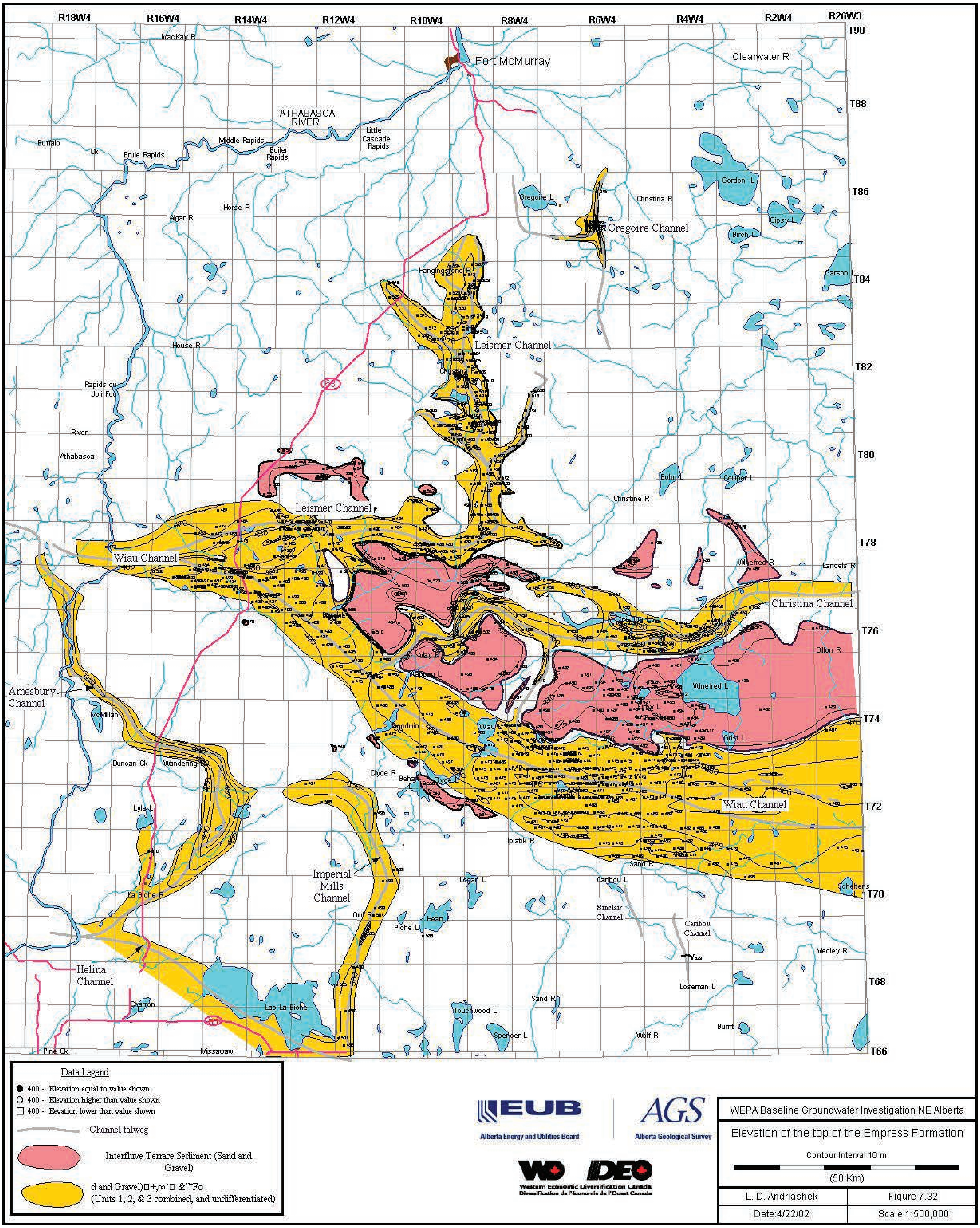
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Fort McMurray
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Channel talweg
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(Units 1, 2, & 3 combined, and undifferentiated)
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WEPA Baseline Groundwater Investigation NE Alberta
Elevation of the top of the Empress Formation
Contour Interval 10 m
(50 Km)
L. D. Andriashek
Figure 7.32
Date:4/22/02
Scale 1:500,000

7.5.2 Quaternary Stratigraphy

The interpretation of the Quaternary strata that lie above the Empress Formation in the study area is currently at a resolution that only permits depiction of the results in cross-section form. That is to say, there are insufficient interpreted data that enable mapping of the subsurface distribution, thickness, and topography of the tops of the units at this time.

At least five glacial diamicton (till) units, and associated intertill stratified units, can be differentiated and tentatively correlated within the study area, based on the interpretation of the petrophysical logs, in conjunction with calibration by lithological and petrological information from the seven AGS core holes. A brief discussion of each follows.

7.5.2.1 Bronson Formation

The Bronson Formation is the lowermost diamicton (till) in the Quaternary succession (Table 7.2). The till, is preserved primarily in the Wiau bedrock lowlands where it directly overlies Empress Formation sediments. The Bronson till is characterized by the following:

- It has the most clayey composition of all of the till units, approaching the same value as shale on the resistivity logs (see cross-section A-A', Figure 6.5)
- The high clay content can be attributed to enrichment with shale in the form of pebble-sized clasts in the till matrix.
- The till matrix has a low carbonate content.

The Bronson till likely represents sediment deposited by the first glaciation in the region, although it is possible that the clay-rich till simply represents a basal clay-rich facies of a stratigraphically higher till. Weathered horizons have not been recorded on the surface of the till (although an oxidized profile is recorded in the middle of the unit at core hole WEPA00-2), but the occurrence of thick, fluvial sediment of the Muriel Lake Formation on some areas of the till suggests a non-glacial period of fluvial deposition. In either case, the distinctive sharp contact at the top of the clay-rich till makes it a prominent, mappable unit in stratigraphic correlations in the region, and for this reason it useful to consider it as a separate till unit. Further work on the till geochemistry may provide additional criteria that enable the Bronson till to be differentiated from other till units.

The Bronson till is currently mapped within the Wiau and Christina channels in the Wiau Lowlands, and in the Leismer Channel in the Hangingstone Plains. Within the Leismer Channel, the Bronson till appears to be relatively thin (~10 m) possibly because it has been eroded by glacial meltwater that later deposited the relatively thick sand and gravel of the Muriel Lake Formation on the till surface (see cross-section E-E', Figure 6.9).

7.5.2.2 Muriel Lake Formation

The Muriel Lake Formation consists dominantly of sand and gravel, with lesser amounts of silt and clay, of glaciofluvial origin (Table 7.2). The formation is currently interpreted to be extensive and continuous along the eastern segment of the Wiau Channel (cross-section D-D', Figure 6.8) and along the Leismer Channel (cross-section E-E' Figure 6.9), though this interpretation may be revised in future stratigraphic studies. There is a strong possibility that locally within both of these channels, the Bronson till is eroded and Muriel Lake sediments directly overlie Empress stratified sediments. This stratigraphic superposition would account for some of the anomalously thick deposits that are mapped as the Empress Formation, as alluded to in the previous discussion of the Empress Formation.

7.5.2.3 Bonnyville Formation

The Bonnyville Formation consists of three lithologically distinct units; a lower clayey diamicton (till), referred to as Unit 1; a stratified middle unit composed of sand and gravel; and, an upper, sandier diamicton unit, referred to as Unit 2. Collectively, till of both units is characterized by a very low carbonate content in the silt-clay fraction of the till matrix (Figure 7.10). Individually, the two units are characterized by the following:

- Unit 1 is more clayey than unit 2, which is expressed by a lower resistivity on the petrophysical logs
- Glaciofluvial sand and gravel commonly, though not always, separate the upper unit from the lower unit. The sand and gravel is thick (~10-15 m) and laterally extensive along the eastern segment of the Wiau Channel (Figure 6.8), and along the western segment of the Leismer Channel where it merges with the Wiau Channel (cross-section E-E', Figure 6.9).
- A buried oxidized profile is present on the surface of Unit 2 from place to place, which has not been recognized on the surface of unit 1. The occurrence of this oxidized horizon is presented as evidence that the surface of the till was exposed to subaerial weathering for a substantial period of time, and that it therefore represents a major interglacial time interval.
- There is a relative abundance of sand beds within Unit 2, which, though not correlative at a regional scale, occur widespread throughout the study area.

Andriashek and Fenton (1989) have conceptually treated both till units of the Bonnyville Formation in the Cold Lake region to be textural facies of glacial sediment deposited by a single glacial event. However, the presence of thick and relatively extensive sand and gravel between the two till units in the study area suggests that deposition of till occurred as a result of two glacial episodes, in between which time glaciofluvial sediment was deposited. What is unknown is the time difference between these glacial episodes – do the units simply reflect pulses in the advance of a single glacier, or do they represent two separate glacial events?

Unit 2 of the Bonnyville Formation represents the first of the drift units in which the deposition was not confined, or constrained, by the basin-effects of the Wiau Lowlands. That is to say, the units below the base of Unit 2 of the Bonnyville Formation progressively infilled the regional basin-like physiography of the Wiau Lowlands, such that the deposition of Unit 2 till was no longer confined to the lowland valley.

The elevation of the top of the Bonnyville Formation approximates the depth at which surface casing is installed in many of the oil and gas wells, consequently, the upper part of the formation is not as well recorded in the bore hole data as the lower stratigraphic units. However, where data are available, they show that the cumulative sum of units 1 and 2 of the Bonnyville Formation constitute the thickest of all of the drift units, exceeding 120 m above the Leismer Channel in the Stony Mountain and Mostoos uplands, for example (see cross-section B-B', Figure 6.6).

Mapping of the stratigraphic succession above the top of the Bonnyville Formation becomes highly speculative because of the paucity of data. It is for this reason that a series of question marks appear on the upper stratigraphic units depicted in the geological cross-sections.

7.5.2.4 Ethel Lake Formation

The Ethel Lake Formation consists of all stratified sediments, including clay, silt, sand and gravel that lie on the surface of Bonnyville Unit 2 till. The petrophysical data density at this level of the stratigraphic succession is poor, consequently little is known about the characteristics and distribution of this formation. The formation is interpreted to be deposited by glacial meltwater, either in proglacial lakes, or in glacial meltwater channels (Andriashek and Fenton, 1989). Thus, there is potential for this unit to be widespread, if not continuous, on the surface of the Bonnyville till. If the thick occurrence of the Ethel Lake Formation encountered at core hole WEPA00-2 can be considered representative of the formation in that area, then the Ethel Lake Formation may constitute a significant intertill aquifer above the Christina Channel (see cross-section A-A', Figure 6.5). Further stratigraphic interpretations of the drift may permit the subsurface mapping of this formation in that area.

7.5.2.5 Marie Creek Formation

The Marie Creek Formation consists primarily of glacial diamicton (till) characterized by a relative abundance of carbonates, primarily dolomite and dolostone, in the coarse-sand and silt-clay fractions of the till matrix (Figure 7.10). In addition, it has the following attributes:

- A buried oxidized profile is present on the till surface, as shown in Figure7.6. This is evidence that the surface of the till was exposed to subaerial weathering for a substantial period of time, and that it therefore represents a major interglacial time interval. Andriashek and Fenton (1989) interpret this weathering to have occurred during the mid-Wisconsin, making the Marie Creek till of Early Wisconsin age (Table 7.2).
- The till is generally less clayey than the overlying Grand Centre till; at least at core hole WEPA99-1.
- Outcrops of the till along Highway 881 at the Christina River crossing near the community of Conklin show numerous interbeds of sand within the till.

The relative abundance of carbonates in the silt-clay fraction, combined with the oxidized weathered surface (where preserved), makes the Marie Creek till the most easily differentiated till within the Quaternary succession in eastern Alberta, particularly where it is nested between the uppermost low carbonate Grand Centre till, and the low carbonate of the lower Bonnyville till.

The Marie Creek till is interpreted to be a pre-Late Wisconsin aged till, and therefore is expected to be covered by Late Wisconsin-aged till of the Grand Centre Formation. Surprisingly, however, the Marie Creek till appears to lie at, or very near to, the present-day surface in the southeast part of the study area (Figure 6.5 and 6.6), as determined by the carbonate analyses data from core holes WEPA00-1, WEPA00-2, and WEPA00-3. This contrasts with the data from core hole WEPA99-1 to the west, which shows at least 40 m of Grand Centre till overlying the Marie Creek till at that site. The apparent absence of the uppermost Grand Centre till in the southeast is at odds with the geomorphic evidence in that area. Ice-flow patterns on the present-day surface (Figure 5.2) are identical to those on the surface of Grand Centre till south of the study area in the Cold Lake region, indicating that the last glacier (which deposited the Grand Centre till) crossed the study area before entering the Cold Lake area. If so, then little, or no, Grand Centre-type till was deposited by the last glacier that flowed over the southeast part of the study area. This is a stratigraphic issue that will require the evaluation of more high-quality data from additional core holes before it can be resolved.

7.5.2.6 Sand River Formation

The Sand River Formation consists of all stratified sediment that was deposited by glacial meltwater on the surface of the Marie Creek till (Andriashek and Fenton, 1989). Based on the current level of interpretation, there are very few examples of the occurrence of the Sand River Formation in the study area. It is anticipated that future work will show that the formation has limited extent, but where present, may consist of relatively thick stratified sediment deposited in a buried glacial channel setting. Consequently, at a local scale the formation has the potential to be a significant drift aquifer.

7.5.2.7 Grand Centre Formation

The Grand Centre Formation consists primarily of diamicton (till) deposited by the last glaciation in the area during the Late Wisconsin (Andriashek and Fenton, 1989). In this regard, the till outcrops on present land surface and theoretically is represented by the morainal materials, landforms and features that are depicted on the terrain analysis map (Figure 5.2). However, as discussed previously, there remains uncertainty regarding the occurrence and distribution of the Grand Centre till in the study area. The till is widespread in the Cold Lake region to the south, but, on the basis of carbonate values, appears to be either very thin or absent in the south eastern part of this study area. Furthermore, mapping of this till is made difficult by the absence of abundant petrophysical log data in this stratigraphic unit. Consequently there is a high degree of uncertainty at this time regarding the distribution and thickness of the uppermost Grand Centre till, and the occurrence of the till as depicted in Figures 6.5 to 6.9 should be treated as conceptual only.

7.6 Implications to Hydrostratigraphic Interpretations: Layer-Cake Versus Labyrinth Architecture

The discussion to this point has only focussed on the rock framework and architecture of the 300 m or more of drift sediments in the study area- in other words, the stratigraphy. We have not yet addressed the issue of the water contained within these strata. However, in terms of baseline groundwater assessments, these units must be evaluated in terms of their capacity to either transmit economical supplies of water (aquifer) or retard the movement of groundwater (aquitard). In other words, the Quaternary sedimentary units must now be assessed in term of their hydraulic properties, and discussed in terms of hydrostratigraphic units operating on an engineering time scale.

The ‘glacial flooding’ model, in which till sheets represent major depositional events, provides the framework for the classification and correlation of coarse, permeable strata that occur in the drift succession. Local sand and gravel units which occur as inclusions within an individual till unit can now be differentiated from proglacial or interstadial fluvial deposits that were deposited on the surface of major till units, and which are more likely to have limited extent and continuity.

Thick Quaternary successions have conceptually been treated as layer-cake, with coarse, permeable units (aquifers) sandwiched between tills of low hydraulic permeability (aquitards) (Figure 7.33). However, glacial environments are not characterized by the gradual and predictive erosional and sedimentary facies typified by a marine environment, for example. Rather, glaciers are conducive to sudden and catastrophic releases of meltwater, resulting in the localized deep scour of the underlying sediments, and the subsequent in-fill with coarse fluvial sediment, or in some cases, till. Given the multiple till stratigraphy and thick drift in the study area, the opportunity for multiple glacial meltwater scour and channel in-fill sequences to be present in the stratigraphic record is high. Channelization and in-fill can occur over lateral distances of a kilometre or less, making the prediction and mapping a difficult task. Further, underlying topographic lows during time of meltwater release can focus the discharge path so that multiple stacked flood sequences may occur over buried bedrock channels, for example (Figure 7.34). The cumulative effect of this is that hydraulic pathways and connections can conceivably extend from near surface to the bedrock, greatly increasing the potential for surface water – channel aquifer interaction. Increases in groundwater withdrawal, or changes in surface recharge may therefore be affected over much shorter time frames as a result of aquifer interconnection.

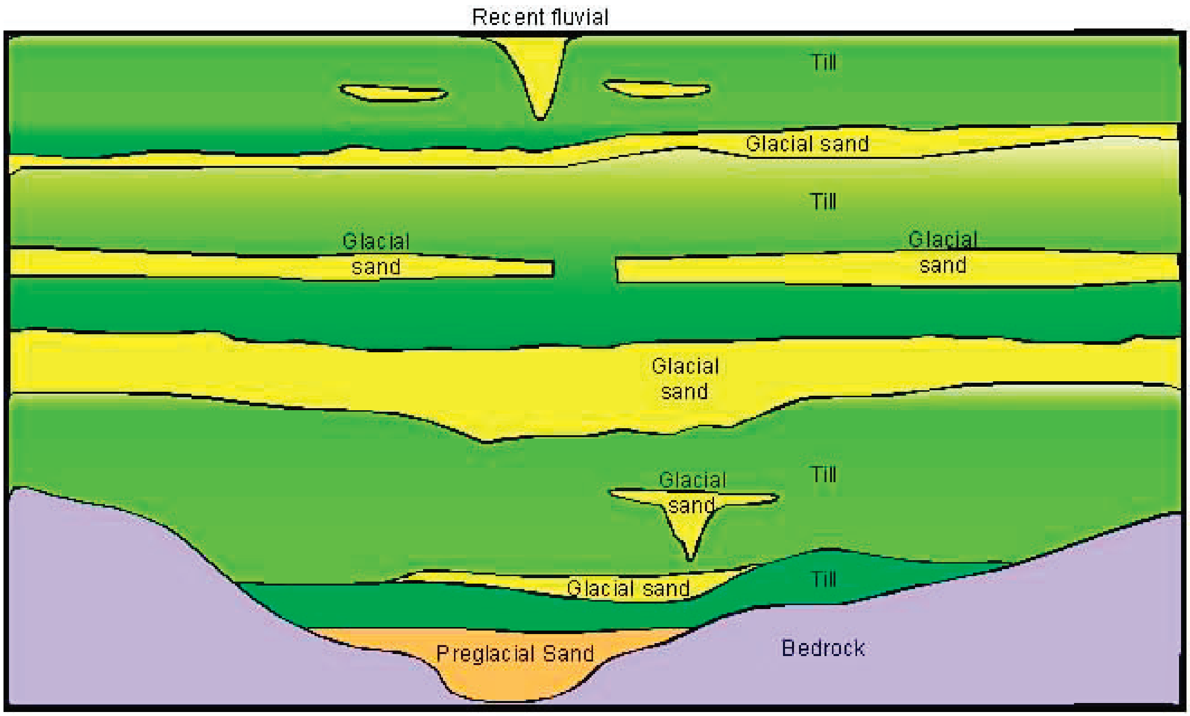

Figure 7.33. Layer-cake hydrostratigraphic model. Coarse, permeable aquifer units (sand) are sandwiched between aquitards (bedrock, till) and are hydraulically isolated.

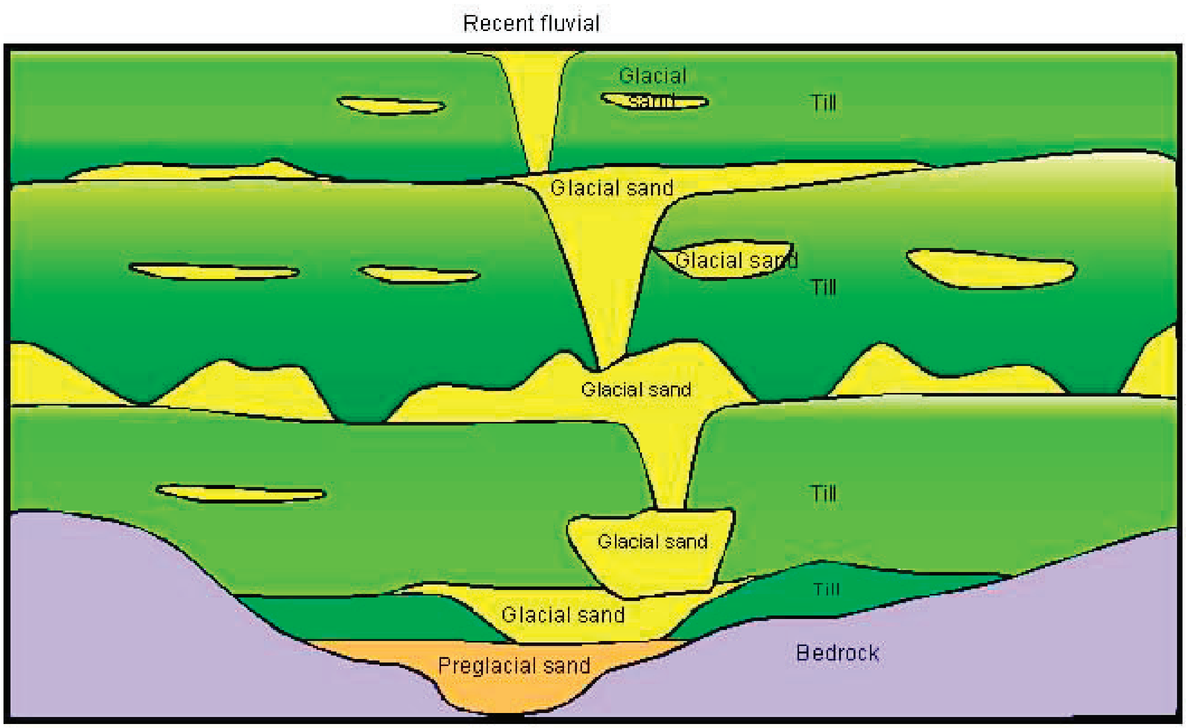

Figure 7.34. Labryinth, stair-step hydrostratigraphic model. Coarse, permeable units are hydraulically connected as a result of downcutting through aquitards and superposition of younger glaciofluvial deposits

Weber and van Geuns, 1990, proposed a threefold division of clastic reservoir types and conceptual approaches to their characterization for flow modeling. In their scheme, reservoirs vary from straightforward layer-cake models to labyrinths to jigsaw-puzzle types. With progressive complication of stratigraphic architecture, the data needs for adequate characterization for exploration or production forecasting grow exponentially. Recognition of the labyrinth to jigsaw puzzle type architecture of the Quaternary succession will lead the hydrogeologist to the most appropriate characterization "toolkit" for groundwater exploration and management.

7.7 Implications of Buried Channels to In Situ Oilsands Development

Thick, coarse infills of glacial channels can be reservoirs of high-quality groundwater needed for steam injection at a local SAGD scale, and the presence of a major glacial channel aquifer on an operator's lease can improve economic viability of that operation. However, there are some aspects of glacial channels that can hinder or limit oilsands development, including the following:

- glacial channels can be difficult to locate - thick drift cover can mask them, and their narrow width and abrupt truncations may lie between the exploration-borehole spacing, requiring other methods to locate, such as high-resolution seismic surveys;
- the catastrophic erosional and depositional environment associated with the formation of glacial channels increases the likelihood that sediments contained within are varied in their composition and subsurface distribution (e.g., glacially displaced bedrock, high-wall slump blocks). Deposits may exhibit a wide range in hydraulic conductivity values;
- gravelly, boulder horizons in glacial channels pose drilling problems in the form of loss of circulation and drill fluid, impeded drilling rates and equipment damage;
- glacial channel aquifers may have limited recharge areas and would be capable of supplying only a few operators in the area hence, water licensing and use-restrictions become a regulatory issue;
- in areas of shallow drift and bedrock overburden, glacial channels may erode deep enough to intersect oil sand horizons, resulting in:
  - loss of oilsand payzone
  - erosion of capping shales above SAGD steam chambers
  - direct hydraulic link with near-surface water bodies
- increased potential for hydrocarbon migration into potable aquifers (Figure 35).

Preglacial channel settings may be considered more favourable because:

- preglacial channel floors are covered by thick, extensive and permeable fluvial sediment making them large regional aquifers capable of supplying major amounts of groundwater to multiple users;
- preglacial channels function as basins for the deposition of multiple tills and numerous intertill glaciofluvial deposits, the latter of which can also form regional aquifers.

However, there are associated risks or issues associated with preglacial channels as well, such as:

- complexity in hydrogeological interpretations and modeling of buried preglacial channel successions resulting from:
  - stratigraphic superposition of younger glacial aquifers on top of deeper aquifers, leading to increased vertical permeability and hydraulic communication,
  - glaciotectonic deformation or displacement of aquifer and aquitard units during successive glacial events;

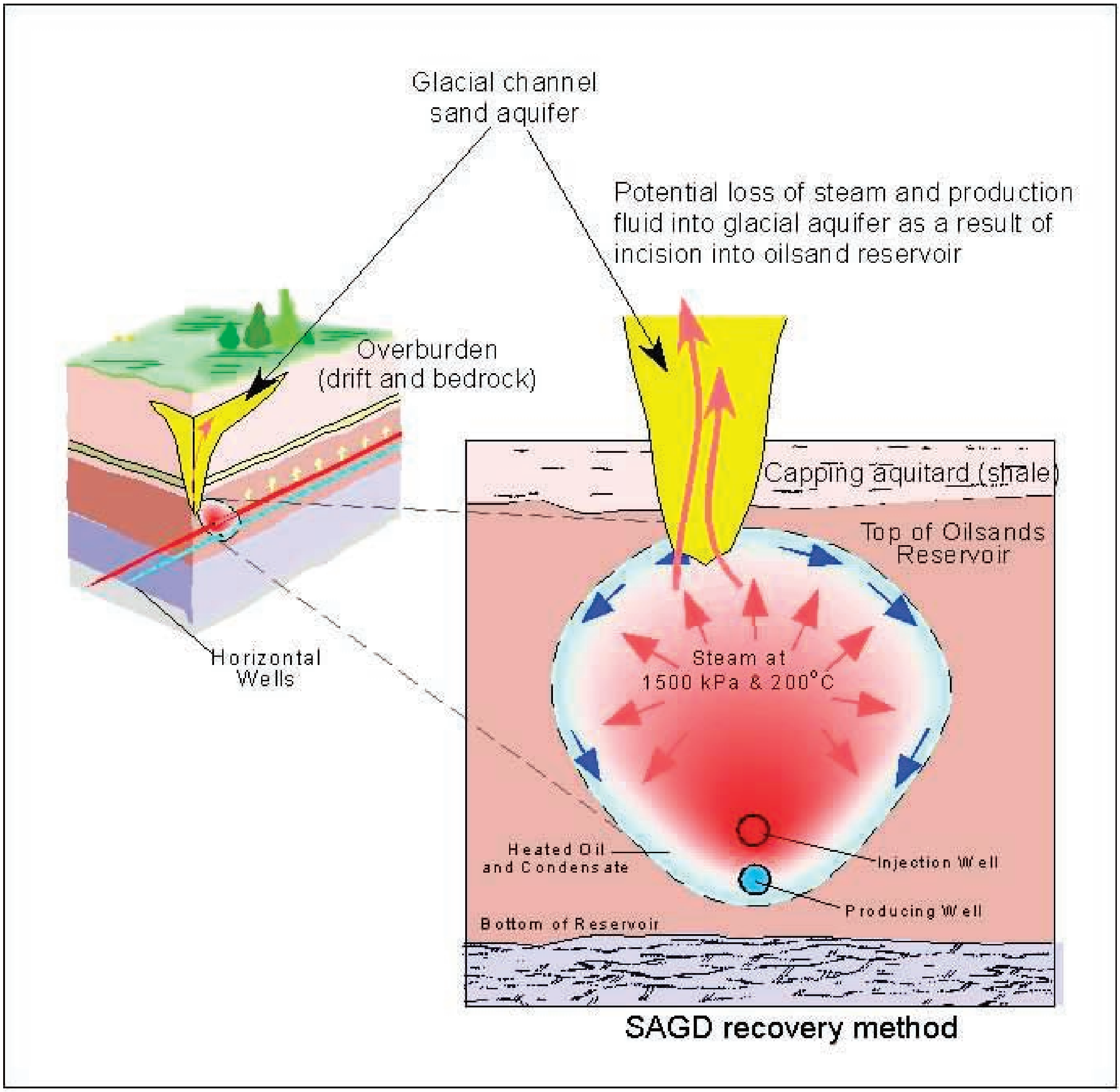

Figure 7.35. Cartoon diagram of glacial channel incision through thin overburden above SAGD operation.

- water-use conflicts arising from competing needs by domestic users, agriculture, municipalities, and various industries;
- increased drilling costs/risks due to:
  - deeper surface casing depth requirements than in shallower glacial channels (>300 m in some cases);
  - loss of drill fluid and circulation in coarse permeable zones;
  - damage and/or delays due to boulder horizons;
  - potential to encounter migrated natural gas – this can have both negative or positive economical aspects, depending on the value and costs associated with extracting the gas, as in the example of the Sousa area of northwestern Alberta (Canadian Discovery Digest, 2001).

7.8 References

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8 Baseline Investigations of Groundwater Resources, Quaternary Succession, Athabasca Oil Sands (In Situ) Area

8.1 Introduction

Aquifers in the Quaternary sediments of the Athabasca Oil Sands (In Situ) Area can be grouped into six distinct geological settings:

- Buried channels
- Buried-channel interfluves
- Aquifers on buried bedrock plains
- Buried surficial complexes
- Glacial channels
- Surficial deposits on the modern land surface.

The first three settings are controlled by bedrock physiography. The latter three are influenced, but not controlled, by bedrock physiography. The last setting in the list, the modern land surface, is still being modified by modern geological processes. In the manner of facies models (Walker, 1992), the settings provide the hydrogeologist with a norm for comparison, a guide for prediction, a predictor for exploration, and a basis for interpretation of aquifer properties and geometry. These apply both to the exploration and to the development of groundwater resources.

Baseline hydraulic and geochemical information collected during this project show that regional groundwater flow in the Quaternary of the Athabasca Oil Sands (in situ) Area is driven by gravity and controlled by topography. The actual pathways of flow cannot be determined because of the internal complexity of the Quaternary succession. However, the geochemical and isotopic character of baseline groundwater samples collected during this project provides information on the geochemical evolution of the groundwater. From these results we can make inferences about the nature of internal flow paths and geochemical processes affecting groundwater within the Quaternary succession.

8.2 Installation of AGS Piezometers

Three nests of piezometers (i.e., monitoring wells) were constructed by AGS during the project. Their locations are in Figure 8.1. The nests consist of two piezometers at WR99-1, three piezometers at WEPA00-3, and four piezometers at WEPA00-1. One piezometer in each nest was completed as a water-table piezometer, as discussed in Chapter 4. Completion details of each piezometer in the nests are found in Appendix 5. The nests were installed at the same locations as the stratigraphic core-holes discussed in Chapter 7. The nests were co-located with the test holes to ensure that hydraulic information could be correlated to the geological setting.

The piezometers allow for direct measurement of static water levels and calculation of apparent vertical hydraulic head gradients at each locality. They also permit high-quality groundwater samples to be taken. The groundwater samples are considered to be of high quality because AGS had full control over drilling and construction techniques, and the materials used to complete each piezometer. And because these are not water-supply wells, decontaminated or dedicated sampling equipment could be employed to obtain water samples rather than relying on installed downhole pumps.

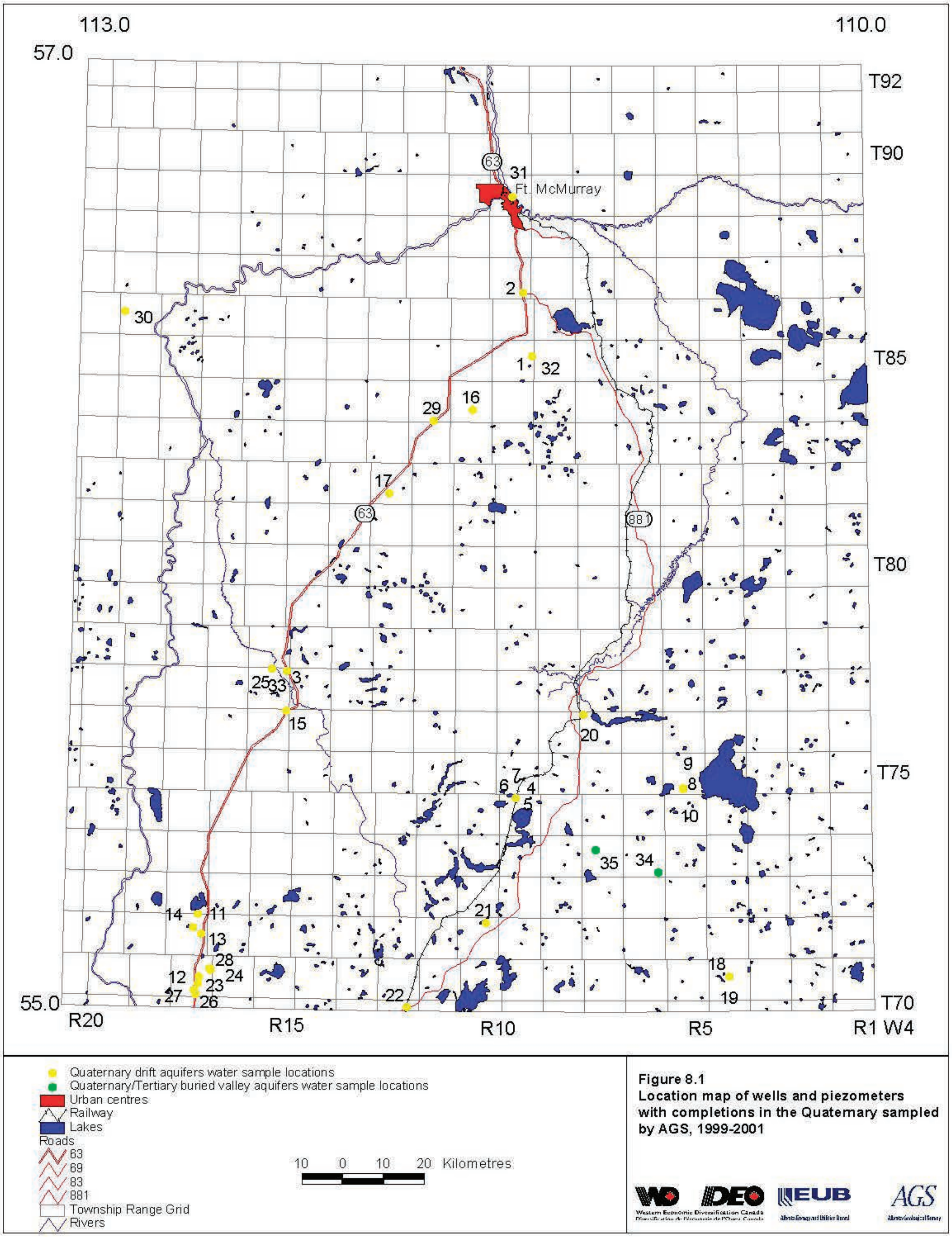

Figure 8.1
Location map of wells and piezometers with completions in the Quaternary sampled by AGS, 1999-2001

8.3 Investigation of Regional Hydraulic Heads and Gradients

As discussed in Chapter 2, hydraulic head gradients drive groundwater flow. Hydraulic head variations in three dimensions can be captured in slice maps of hydraulic head (also called potentiometric or piezometric maps) and on hydraulic head cross-sections. Groundwater flow directions can be inferred from hydraulic head maps as being the set of orthogonal trajectories to the set of iso-head contours drawn on the map. Such interpreted regional flow directions are reasonably reliable provided that there are not significant regional variations in groundwater density or a strong degree of anisotropy in the hydraulic properties of the rock fabric.

Hydraulic heads are determined by measuring the elevation of static or non-pumping water levels in piezometers or water-supply wells. Hydraulic heads can be determined from pressure measurements in deep wells through use of Equation 2.1. Care must be taken not to use water-levels or pressures affected by pumping or injection. Residual drawdown effects will depress hydraulic head values and may confound the determination of natural flow directions from hydraulic head maps.

A generalized regional hydraulic head map for the study area is shown in Figure 8.2. This map was constructed using a combination of measured static water-levels in AGS piezometers and static-water levels reported on water-well driller's reports on file with Alberta Environment. Where the wells had been visited by AGS for sampling, a location and elevation of the well was determined by a hand-held GPS. AGS piezometers were accurately surveyed using a GPS base-station. The locations and elevations of other wells with recorded static-water levels were estimated from topographic maps.

The regional hydraulic head map shows that the head distribution in the uppermost 50 m of the subsurface generally conforms to topography, with radial flow away from surface highlands and convergent flow towards major rivers. There are two centres of radial divergent flow in the area. One area corresponds to the Stony Mountain Upland and one corresponds to the Mostoos Uplands-May Hills ridge. There are several saddle points where regional flow appears to converge from the uplands and then diverge towards different river courses. Lateral hydraulic gradients range in magnitude from 0.003 to 0.087.

The main purpose of this regional map is to identify regional flow-system elements such as recharge and discharge areas. A second purpose is to help the hydrogeologist interpret lengths of regional-scale flow paths so as to provide spatial context needed to interpret groundwater geochemistry data. Local systems are expected to be superimposed on these regional hydraulic trends, so Figure 8.2 cannot be used to predict local groundwater flow in any meaningful way. Also, this map is not a water-table elevation map and cannot be used to determine or predict depth-to-water-table nor non-pumping water levels in wells, except in a most general fashion.

Vertical hydraulic head gradients provide information about flow in the third dimension. Vertical hydraulic gradients are best determined from close-spaced, or "nested" piezometers, where head differences will be solely due to vertical distances and not caused by lateral gradients. Close-spaced water-wells completed in aquifers at different depths can also be used. Care must be taken when interpreting vertical gradients - under the right conditions, hierarchical flow systems can be present, in which case vertical gradients may not be meaningful because the observed heads will actually be in different flow systems (Toth, 1963).

A pressure-depth plot of all reported, non-artesian static water levels for the study area is shown in Figure 8.3. A hydrostatic pore-pressure gradient is shown for reference. The data show a considerable scatter, reflecting complex flow paths, but the pressures are generally subhydrostatic in magnitude for their depth. As well, the pressures increase with depth along a generally subhydrostatic gradient. This pattern suggests that recharge conditions predominate over much of the area. Springs (see Chapter 4) and

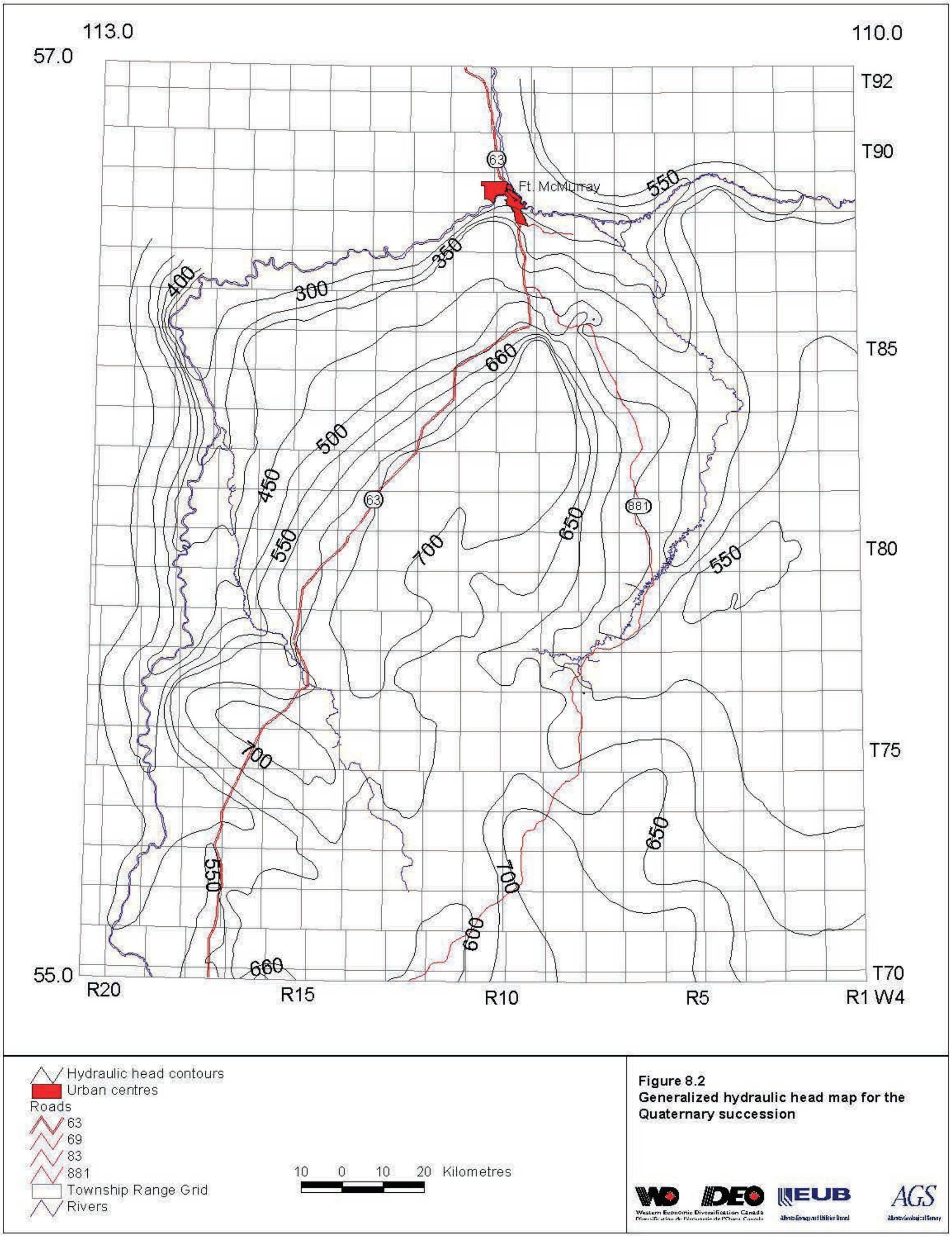

Figure 8.2
Generalized hydraulic head map for the Quaternary succession

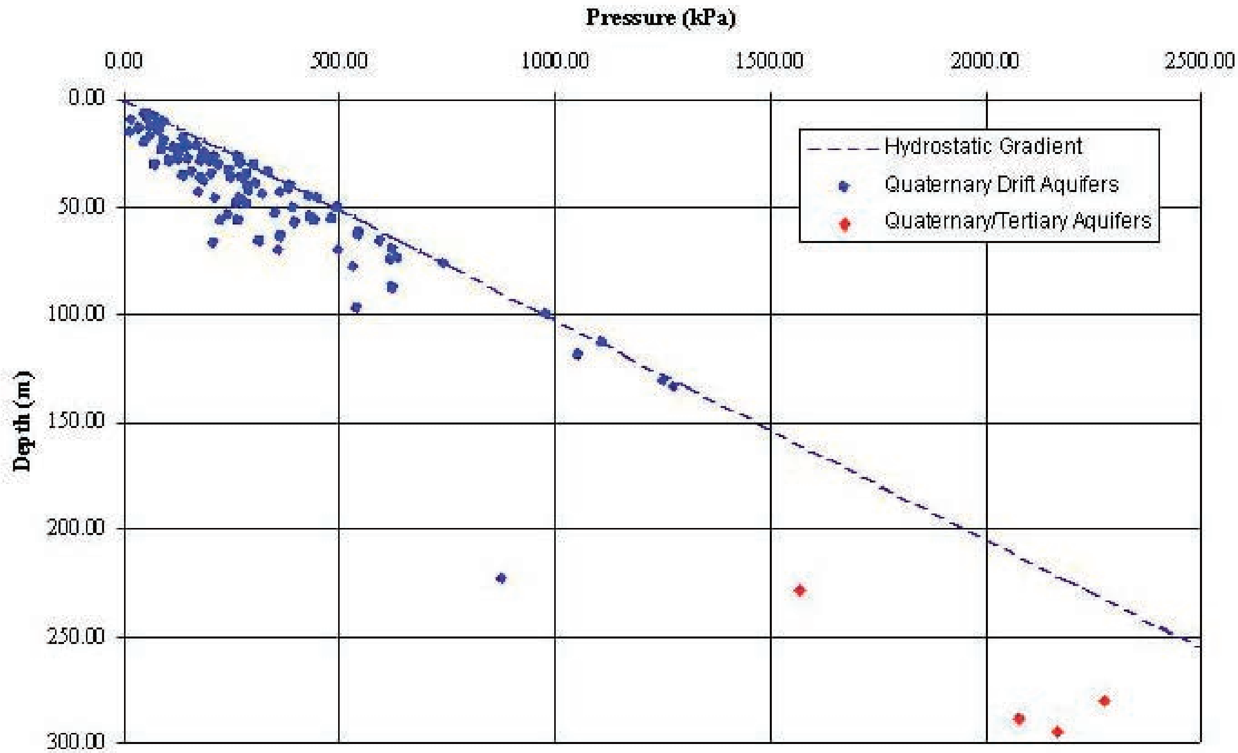

Figure 8.3. Pressure-depth plot of reported static-water levels of wells completed in the Quaternary succession.

occasional records of flowing wells in low-lying areas attest to the existence of regional discharge areas. But since these areas tend to occupy small portions of groundwater basins that are usually unfavourable for settlement, superhydrostatic wells are under-represented in water-supply records.

The static water levels of the AGS piezometers are in Table A5-1 in Appendix 5. Elevations of the static water levels, which equal the hydraulic head, are shown. The apparent vertical gradients, which range from 0.03 to 0.30 are shown as well.

8.4 Geochemical Pathways and Stable Isotope Systematics

Despite the evidence presented in Chapters 5 through 7 that there may be a decipherable stratigraphy of the Quaternary, the degree of geological heterogeneity present relative to available borehole control is great. The high degree of unmappable heterogeneity means that it is essentially impossible to document the flow path of any elementary volume of water through the system, except in the most general fashion accorded by use of hydraulic head maps and cross-sections.

Examination of the geochemical variation of groundwater with position can reveal the type and extent of geochemical processes that acted on an elementary groundwater volume during flow. Disentangling the geochemical evolution of groundwater is commonly known as geochemical pathway analysis. Pathway analysis is strongly aided by examination of various ratios of stable isotopes in groundwater and in its dissolved constituents. Stable isotopes are effective natural tracers of flow and process in natural systems.

In this project, groundwater samples were collected from twenty-one wells completed in the Quaternary succession, including the ten AGS piezometers (see Figure 8.1). The wells were selected based on geographic area, penetration of a horizon of interest, well-completion quality, water-production history, and where available, verification of completion interval using geophysical logs. Field measurements of temperature, pH, conductivity, dissolved oxygen, oxidation-reduction potential and alkalinity were made. The water samples were analyzed for major, minor and trace elements, extractable silica and silicon, chloride, bromide and iodide, $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{11}B$, $\delta^{34}S_{sulphide}$, $\delta^{34}S_{sulphate}$ and $^{87}Sr/^{86}Sr$. Seven blank samples, six duplicate samples, six split samples and one trace metal standard were submitted along with the samples. The protocols used for field determinations, sampling and quality control were developed based on those defined by the Geological Survey of Canada, the United States Geological Survey, the United States Environmental Protection Agency and the universities of Alberta, Calgary and Saskatchewan. The protocols are documented in Appendix 6.

In addition to the twenty-one samples collected as part of this study, historical data was also incorporated into the data set. Data from eleven water samples previously collected from Quaternary drift aquifers were added to the data set (Figure 8.1). The completion history and quality, verification of completion interval and geochemical criteria were used to determine the quality of this additional data. Because the collection protocols are unknown however, this data is considered less reliable than that collected as part of this study.

The chemistry and isotope data from these wells are shown in Table A7-1 and Table A7-6 in Appendix 7. The data were examined in terms of their ranges of variation and for spatial relationships relative to their depth and place in the regional flow system. Preliminary consideration of the hydraulic, geochemical, and isotope data indicates that throughout the study area, the geochemistry of the groundwater can generally be described as the product of rock-water processes acting on infiltrating meteoric water. The original composition of the meteoric water has varied, which probably reflects changing climatic conditions over the Quaternary Period. The infiltrating meteoric water evolves primarily by dissolving minerals in the till (mostly carbonate minerals because of their high solubility) coupled with congruent ion exchange of calcium for sodium on the surfaces of clay minerals in the till. This evolution pathway is indicated by the following observations:

- Oxygen and deuterium isotopic ratios (d18O and d2H, respectively) fall on or near the global meteoric water line (Rozanski et al., 1993), confirming that most groundwater in the Quaternary is likely of meteoric origin (Figure 8.4). Shifts up and down the meteoric water line reflecting variation in the temperature or seasonality of the recharge water (summer rainfall being isotopically enriched while snowmelt and glacial water being isotopically depleted) and shifts above and below the line suggesting variations in humidity of recharge water (e.g., Clark and Fritz, 1997, p. 44-45). The future study of the patterns of these observed shifts will be useful for reconstructing paleoclimates of the area and projecting impacts of future climate change.
- A general increase in total dissolved solids is observed with depth, reflecting dissolution of soluble minerals by infiltrating meteoric water (Figure 8.5).
- An evolution from calcium-bicarbonate type groundwaters in shallow wells towards sodium-calcium bicarbonate type groundwaters in deep Quaternary aquifers. This evolution is evident on the Piper plot in Figure 8.6 and reflects natural water-softening processes controlled by ion exchange on clays (e.g., Macpherson and Townsend, 1998).
- An evolution of the 87Sr/86Sr ratio towards a relatively stable value comparable to Devonian-age rock (e.g., Veizer and Compston, 1974) with depth, consistent with the borehole evidence that some till sheets contain carbonate minerals from up-ice outcrops of Devonian rock (Figure 8.7).

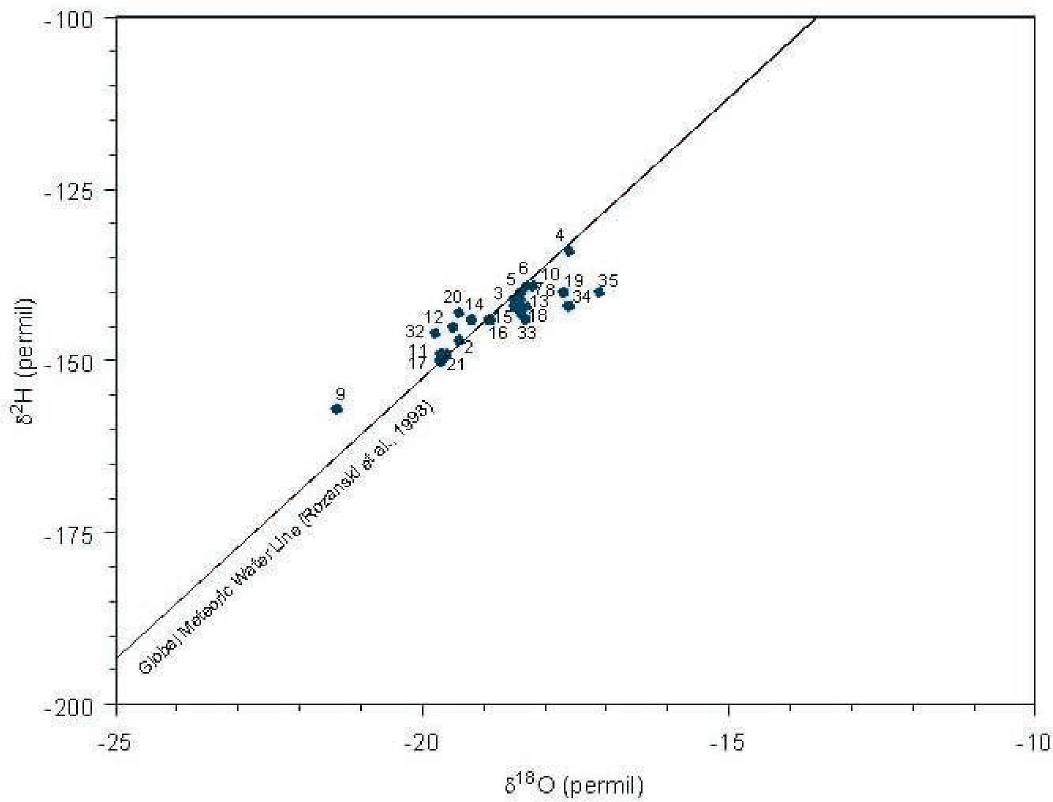

Figure 8.4. Oxygen-deuterium isotope plot for quaternary groundwater samples.

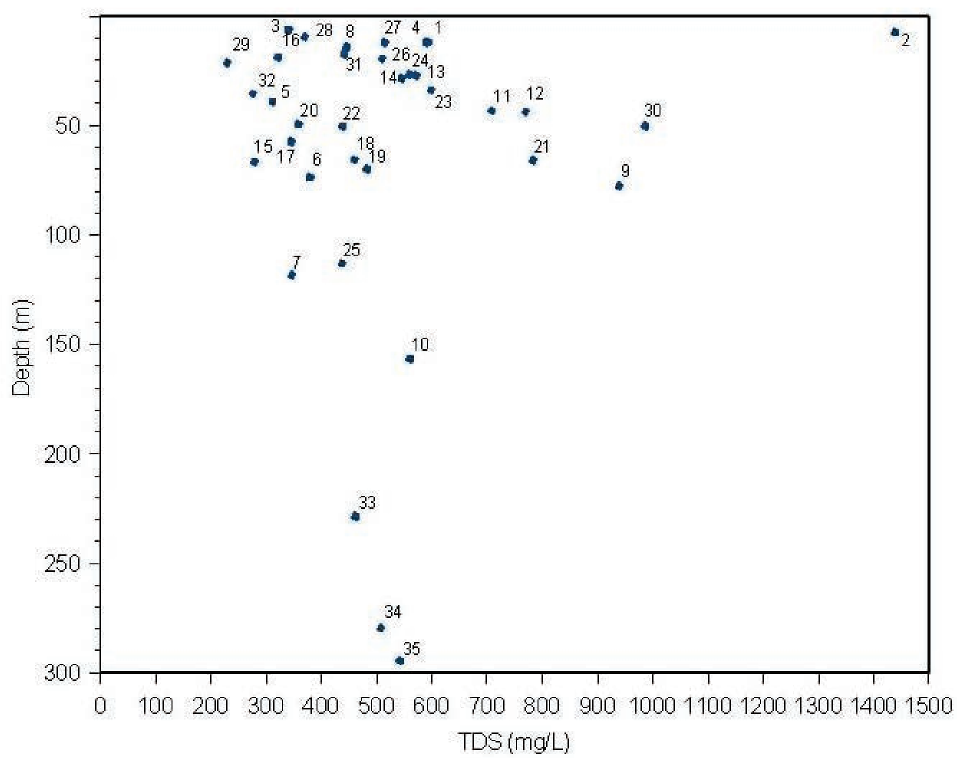

Figure 8.5. Total dissolved solids versus well-completion depth, Quaternary groundwater samples.

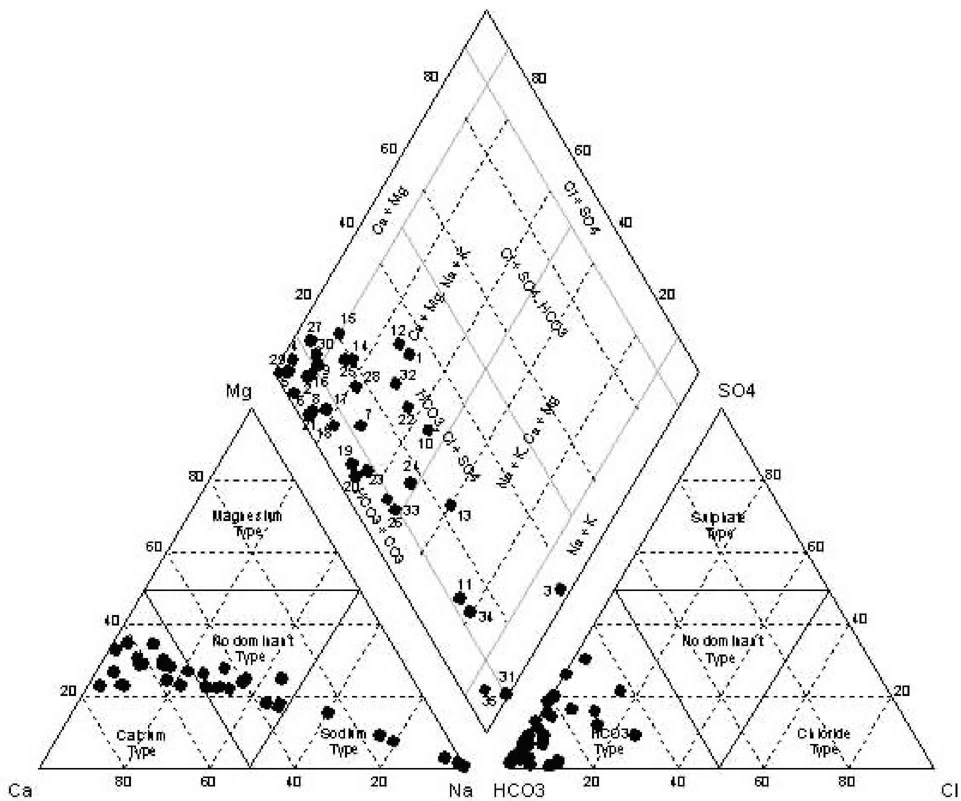

Figure 8.6. Piper plot, Quaternary groundwater samples.

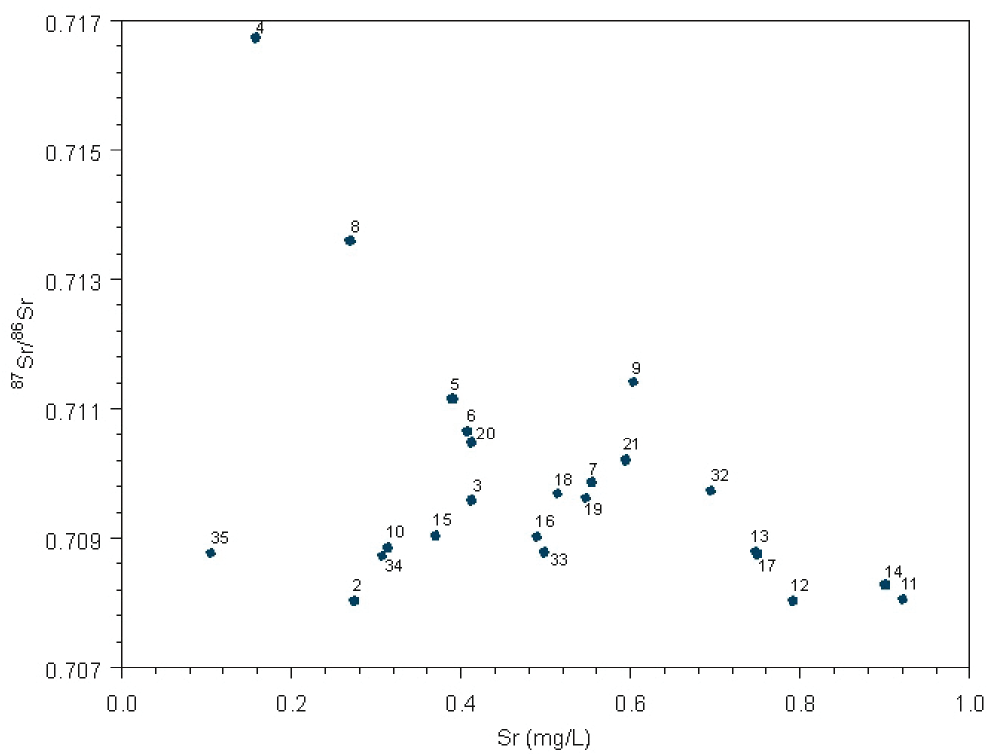

Figure 8.7. Strontium-87/Srontium-86 isotopic ratio versus strontium concentration, Quaternary groundwater samples.

- A progressive enrichment of d13C with increasing depth consistent with models of carbonate dissolution (e.g., Clark and Fritz, 1997) in the absence of bacterially-mediated methanogenesis (Figure 8.8).
- Carbon-14 dates of dissolved inorganic carbon fractions that increase with depth, being 1558 ± 91 years old at piezometer WEPA00-1-41, increasing to an age of 30880 ± 249 years near the top of the bedrock at AGS deep piezometer WEPA00-3-158 (Table A7-11 in Appendix 7). The oldest age is at the edge of reliable dating by this method.

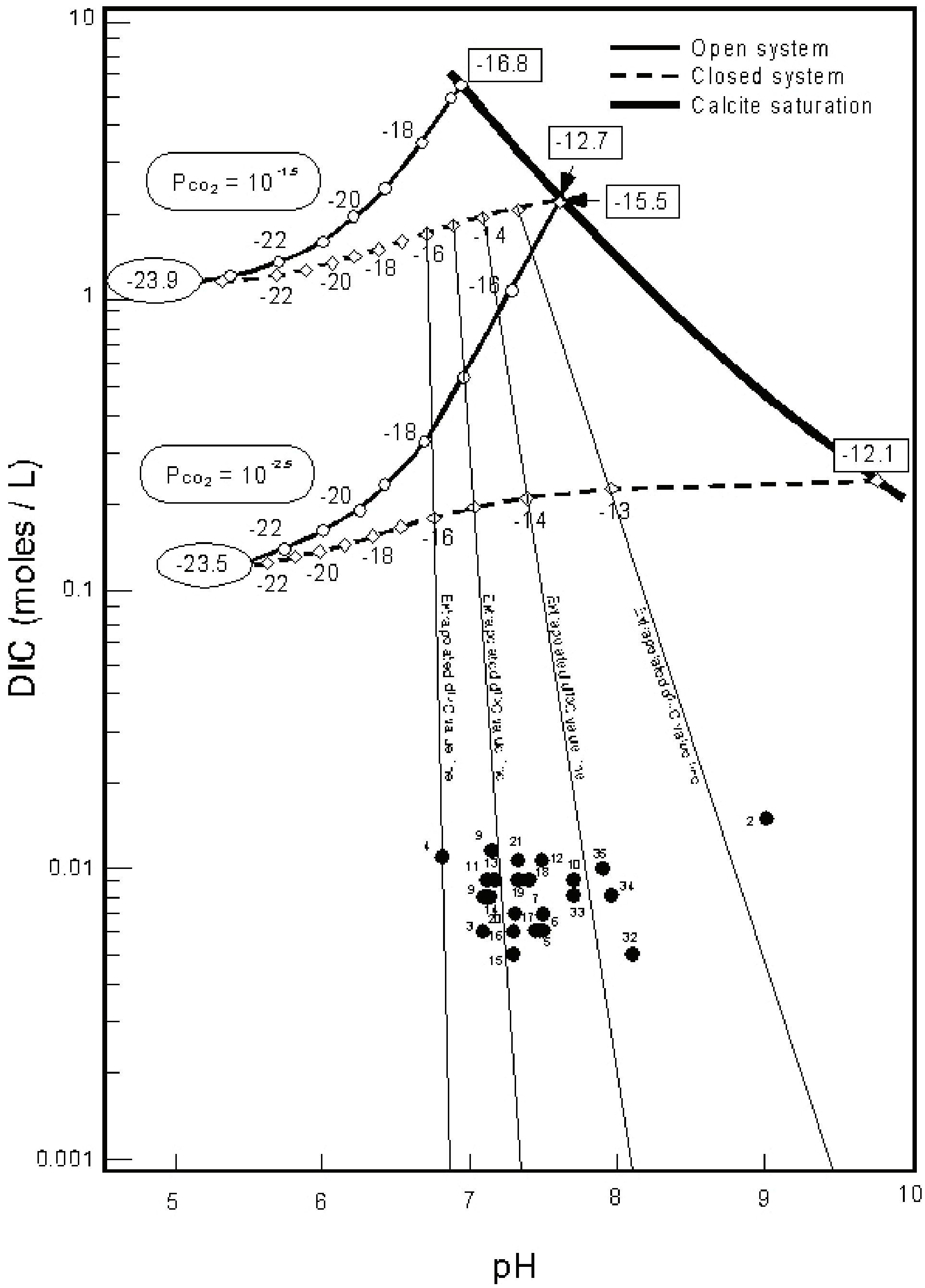

Figure 8.8. Comparison of Carbon -13 isotope ratio values in Quaternary water to carbon isotope evolutionary diagram after Clark and Fritz, 1997.

There are no geochemical or isotopic data to suggest that there is any substantial mixing of connate waters from underlying Cretaceous rocks with the groundwater of the Quaternary. The boron isotopes suggest there is some contribution of water which has interacted with Cretaceous-age rock in some aquifers sitting directly on the top of bedrock, but it has not yet been determined if these signals are significant or, if so, whether they represent mixing by diffusion at the bedrock contact or mixing related to upward discharging Cretaceous waters (Figure 8.9).

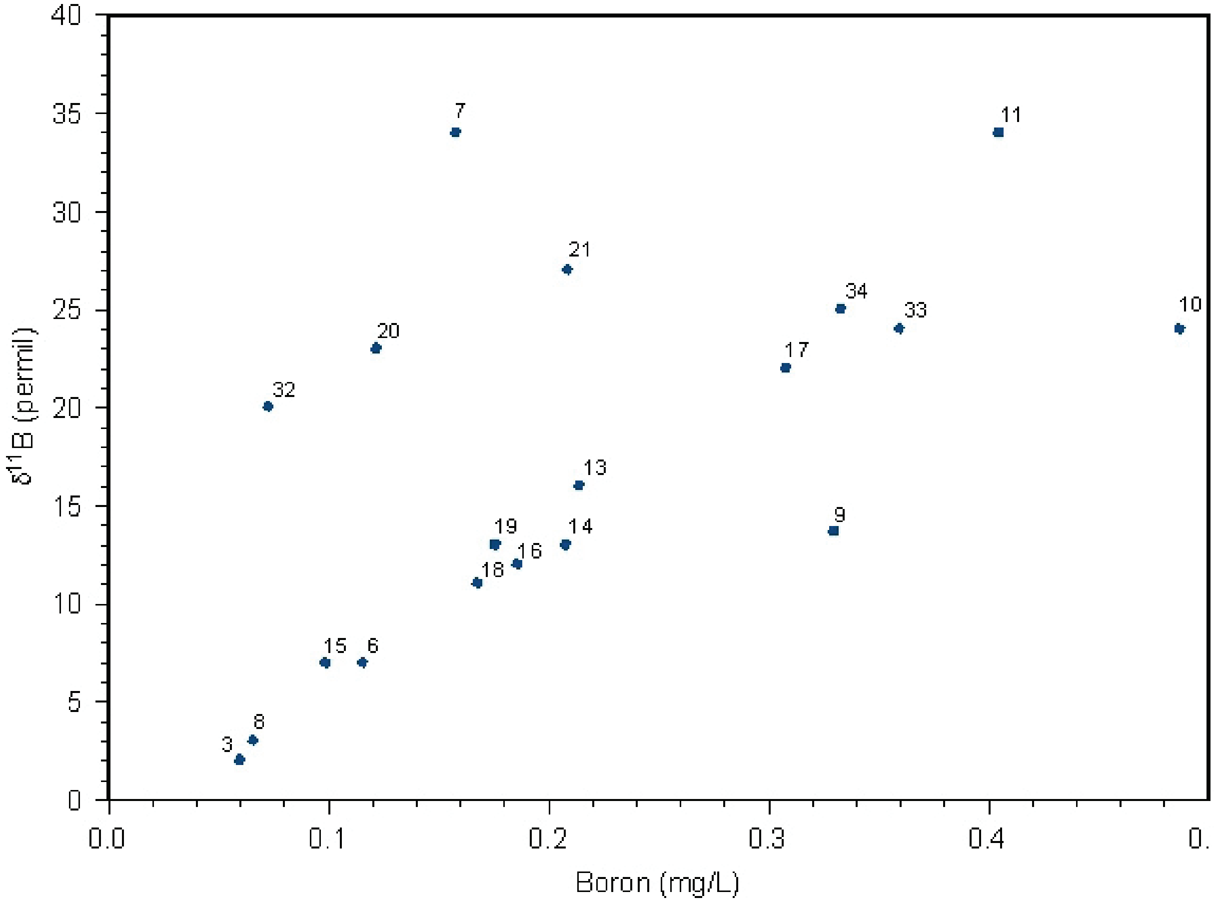

Figure 8.9. Boron-11/Boron-10 isotopic ratios versus boron concentrations, Quaternary groundwater.

In terms of chemical quality with respect to boiler feed (see Chapter 1), water from Quaternary aquifers is generally acceptable, with the exception of being generally too hard and possibly requiring treatment for undesirable levels of iron and extractable silica.

8.5 Groundwater Resource Characterization by Setting

8.5.1 Buried Channels

The coarse sand and gravel deposits of the buried channels lying directly on the top of bedrock comprise the largest confined aquifers in the area. Maps of the thickness of the Empress I and Empress III units in the study area are found in Figure 7.21, 7.25, and 7.27. The continuity of the fine-grained Empress II is not likely to be complete in all areas because of scour or down-cutting at the base of the Empress III. Similar effects are noted in buried channels in the State of Wisconsin by Ritzi et al. (1994). Consequently, the Empress I and Empress III units should be considered to be in direct hydraulic communication unless field data show it to be the opposite at any given locality.

The lateral continuity of the Empress I and III sand and gravel within any one of the buried channels is expected to be continuous. However, the bedrock topography map suggests there may be hydraulically significant breaks at some of the intersections of the major buried channels. There is no hydraulic evidence to support this conclusion at this time but it is inferred based on the differences in elevation of the bottom of the channels at these intersections points. For example, there is about a 60 m difference between the base of the Amesbury and the base of the Wiau buried channels at their intersection (see Figure 6.1). Such elevation differences may lead to thinning of the Empress units or to a complete disruption of sand continuity if the elevation differences are great enough. Future observations of hydraulic head values and responses to pumping will determine the degree of continuity at these points.

Shaver and Pusc (1992) discuss longitudinal and transverse internal boundaries present in buried channel aquifers in glacial settings. They observe that longitudinal bedrock ridges which form between scours on the buried-channel floor and transverse, till-filled, cross-cutting glacial channels can essentially isolate different parts of the buried channel aquifer, even though regional maps show the aquifer sediments to be otherwise continuous. Parks and Bentley (1996) used this conceptual model to help interpret aquifer-test results in the Calgary Buried Channel Aquifer. The buried channels of the study area may be expected to behave in a similar fashion.

Because of the depth to the buried channels, few wells have been completed in the buried channel aquifers. This is expected to change as development proceeds in the area. The hydraulic conductivity of the water wells has been documented in several reports. These values are summarized in Table 8.1. These values, all from aquifer tests, range from about 7×10^{-6} m/s to 7×10^{-4} m/s. The wide range in values is not unexpected and is consistent with the properties of moderately sorted sand. This range of values also strongly suggests that aquifer-specific characterization is necessary to arrive at estimates of long-term well yields in buried channels at any given locality in this area.

8.5.2 Aquifers on Channel Interfluve

These confined aquifers consist of the sand deposits topping the channel interfluves and their terraces discussed in Chapter 6. The interfluves are bounded on all sides by the buried channels themselves. Aerially continuous deposits of coarse-sediments appear to lie on top of these interfluves (see Figure 7.29), which suggests that they may be significant regional aquifers. However, they have not been developed as aquifers by anyone to date. One AGS piezometer, WEPA00-3-158, was completed on the Wiau-Christina Interfluve. A point value of K of 3×10^{-5}m/s was determined by a slug test. The available subsurface control suggests that the interfluve aquifers will be relatively hydraulically isolated from the buried channel aquifers, based on the elevation differences between the bottom of the interfluves and the top of the buried valley aquifers (see Figure 6.1)

8.5.3 Aquifers on Buried Plains

These confined aquifers include the sporadically occurring sand and gravel deposits of varying thickness and continuity that lie directly on top of the buried bedrock plains between buried uplands and buried lowlands in the study area (see Figure 6.3). Except in the settled area around Wandering River, where some water-wells appear to be completed in aquifers resting on the Amesbury Plain, there has been little development of these aquifers.

Table 8.1. Reported values of hydraulic conductivity in buried channel aquifers.

Source	Reported Value and Value Restated as K (m/s)	Comment
Home Christina Pilot TH-3 10-14-76-7W4M Aquifer Test Date: 1983	T = 1664 igpd/ft T = 2.9e-4 K = 7.2 e-4 m/s	Christina Buried Channel Aquifer test interval reported 4 m
AEC Kirby Project ww 12-1 12-1-73-6W4M Aquifer Test Date: not reported	T = 472 m2/d T = 8.1 e-5 m/s K = 9.1 e-6 m/s	Wiau Buried Channel Aquifer test inteval reported 9 m
Rio Alto Kirby Thermal Pilot WSW 11-21, 11-21-73-7W4M Aquifer Test Date: 2/25/00	T = 470 m2/d T = 8.1 e-5 m2/s K = 8.1 e-6 m/s	Wiau Buried Channel Aquifer test inteval reported 10 m
Rio Alto Kirby Thermal Pilot WSW 13-21, 13-21-73-7 W4M Aquifer Test Date: 4/27/01	T = 480 m2/d T = 8.3 e-5 m2/s K = 8.3 e-6 m/s	Wiau Buried Channel Aquifer test interval reported 10 m
PCP Christina Lake WSW 9-17, 9-17-76-6 W4M Aquifer Test Date: 1/98	T = 800 m2/d T= 1.4 e-4 m2/s K = 6.9 e-6 m/s	Christina Buried Channel Aquifer test interval reported 20 m
Petro-Canada Meadow Creek WSW 100, 15-27-84-9 W4M Aquifer Test Date: 03/07/2001	T = 70 m2/d K = 3 m/d K= 3. 5 e-5 m/s	Leismer Buried Channel K reported as a thickness-weighted mean by proponent.
AEC Primrose Pilot PW-1 , NW 5-22-70-4 W4M Aquifer Test Date: 11/7/95	T = 12900 igpd/ft T = 2.2 e-3 m2/s K = 7.3 e-4 m/s	Unmapped aquifer south of the Wiau Buried Channel Aquifer thickness reported 10 ft
AEC Primrose Pilot PW-2 , SE 5-22-70-4 W4M Aquifer Test Date: 11/15/95	T = 24600 igpd/ft T = 4.2e-3 m2/s K = 2.0 e-3 m/s	Unmapped aquifer south of Wiau Buried Channel Aquifer thickness reported 7 ft

8.5.4 Buried Surface Complexes

Episodic processes associated with glacial stagnation and melting leaves a variety of well sorted, stratified coarse-grained glacio-fluvial, glacio-deltaic, and glacio-lacustrine deposits. These deposits can form locally significant but regionally discontinuous confined aquifers. As discussed in Chapter 7 these aquifers are predominantly, but not exclusively, found immediately below basal till log-markers. The surficial geology map of the modern land surface can be used to conceptually model the geometry and continuity of such aquifers. However, the buried surfaces will be more a discontinuous, even censored version of the surficial geology due to glacial erosion associated with deposition of overlying till sheets.

If a buried surface aquifer is reasonably well connected to shallower aquifers by down-cutting glacial channels and fractures, these aquifers may have reasonable quality water and experience some degree of recharge. If they are not so well connected, the contained groundwater will be expected to be relatively more mineralized. Such aquifers will behave hydraulically as bounded bodies and long-term well yields will rely on induced leakance from confining tills.

8.5.5 Glacial channels

Buried glacial channels are described in Chapter 6. They can occur at any stratigraphic level, including the modern land surface, and can downcut to any stratigraphic depth, including into the top of bedrock.

To date, they have not yet been systematically mapped from well control, except in the areas where they scour into the bedrock, like the Gregoire Channel. Glacial channels can be filled by glacio-lacustrine deposits, till, or sand and gravel. If filled or floored by sand, glacial channels may contain reasonably productive aquifers. One AGS piezometer, WR99-1-230, was screened in a buried glacial channel that downcut into the Empress Formation in the Wiau Buried Channel. A point value of $K = 3.4 \times 10^{-5}$ m/s in this aquifer was determined by a slug test.

If sand-filled stacked glacial channels exist, they may also provide high-permeability vertical conduits from surface to deeply buried aquifers. An occurrence of this circumstance is believed to have been noted at the ARC Test Hole in LSD14 Sec 31, Tp 76 Rg 7 W4M, on the west end of Christina Lake. Sand was logged in this hole from surface to the base of the Christina buried channel, with no reports of intervening till sheets.

Because so little is known about the distribution of these aquifers in the Athabasca Oil Sands (In Situ) Area and because of their potential to be good aquifers and/or provide vertical conduits through till sheets if stacked, it would be a worthwhile exercise to continue calibrating existing borehole logs to glacial channel properties in an effort to map them and perhaps generate a predictive exploration model.

8.5.6 Aquifers on the Modern land surface

Coarse surficial materials can become saturated and form unconfined aquifers. The surficial materials map of the study area discussed in Chapter 5 can be used as a fairly reliable exploration guide to their location and geometry, though site-specific study is always required. Though the surficial sand and gravel deposits can be very productive aquifers, they are often connected to surface water bodies and exploitation must consider the consequences of induced infiltration from such bodies. Water levels in unconfined aquifers tend to be seasonal. Well yields are therefore contingent on yearly weather patterns. Surficial aquifers are also vulnerable to surface pollution from both natural and anthropogenic sources.

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9 Baseline Investigations into the Groundwater Resources of the Upper Mannville Group

9.1 Introduction

In this part of the project, the geology of groundwater resources in the Upper Mannville Formation was investigated in four new ways. First, the aggregate hydraulic properties of the entire package were statistically summarized with a binary mixing model using vertical moment-statistics. These were compared to potentiometeric surface maps in an effort to understand first-order controls of geology on the regional flow system as documented by others. Second, slice maps of the succession were used to locate and then to aggregate sandstone accumulations into hydro-lithostratigraphic units. These units appear on first pass to be sufficiently isolated by shale-dominated horizons above and below and yet sufficiently well-connected within by sand-on-sand contacts to act as distinct regional aquifers. These maps will be used in future efforts to focus hydrogeological mapping on the best parts of the aquifer system using techniques of high-resolution sequence stratigraphy. Third, textural descriptions of cores were used as a basis of characterizing controls on intrinsic permeability. These results can be used in future studies to characterize the internal nature of the aquifers. Fourth, regional geochemical variations were examined using major and minor ions plus stable isotopes from high-quality formation-water samples obtained by AGS.

9.2 General Stratigraphic Framework

The Upper Mannville Group in the Athabasca Oil Sands (In Situ) Area comprises a 175-m thick succession of interbedded shale, siltstone, and sandstone. It lies above the prominent Wabiskaw Shale marker bed and below the basin-wide Joli Fou Shale. It was deposited in Aptian time as a north to northwest prograding succession consisting of offlapping clinoforms of shoreface sand and shelfal silt and mud beds which infilled the basin behind a retreating interior seaway (Hayes et al., 1994). The Upper Mannville Group in northeast Alberta is divided into two formations, the lower being the Clearwater Formation and the upper being the Grand Rapids Formation.

Cant (1996) summarized the sequence-stratigraphic relationships of the Mannville Group at the basin scale using the interpretive paradigm of sequence stratigraphy (e.g., Van Wagoner, 1990). To understand the significance of this stratigraphic interpretation for hydrogeology and to understand how these investigations lay the groundwork for future aquifer characterization, a diversion into some of the concepts of sequence stratigraphy is in order.

9.3 Basic Concepts in Sequence Stratigraphy

Sequence stratigraphy is essentially an allostratigraphic, or bounding surface-based, approach to subsurface geological analysis. The prediction of the three-dimensional architecture of lithofacies is based on a conceptual model of sedimentary infill of a basin as the record of sedimentary depositional systems reacting to cyclic changes in relative sea level. Relative sea level is regarded as the local sum of cyclic and episodic variations in local subsidence rate, sediment supply, and global or eustatic sea-level changes.

Sequence stratigraphy proceeds through examination and interpretation of the rock record in terms of a hierarchy of stratal packages at all scales, bounded above and below by significant bounding surfaces. A sequence is defined as a relatively conformable, genetically related succession of strata bounded by unconformities or their correlative conformities. Within each sequence there are genetically related, three-dimensional assemblages of lithofacies called depositional systems. The depositional systems themselves are the amalgamation of genetically linked, contemporaneous facies belts called systems tracts. The stratigraphic building blocks of the systems tracts are parasequences and parasequence sets. Parasequences are defined as relatively conformable, genetically related successions of beds or bedsets bounded by marine flooding surfaces or their correlative surfaces. Parasequence boundaries form in response to increased water depth whereas sequence boundaries form in response to sea level fall (e.g., Van Wagner et al., 1990).

The patterns and assemblages of lithofacies are generally more predictable between bounding surfaces than across the bounding surfaces, depending on the degree of temporal discontinuity and stratigraphic reorganization present across the bounding surface. The order of a sequence reflects a sequence's hierarchical position in geological time relative to global cycles in relative sea-level change charted for the Phanerozoic history of the earth (Vail et al., 1977). An ideal transgressive systems-tract records the assemblage of lithofacies belts present during relative sea-level rise, up to the point of maximum marine incursion onto a craton. An ideal highstand systems-tract records the lithofacies assemblage present from the relative sea-level stillstand at the point of maximum marine incursion onto a craton through the interval of relative sea-level fall to the inflection point of the relative sea-level curve on the way to the point of minimum relative sea level of the next cycle.

If relative sea-level falls to the point of subareal exposure of the high-stand systems tract, an erosive unconformity forms and sediment bypasses the area, only to be deposited much more distally in the sedimentary basin in a third kind of assemblage called a lowstand systems-tract. Channels down-cutting into the underlying highstand systems-tract can form significant lateral discontinuities in sand bodies when infilled with shale. When infilled with sand, such down-cutting channels can create significant vertical conduits for flow. When transgression occurs following a highstand or lowstand, erosive processes accompanying the transgression of the sea can remove the highest stratigraphic units of the previous sequence. This erosion leaves a characteristic type of unconformity called a transgressive surface of erosion which, when identified in core, can be used to guide the stratigrapher in identifying it as a significant stratigraphic bounding surface. As the sea transgresses and relative sea level rises above storm-weather wave base, only shale and siltstone will be deposited. Highly-radioactive, finely laminated shale deposited during the maximum relative-sea level rise will mark another key bounding surface known as the maximum flooding surface. The maximum flooding surface is a key bounding surface surrounding parasequence sets. An alternative set of definitions for understanding depositional episodes in a prograding clastic succession was introduced by Galloway (1989) based on use of the maximum flooding surface as the start and end point of genetic depositional episodes. The differences between the alternative interpretive paradigms are significant in practice, but are not germane to this discussion.

The pursuit of a correct and robust sequence stratigraphy for hydrogeology will be rewarded with a higher degree of predictive reliability when forecasts of hydraulic behaviours in aquifers under stress from pumping or injection are made. The quality of prediction will be a function of the successful capture of the connectivity and anisotropy of both the high and low permeability sediments in a three-dimensional model of the subsurface assemblage. On the other hand, simple lithostratigraphy, which entails the direct, mechanistic correlation of similar lithofacies between broadly spaced boreholes, creates a layer-cake vision of subsurface heterogeneity. A lithostratigraphic approach amplifies lateral continuity of aquifers and amplifies vertical isolation by aquitards. Consequently, any estimates of the transition time for evolution from groundwater extraction from pure storage to an end-state of capture could be significantly biased. As well, monitoring wells could be incorrectly sited or their responses incorrectly interpreted.

9.4 Sequence Stratigraphy of the Upper Mannville

Cant (1996) described the Lower Mannville to be a third-order transgressive systems tract and the Upper Mannville to be a third-order highstand systems tract. Furthermore, Cant divided the Upper Mannville regionally into two units of fourth-order sequences, a basal unit (which corresponds to the Clearwater Formation in the study area), and an upper unit (which corresponds to the Grand Rapids Formation). Both units are progradational in nature. However, the basal unit is characterized by a strongly progradational (i.e., laterally offset) stratal stacking pattern while the upper unit is characterized by a more aggradational (i.e., vertically stacked) stratal stacking pattern. The two units are separated by a regionally persistent surface that marks the end of the basal episode of relatively more rapid marine regression. The stratigraphic surface marking the top of the basal unit from the upper unit in the Cold Lake area has a paleontological significance, being marked by a change from open-marine microfossil assemblages in shales below the surface to brackish assemblages in shales above (Putnam, 1982).

The Clearwater Formation in the study area is characterized by fine-grained marine siltstones and shales and is correlative to the shoreface sandstones of the Lloydminster, Rex, General Petroleum, and Sparky Formations of the Upper Mannville in the Cold Lake area, south of the study area. The Grand Rapids Formation is composed of well-developed shoreface sandstones that are correlative to thin upper shoreface sandstones and channels of Waseca, McLaren, and Colony sandstones to the south.

Figure 9.1 illustrates some of the stratigraphic complexity of the Upper Mannville in the study area in the style of Cant and Abrahamson (1997). The cross sections show the division of the Upper Mannville into the familiar Clearwater and Grand Rapids formations. Each formation is further subdivided into working allostratigraphic units based on the concept of parasequence sets being bounded by flooding surfaces. In this case, candidate-flooding surfaces are identified by shales with relatively high gamma-ray response and a deep-resistivity log value of less than 5 ohm-m. One can see that there is a high degree of interpretation in subdividing the units at this scale. However, the cross-sections illustrate how lateral and vertical hydraulic continuity in this type of interpretative framework may be markedly less than that interpreted from a lithostratigraphic framework of correlations, erosive unconformities and down-cutting channels notwithstanding.

The cross-section (Figure 9.1) is a stratigraphic cross-section using the top of the Clearwater Formation as a datum. The northward rise and fall of several stratigraphic markers above the datum, in the Grand Rapids, is suggestive of differential subsidence rates during deposition, perhaps due to differential compaction of underlying shales, salt dissolution tectonics, karst collapse, or basement-involved tectonic adjustments. These flexures suggest that there may be adjustment faults present in the succession, which could be significant hydraulic heterogeneities. These features need further investigation.

9.5 Moment Statistic Analysis of Upper Mannville Aquifer System

Moment-statistic maps are extensions of lithology maps derived from single well logs. In single-well lithology mapping, a vertically-averaged petrophysical attribute recorded in boreholes is used to map spatial variations in lithology or porosity. For example, average shale volumes can be mapped for stratigraphic intervals with gamma-ray logs, where constant GR values or a borehole-normalized extreme values are used to represent pure lithology end-members of a non-radioactive lithology like sandstone or limestone and a radioactive lithology like shale. Shale volumes can be scaled-off linearly by a simple end-member mixing formula, and then vertically averaged to represent the interval with a single number denoting shaliness.

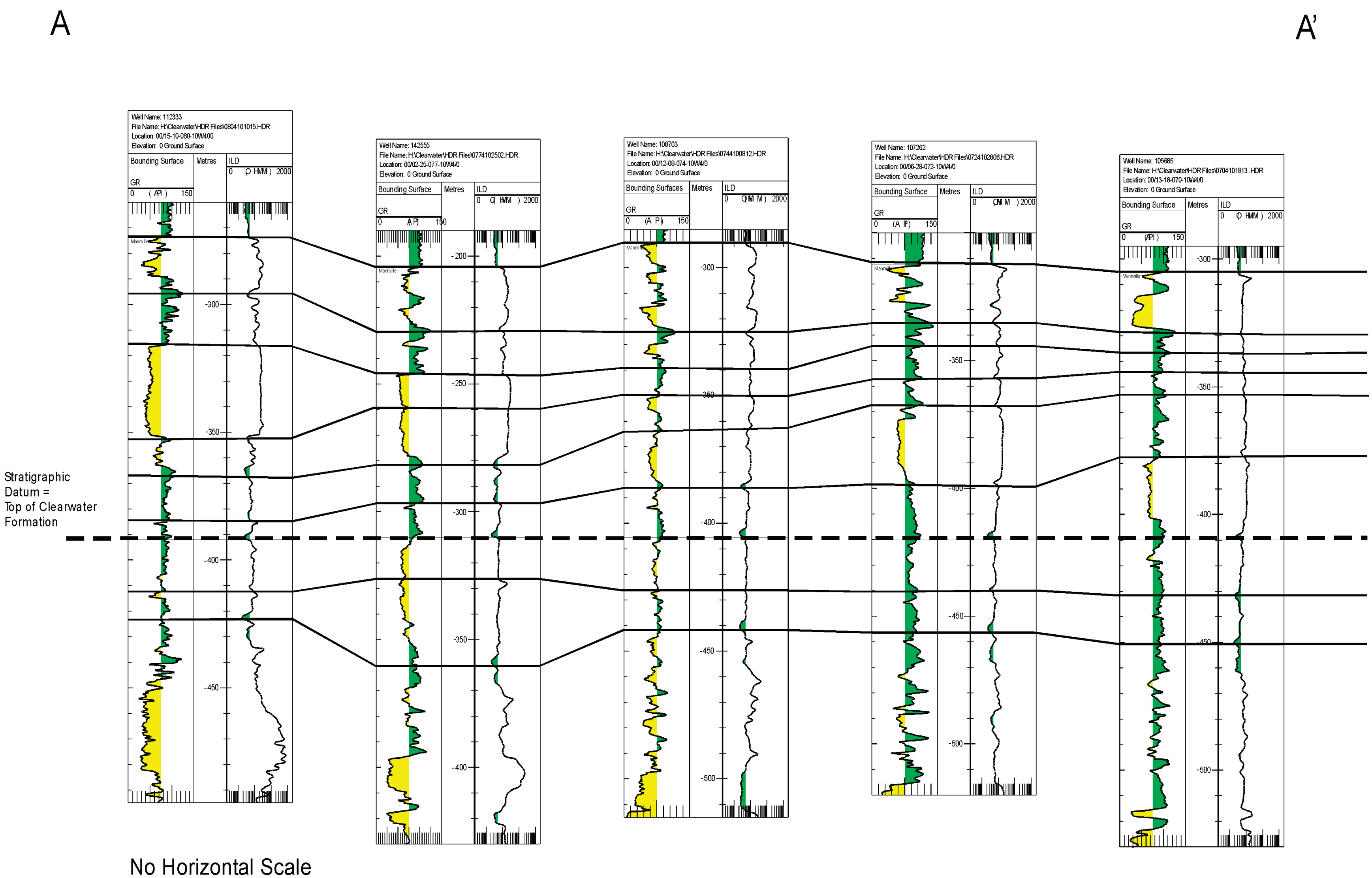


Figure 9.1. Stratigraphic cross-section highlighting stratigraphic complexity in the Upper Mannville Group.

Lithology maps of this sort lose their geometric meaning when applied to thick sedimentary successions. For thick successions, an alternative method was proposed by Krumbein and Libby (1957) and recapitulated in Doveton (1986). Their extension of single-log lithofacies mapping method is called the method of moments. In this mapping technique, a lithology-sensitive log like the gamma-ray log is converted into a shale profile based on an end-member mixing formula.

If the depth of each digitized and transformed interval beneath the top of the zone (or above the bottom) is d_i and S_i is the proportional shale volume at d_i, then the first statistical moment is calculated by:

$$\nu_1 = \Sigma S_i d_i / \Sigma S_i. \qquad \text{(Equation 10.1)}$$

The first moment statistic measures the relative stratigraphic depth of the balance point of the shale in the interval if it were modeled as mass. The second moment statistic is similarly calculated by:

$$\nu_2 = \Sigma S_i d_i^2 / \Sigma S_i. \qquad \text{(Equation 10.2)}$$

It describes the relative amount of dispersion of the shale distribution around the first moment. It is converted to a measure of relative standard deviation by:

$$m_2 = \sqrt{(\nu_2 - \nu_1^2)}. \qquad \text{(Equation 10.3)}$$

The premise of using moment maps to characterize the hydraulic properties of thick sequences is based on two observations. One is that though the Upper Mannville succession is thick (over 170 metres), the extent of the study area is so great that it is not unreasonable to view the hydraulic properties of the Upper Mannville in some sort of vertically averaged and yet meaningful lithological property. The second observation is the one made by Cant (1996) that the upper unit of the Upper Mannville is characterized by aggradation of shoreface sandstone bodies and thus sand-on-sand contacts are expected to be more numerous than if the succession was more progradational in nature. More sand-on-sand contacts increases the difficulty in separating meaningful stratigraphic units which behave as isolated aquifers, and so invite the use of more aggregated descriptors.

Figures 9.2 and 9.3 show the first and second moments expressed in terms of stratigraphic depth below the top of the Mannville. Juxtaposed against the moment maps in Figures 9.2 and 9.3 are the regional potentiometric maps prepared by Petro-Canada for the Gulf Surmont Gas-Over-Bitumen Hearing (Petro-Canada, 1999) and later republished as Barson et al. (2001). The first moment shows a clear correspondence to the potentiometric surface constructed for the Clearwater Formation by Petro-Canada, particularly in the strong spatial correlation between a potentiometric trough in the southwest part of the study area and a region of low first shale moments. The second-moment map shows a clear correspondence between the potentiometric map of the Grand Rapids Formation and the second-moment statistic. In particular, there is a very strong correspondence between the shape of the second moment and the potentiometric mound beneath Stony Mountain.

The correlation between flow patterns in vertically-averaged potentiometric surfaces and the moment statistic maps are not particularly surprising. What is intriguing is that the two different moment maps have their strongest correspondence with two different potentiometric surface maps. This suggests that the lithological signal embedded in the first-moment map is strongly influenced by the geology within the Clearwater Formation, and the second-moment map is strongly influenced by the geology within the Grand Rapids Formation. If this exercise were to be repeated, it would be best to separate the two formations because the change in stratal pattern from progradational in the Clearwater to the aggradational style in the Grand Rapids may be biasing the moment statistic calculations. Or conversely, the change from a progradational style of stratal architecture to an aggradational style is in some way controlling regional groundwater flow directions.

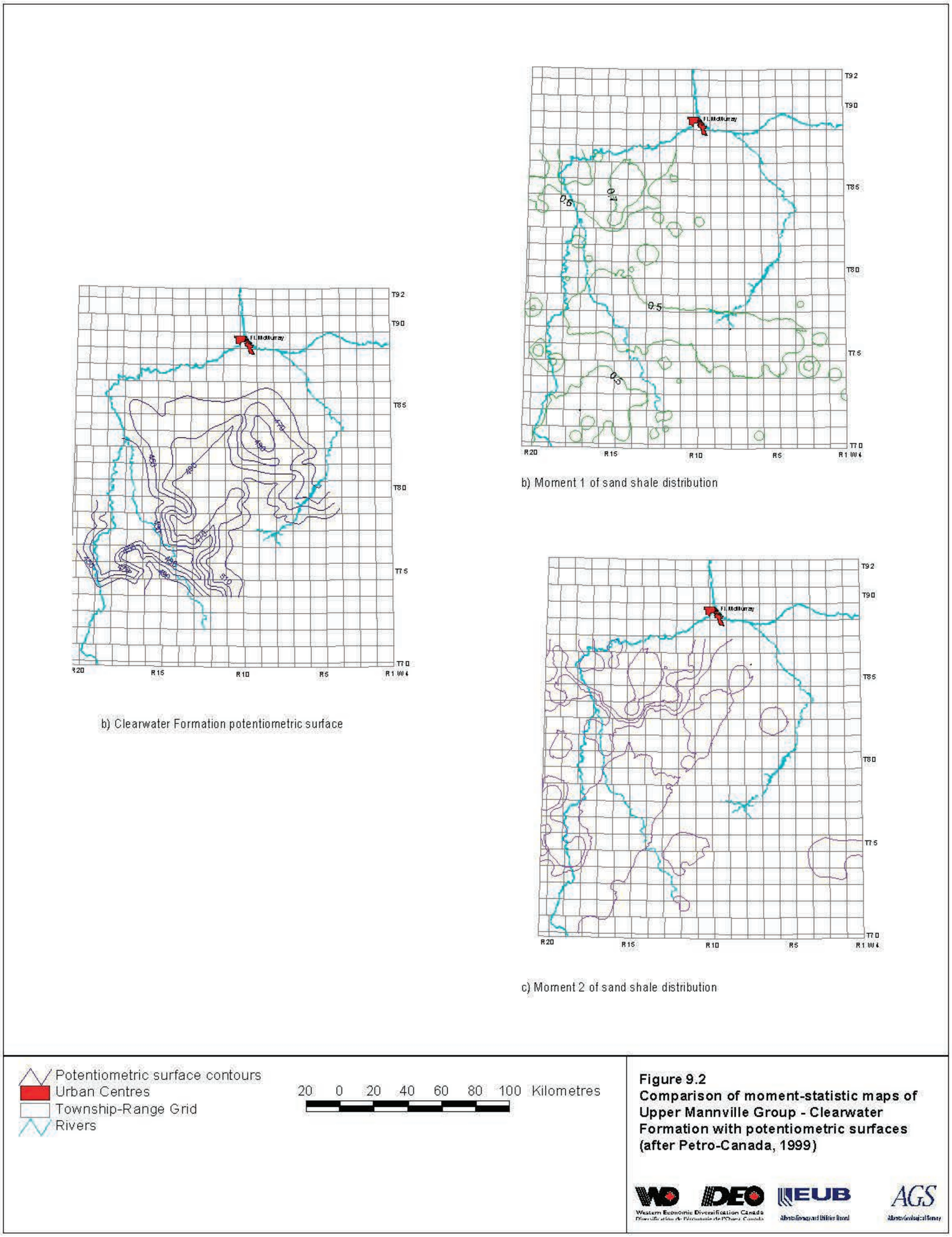
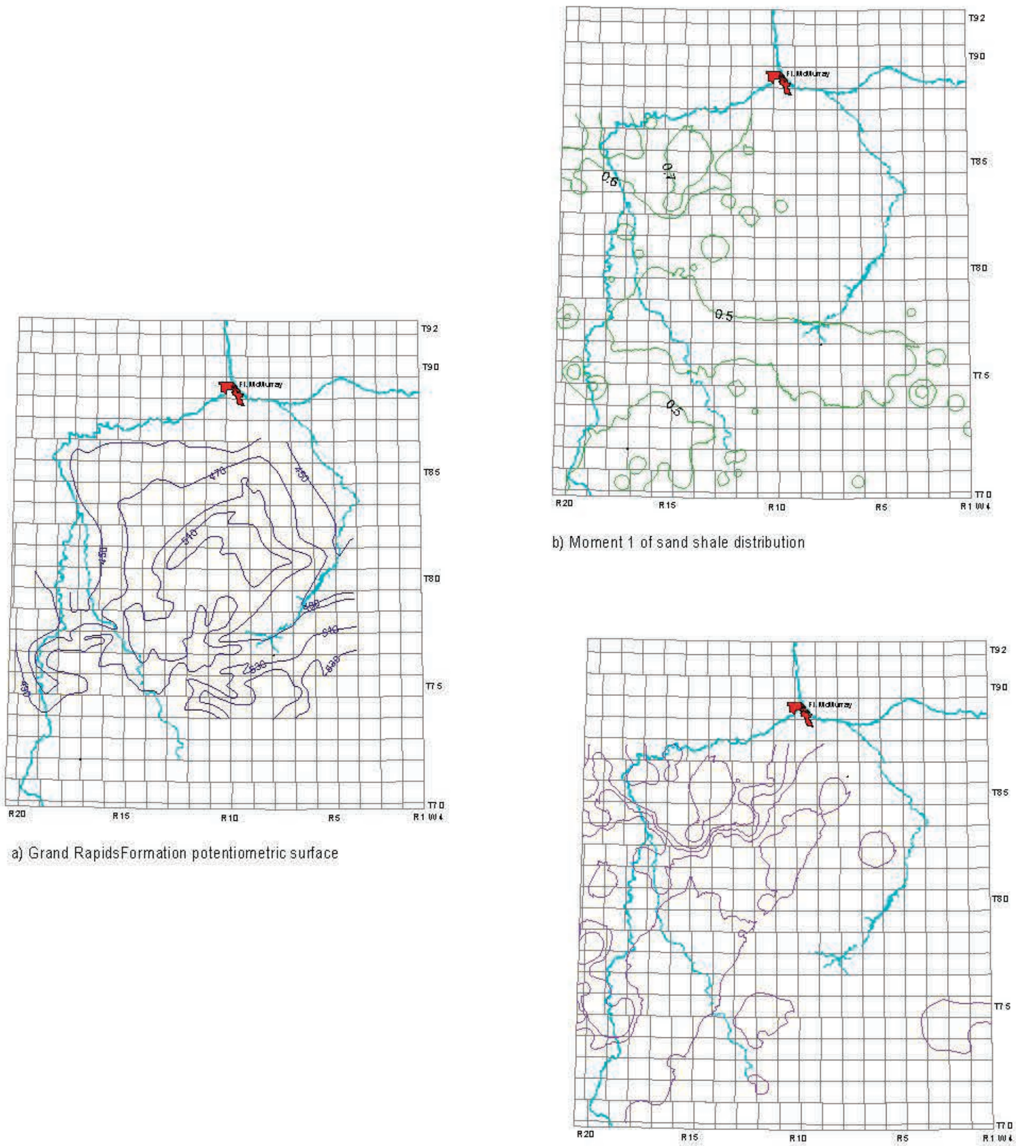


Figure 9.2
Comparison of moment-statistic maps of Upper Mannville Group - Clearwater Formation with potentiometric surfaces (after Petro-Canada, 1999)



a) Grand RapidsFormation potentiometric surface

b) Moment 1 of sand shale distribution

c) Moment 2 of sand shale distribution

Potentiometric surface contours
Urban Centres
Township-Range Grid
Rivers

20 0 20 40 60 80 100 Kilometres

Figure 9.3
Comparison of moment-statistic maps of Upper Mannville Group - Grand Rapids Formation with potentiometric surfaces (after Petro-Canada, 1999)

9.6 Slice Maps and Aquifer Delineation

To better understand the physical meaning of the observed correspondences of potentiometric surfaces and moment-statistic maps, a series of slice maps were constructed through the Upper Mannville. These maps were created by dividing the gamma-ray log for selected industry boreholes into ten-metre slices below the top of the Mannville and summing the thickness of each interval that had a gamma-ray response of less than ½ (GR max + GR min) in API units.

The slice maps show the general distribution of sand within each interval but cannot be used to identify genetic stratigraphic units like parasequence sets. They do have utility, however in helping to define or scope-out priority areas for performing high-resolution sequence stratigraphic analysis. In this study, the slice maps are used to help understand geological controls on regional groundwater flow and identify possible stacked sandstone bodies that are candidates for identification as aquifers by future high-resolution stratigraphic analysis.

Sixteen 10-m slice maps are shown in Figures 9.4 to 9.7. The top of the interval in each control well was the EUB-designated top of Mannville Group or top of the Grand Rapids Formation. The bottom of the Upper Mannville in each control well was the EUB-designated top of the McMurray Formation. Computer-generated eight and ten-metre isopach of gamma-ray defined sandstone are shown on each map. The sequence shows the depositional history of the area as one of northward progradation of sandstone bodies. The hiatus marked by the top of the regional Clearwater Shale is in the slice 80-90 m below the top of the Mannville. Immediately on top of that interval is a widespread sandstone body. In lithostratigraphic terms, this body would be described as a sheet sandstone. However, the knowledge of the sequence stratigraphy of the area suggests that this interval is capturing a succession of clinoform bottomsets that are downlapping onto the top of the fourth-order flooding surface, which marks the transition from basal Upper Mannville (Clearwater Formation) to upper Upper Mannville (Grand Rapids Formation).

A cursory examination of the distribution and stacking of the thickest sandstone in each slice suggests that there are at least three major hydro-lithostratigraphic bodies in the Upper Mannville in the area (Figure 9.8). These bodies appear from the stacking patterns to have a reasonable expectation of a high degree of internal hydraulic connectivity generated by numerous sand-on-sand contacts. Thus they may be considered to be candidate regional aquifer bodies.

One body is found in relative spatial isolation below the 80-90 m slice. From its stratigraphic position it is likely to be a progradational, highstand systems-tract Clearwater shoreface-sandstone. Regional correlations will be necessary to confirm this conclusion. If it is a Clearwater shoreface, the strong progradational nature of this formation would suggest that, as an aquifer, this sandstone would be laterally isolated.

The first significant regional aquifer body overtop the 80-90 metre slice is found from 50-80 m below the top of the Mannville, in the central part of the study area. It is aerially extensive, vertically persistent, and from the slice maps can be seen to have complex spatial geometries. From its thickness and stratigraphic position, it is likely to be composed of multiple, aggradational, highstand systems-tract shoreface-sandstones of Grand Rapids age. Though the slice maps indicate ammalgamation into a single aquifer body is reasonable, high-resolution stratigraphy will be needed to determine if this body is sufficiently amalgamated to be treated as a single aquifer.

A second significant aquifer body is found in the very northwest corner of the study area. Its occurrence in the upper 30 metres of the Upper Mannville indicates that it is a younger sandstone body than the major aquifer in the central part of the study area. It likely represents a later progradation of the Grand Rapids

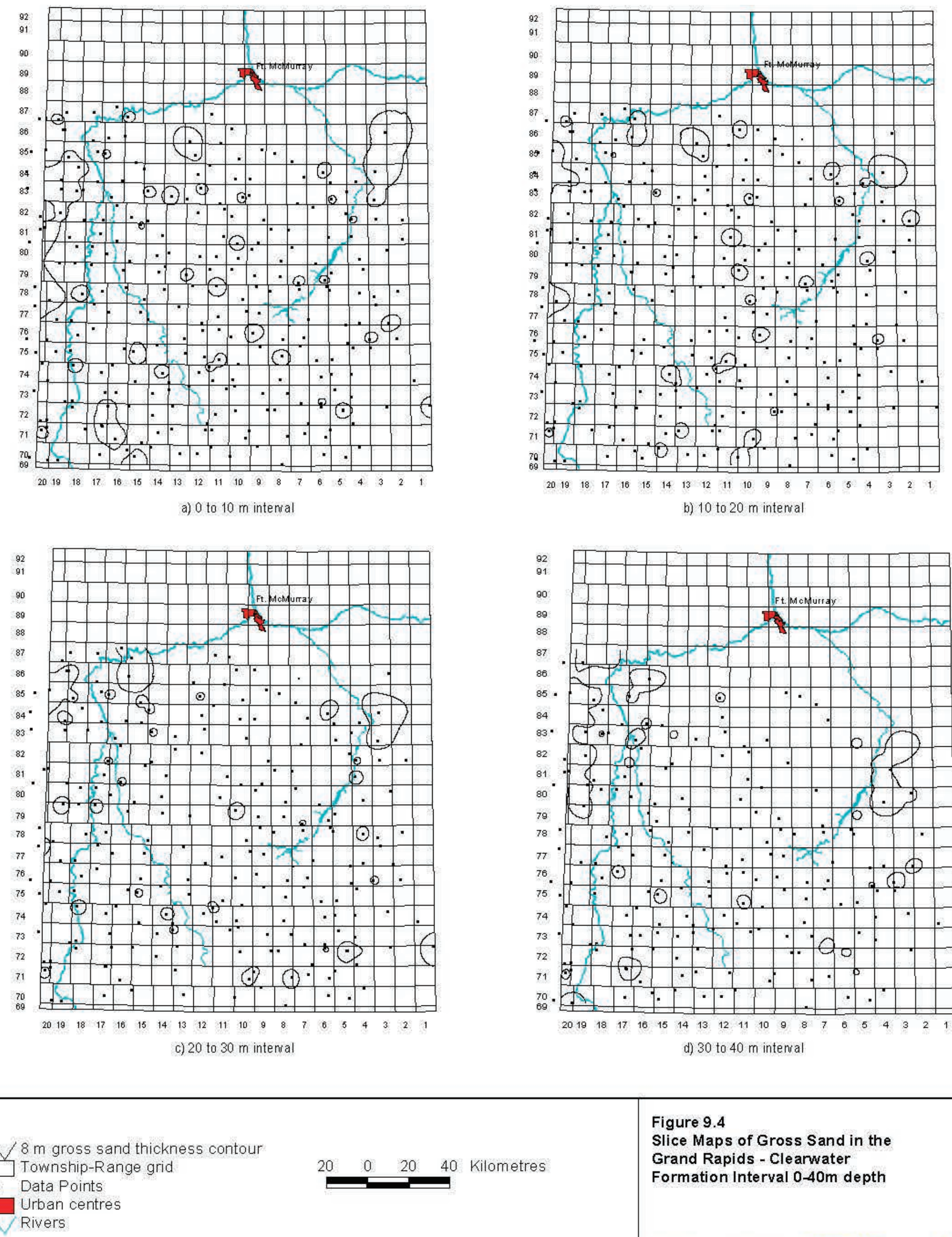
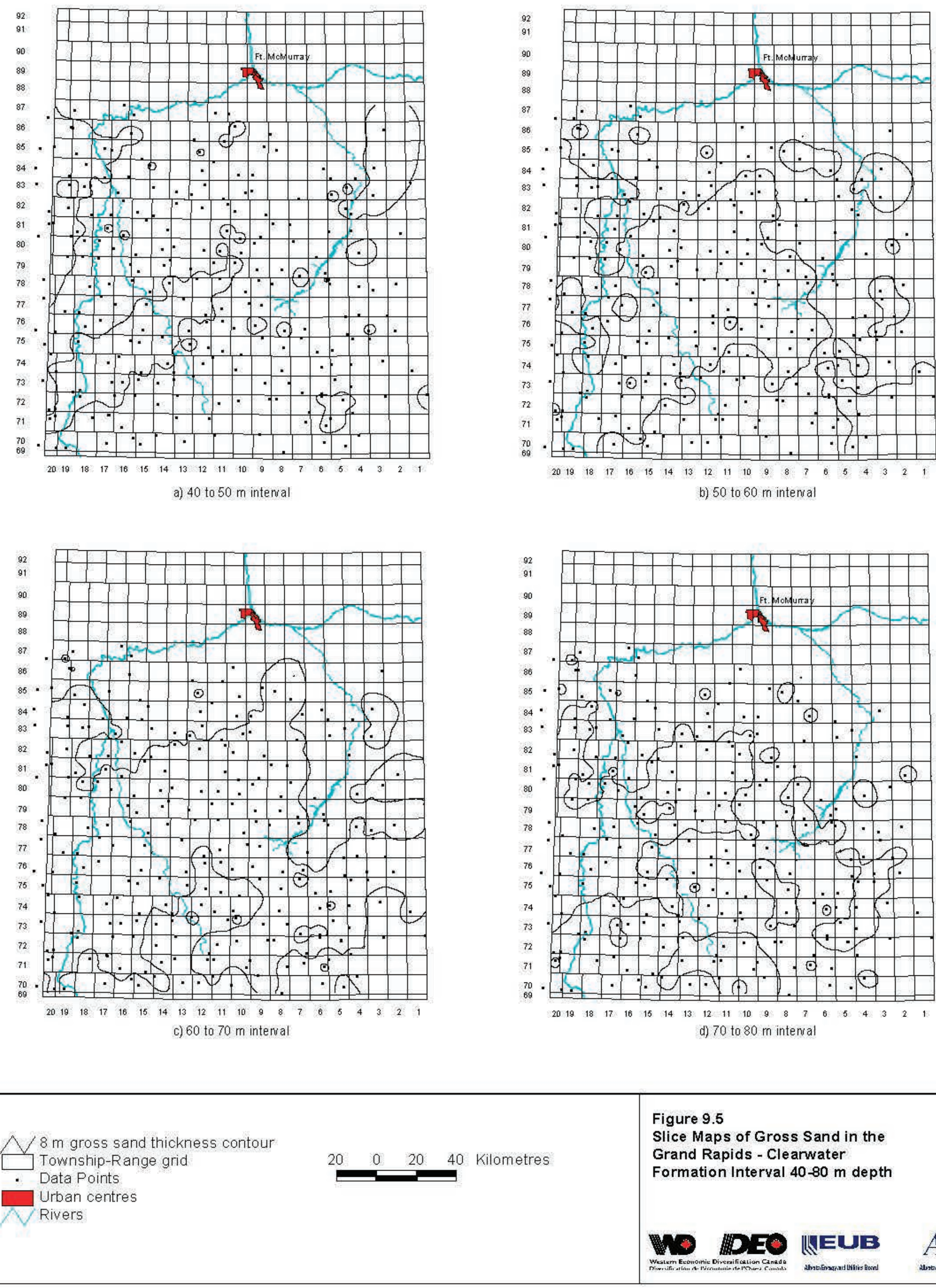


Figure 9.4
Slice Maps of Gross Sand in the Grand Rapids - Clearwater Formation Interval 0-40m depth



a) 40 to 50 m interval

b) 50 to 60 m interval

c) 60 to 70 m interval

d) 70 to 80 m interval

Figure 9.5
Slice Maps of Gross Sand in the Grand Rapids - Clearwater Formation Interval 40-80 m depth

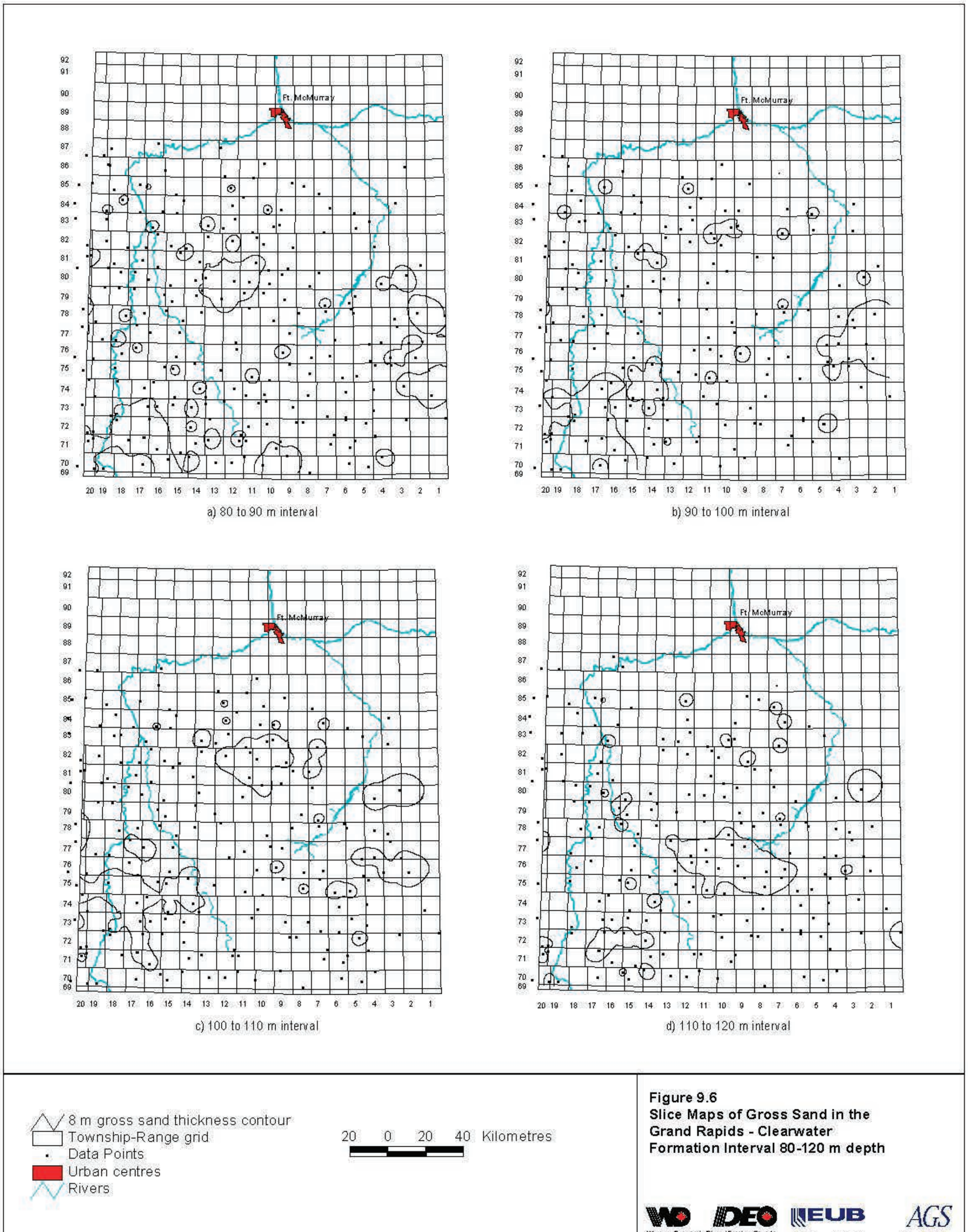


Figure 9.6
Slice Maps of Gross Sand in the Grand Rapids - Clearwater Formation Interval 80-120 m depth

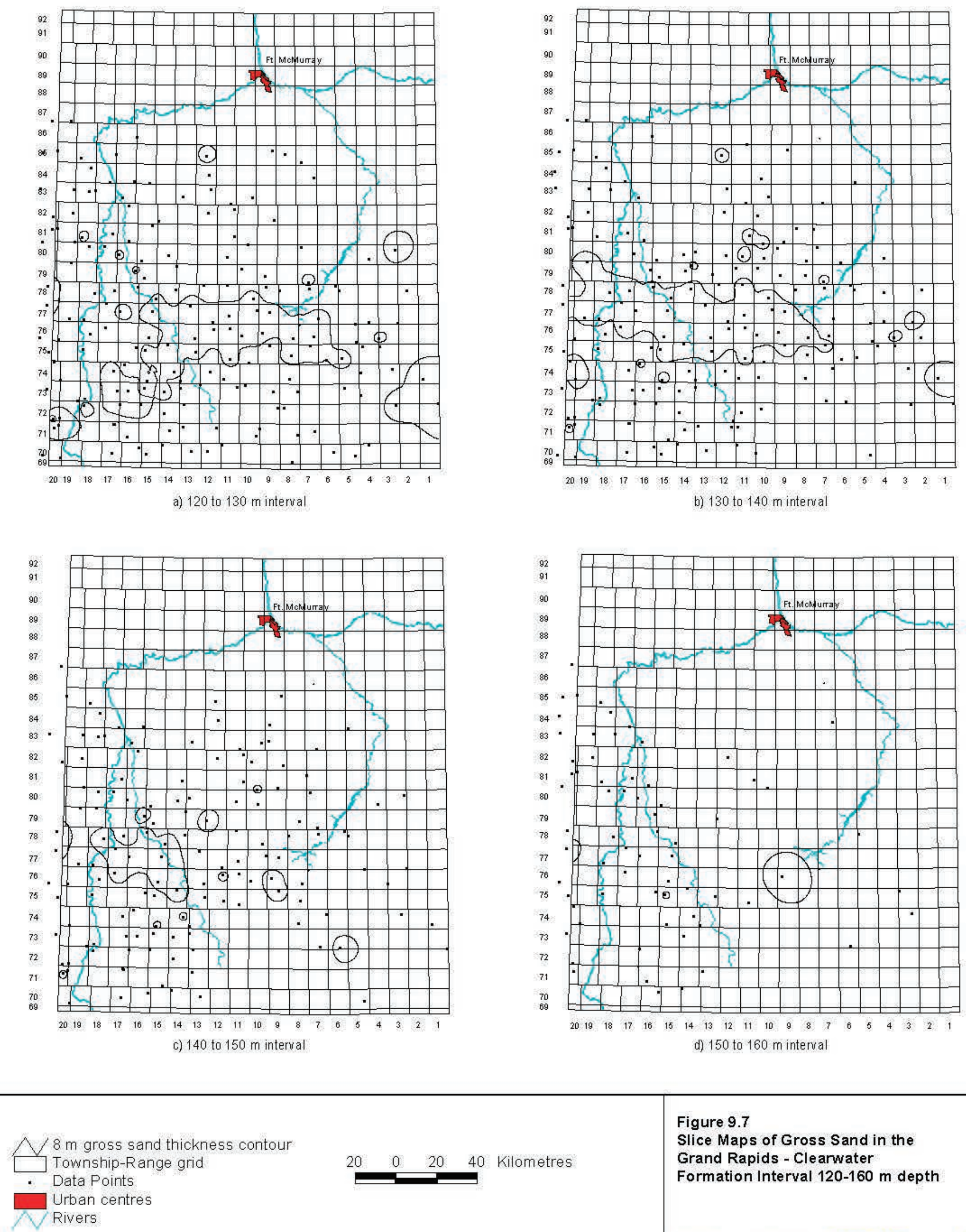


Figure 9.7
Slice Maps of Gross Sand in the Grand Rapids - Clearwater Formation Interval 120-160 m depth

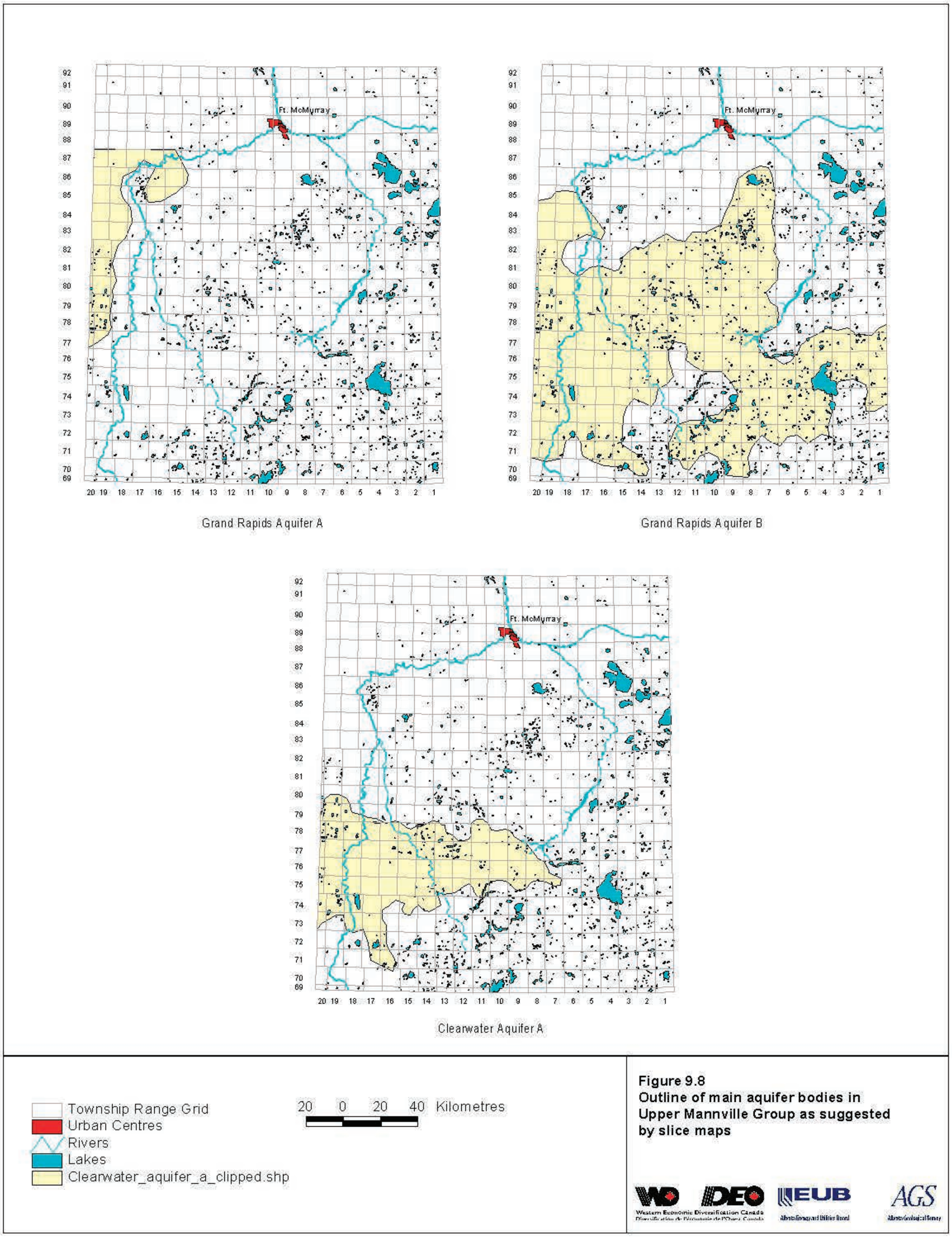


Figure 9.8
Outline of main aquifer bodies in Upper Mannville Group as suggested by slice maps

Formation shoreface northwestward from the study area. Again, high-resolution stratigraphy is needed to define the internal characteristics as well as external geometry of this aquifer body.

The thickness of these candidate aquifer systems varies in space, but it appears that the Grand Rapids aquifer units are thicker over larger areas than the Clearwater aquifer unit. Again, this is consistent with the progradational versus aggradational style of deposition discussed above.

9.7 Hydraulic Conductivity of Upper Mannville Sandstone

The Upper Mannville sandstone bodies are used as both injection zones for oilfield produced waters and as aquifers for water supply. Table 9.1 shows the range of calculated hydraulic conductivity values from well-tests on file with Alberta Environment and from regional groundwater-flow models included in several recent applications to the EUB. The values for sand-rich aquifers tend to fall in the range of 1×10^{-6} m/s to 1×10^{-5} m/s.

Table 9.1. Estimates of Upper Mannville Group aquifer-K from aquifer tests and model calibrations in the public record.

Source	Reported Value and Value Restated as K (m/s)	Comment
Amoco Gregoire Lake WSW-9, 2-27-85-8 W4M Aquifer Test Date: 10/4/77	T = 1320 igpd/ft T = 2.3 e-4 m^2/s K = 3.7 e-5 m/s	Grand Rapids Formation Aquifer thickness reported 20 ft
Amoco Gregoire Lake WSW 11, 7-27-85-8 W4M Aquifer Test Date: 10/19/77	T = 910 igpd/ft T = 1.6 e-4 m^2/s K = 2.5 e-5 m/s	Grand Rapids Formation Aquifer thickness reported 21 ft
Amoco Gregoire Lake WSW 12, 7-27-85-8 W4M Aquifer Test Date: 10/13/77	T = 852 igpd/ft T = 1.5 e-4 m^2/s K = 3.2 e-5 m/s	Grand Rapids Formation Aquifer thickness reported 15 ft
Amoco Gregoire Lake WSW 18, 3-27-85-8W5M Aquifer Test Date: 10/13/77	T = 880 igpd/ft T = 1.5 e-4 m^2/s K = 2.5 e-5 m/s	Grand Rapids Formation Aquifer thickness reported 20 ft
Amoco-AOSTRA GLISP Project WSW No. 1, NW 5-2-86-7 W4M Aquifer Test Date: 6/85	T = 1150 igpd/ft T = 2.0 e-4 m^2/s K = 4.3 e-5 m/s	Grand Rapids Formation Aquifer thickness reported 15.2 ft
Petro-Canada Meadow Creek WSW 105, 15-27-84-9 W4M Aquifer Test Date: 4/3/01	T = 115 m2/d K = 4.6 e-5	Grand Rapids Formation Aquifer thickness reported 29 m
Conoco Surmont In-Situe Project Application Upper Grand Rapids Aquifer	K = 1 e-5 m/s	Value assumed for regional flow model, Kv assumed 1 e-7 m/s
Conoco Surmont In-Situ Project Application Lower Grand Rapids	K = 5 e-5 m/s	Value assumed for regional flow model, Kv assumed 1 e-6, m/s
Petro-Canada Meadow Creek In-Situ Project Application Upper Grand Rapids Aquifer	K = 1 e-9 m/s	Value assumed for regional flow model, Kh:Kv assumed 10:1
Petro-Canada Meadow Creek In-Situ Project Application Lower Grand Rapids Aquifer	K = 5 e-5 m/s	Value assumed for regional flow model, Kh:Kv assumed 10:1

When well-test data are unavailable, an alternative to characterizing hydraulic conductivity from wells is to use average core permeabilities. For flow parallel to a perfectly stratified porous medium, Bear (1972) has shown that the appropriate average is the arithmetic mean permeability (k_A) whereas for flow perpendicular to a perfectly stratified porous medium the appropriate average is the harmonic mean (k_H). For a two-dimensional heterogeneous porous medium, the appropriate average tends to the geometric average (k_G) as the scale relative to the scale of heterogeneity goes to infinity. Natural aquifers are not perfectly stratified, however, and most flow problem-domains are not infinite in area relative to the length-scale of heterogeneities. For the specific case of a heterogeneous medium where the natural log of the hydraulic conductivity is normally distributed with a variance given by σ^2, Desbarats (1992) and Gelhar and Axness (1983) showed that the appropriate vertically averaged effective permeability (k_E) is:

$k_E = k_G \exp[0.5\omega\sigma^2]$ (Equation 10.4)

where ω is a power law exponent that varies can be calculated from formulae that take account of the ratio of horizontal to vertical length scales (λ_H:λ_V) as a measure of the lensiness of the medium:

if

$\rho = \lambda_H/\lambda_V$ (Equation 10.5)

and

$g_{ii} = 0.5/(\rho^2\text{-}1)\cdot[(\rho^2/(\rho^2\text{-}1))^{0.5}\cdot\tan^{-1}(\rho^2\text{-}1)^{0.5}\text{-}1)]$ (Equation 10.6)

then Gelhar and Axness account for the averaging exponent as:

$k_E = k_G \exp[\sigma^2(0.5\text{-}g_{ii})]$ (Equation 10.7)

Some examples are:

Perfectly isotropic: $\rho = 1$, $g_{ii} = 1/3$, $\omega = 1/3$

Lensey: $\rho = 6$, $g_{ii} = 0.1$, $\omega = 0.8$

Nearly layered: $\rho = 100$, $g_{ii} = 0.01$, $\omega = 0.98$

Desbarats and Bachu (1994) compared vertically-averaged core permeability values to drillstem-test derived interval permeabilities for sandstones of the Wabiskaw Member of the Clearwater Formation. They found that the median of the DST values were generally two orders of magnitude less than the arithmetic average of the core permeabilities. Their reasons for the discrepancy were considered to be errors in the DST zone assignments, formation damage in the DST zone, other skin effects, and/or enhanced permeabilities in the core plugs due to sampling bias or handling effects.

Table 9.2 shows values of thickness-weighted vertically averaged permeabilities from Upper Mannville cores taken in the study area. The averages are the simple arithmetic averages in this case, which correspond to an averaging exponent of $\omega = 1$. The values range from about 6×10^{-8} m/s to 6×10^{-5} m/s. The median value is 5.9×10^{-6} m/s. This compares very well to the range of hydraulic conductivities from aquifer tests noted in Table 9.1, which fall consistently in the range of 2×10^{-5} m/s to 5×10^{-5} m/s suggesting that the core data and lithofacies mapping will have strong applicability to future exercises in characterizing the aquifers of the Upper Mannville. This work requires more detailed follow-up.

Table 9.2. Estimates of vertically avaeraged aquifer-K from cores.

Well ID	Reported Depth of Core Top (m)	Number of Samples in Core	Thickness-weighted Arithemetic Mean Core-K_{max} (m/s)
00/04-23-083-19W4-0	158.83	1	1.3E-05
00/05-09-070-05W4-0	316.5	3	5.6E-06
	325.25	4	1.1E-06
	442	8	1.1E-05
	451	7	7.4E-06
00/05-23-070-06W4-0	304	1	1.2E-05
	313	4	5.5E-06
00/05-30-078-09W4-0	328	4	2.9E-06
	336.2	4	3.6E-06
00/05-35-070-05W4-0	420	2	4.4E-06
00/06-03-084-09W4-0	362.1	13	1.1E-05
	371.25	17	1.4E-05
00/06-05-071-11W4-0	279	4	1.3E-06
00/06-06-073-06W4-0	356.5	2	5.6E-08
	358.5	4	4.0E-06
	360.5	3	2.4E-07
00/06-09-077-08W4-0	276.45	9	5.9E-06
	285.29	18	2.7E-05
00/06-16-078-07W4-0	236.83	20	1.7E-06
	252.07	28	2.0E-06
00/06-17-085-20W4-0	206.04	8	1.1E-06
	215.19	53	2.6E-05
00/06-22-077-08W4-0	247.5	34	2.1E-05
	256.64	30	1.7E-05
00/07-11-082-20W4-0	197.82	4	3.0E-06
	219.46	16	1.2E-05
	225.55	10	7.5E-06
00/07-19-070-04W4-0	306	1	2.6E-05
	404	11	8.6E-06
00/07-20-070-05W4-0	438.5	9	8.9E-06
	447.5	5	5.8E-06
00/07-21-070-06W4-0	402	1	3.0E-06
	410.5	2	1.1E-06
00/07-24-082-05W4-0	147.25	13	2.9E-06
	156.75	9	1.4E-06
00/08-16-072-06W4-0	468.1	2	7.2E-07
00/09-12-070-06W4-0	443.5	7	3.9E-06
00/09-14-071-06W4-0	315	2	4.4E-06
	325	2	5.2E-06
00/09-32-073-05W4-0	281	3	6.2E-07
00/09-35-070-06W4-0	434.5	5	1.1E-06
	443.5	4	1.1E-06
00/10-06-075-07W4-0	405.38	25	6.0E-06
00/10-08-074-04W4-0	231.04	8	2.0E-06

	315.47	9	6.4E-06
00/10-12-079-08W4-0	255	6	2.0E-06
	261.68	2	2.5E-06
00/10-14-082-19W4-0	195.38	17	1.1E-05
	201.47	12	6.6E-06
00/10-16-073-04W4-0	339	1	9.3E-07
00/10-18-077-08W4-0	263.35	9	2.2E-05
	269.44	25	4.2E-05
	274.32	25	2.9E-05
00/10-22-077-09W4-0	281.33	10	1.7E-05
00/10-25-074-07W4-0	272.49	7	4.8E-06
	278.44	26	3.0E-05
00/10-26-075-04W4-0	338	4	8.6E-06
	350	4	1.9E-06
00/10-26-081-10W4-0	423.67	1	3.3E-07
00/10-27-076-07W4-0	259.99	27	3.4E-05
00/10-32-078-12W4-0	303.99	3	4.3E-05
00/11-01-071-15W4-0	289	1	5.0E-06
00/11-10-084-10W4-0	272.49	6	5.8E-06
00/11-15-070-18W4-0	297	3	1.3E-06
00/11-18-077-17W4-0	258	2	2.0E-05
00/11-23-073-09W4-0	338	5	4.0E-06
00/11-31-076-06W4-0	243.54	15	2.9E-05
	253.59	6	2.8E-05
00/11-34-077-08W4-0	242.93	11	1.3E-05
	251.16	16	1.9E-05
00/12-19-079-08W4-0	333	7	2.9E-06
	341	7	2.8E-06
00/12-26-072-05W4-0	354	1	4.3E-06
00/13-04-084-20W4-0	207.26	13	1.3E-05
	230.43	9	6.5E-06
00/14-06-071-08W4-0	306	1	2.6E-06
	312.25	2	6.4E-06
02/07-25-073-05W4-0	308	2	7.8E-07
	395	4	1.9E-06
	407	8	9.7E-06
	413	10	8.5E-06
02/10-01-077-07W4-0	246.8	3	5.6E-05
AA/04-30-081-19W4-0	225	14	1.2E-05
	234	17	2.8E-05
AA/05-25-083-07W4-0	341	8	1.7E-05
AA/09-01-080-08W4-0	191.72	6	1.3E-06
	197.51	6	5.7E-06
	200.56	7	4.5E-06
	206.96	7	4.0E-06
	213.06	11	5.9E-06
	219.15	6	2.3E-06
	260.3	4	1.6E-05
AA/11-06-086-06W4-0	157	4	1.5E-05
AA/11-12-086-07W4-0	168.6	15	1.6E-05

AA/11-17-082-19W4-0	207.57	5	3.6E-05
AA/11-30-083-06W4-0	257.7	45	2.3E-05
AA/12-35-086-07W4-0	149.5	26	3.2E-05
Summary Statistics			
Maximum			5.6E-05
Minimum			5.6E-08
Median			5.9E-06
10th Percentile			1.1E-06
90th Percentile			2.8E-05

When characterizing subsurface formations, there is always a deficit of physical estimates of hydraulic parameters, even when core are available. These parameters need to be estimated from associations of hydraulic characteristics with rock types and then a model domain can be populated using a depositional assemblage model constrained by the expected geometries and associations of the contained facies tracts. If a porosity-permeability relationship exists, then borehole porosity logs can be used to further constrain these kinds of exercises.

The Kozeny-Carmen equation is sometimes used to estimate the value of permeability from porosity logs:

$$k = (d_m^2/180)\bullet \phi^3/(1-\phi)^2 \qquad \text{(Equation 10.8)}$$

where k is the permeability, d_m is the mean particle size, and ϕ is the porosity (Bear, 1972, p. 166).

The core data from the Upper Mannville in the area were grouped and sorted by recorded grain-size. Figure 9.9 shows a graph of core porosity versus maximum measured core-permeability for plugs so grouped by grain-size. For reference, the intersection of k=10 mD and k=100 mD with an interpreted best-fit line through the data cloud and the corresponding porosity values are marked on the graph. These numbers are general guidelines for minimum permeability needed to produce commercial rates of natural gas and oil in most Alberta clastic reservoirs. The data tend to be more permeable and porous than these industry cutoffs, which suggests that there are no secondary diagenetic effects that would eliminate some part of the siltstone and sandstone beds in the Upper Mannville from being considered potential aquifers.

No linearity is present in the log-linear plot of porosity versus permeability. Had the assumptions of the Kozeny-Carmen relationship been met, log-linearity would be expected on Figure 9.9 once the sorting of the values by grain size had been done. The lack of linearity on Figure 9.59 for any grain-size group indicates that a porosity-based approach to estimating permeability from logs would not be appropriate for characterization of Upper Mannville aquifers.

Some of the population statistics of the Upper Mannville core data are presented in Table 9.3. The mean values of sandstone and siltstone grain-sizes are again in the range of 1×10^{-6} to 1×10^{-5} m/s. The coefficient of variation of each group however is greater than 0.5. A coefficient of 0.5 or greater signals that the underlying population is heterogeneous to very heterogeneous (Jensen et al., 1997, p.147). This degree of heterogeneity suggests that other geological factors, like texture or sedimentary structure, will also need to be taken into consideration when characterizing aquifers in the Upper Mannville.

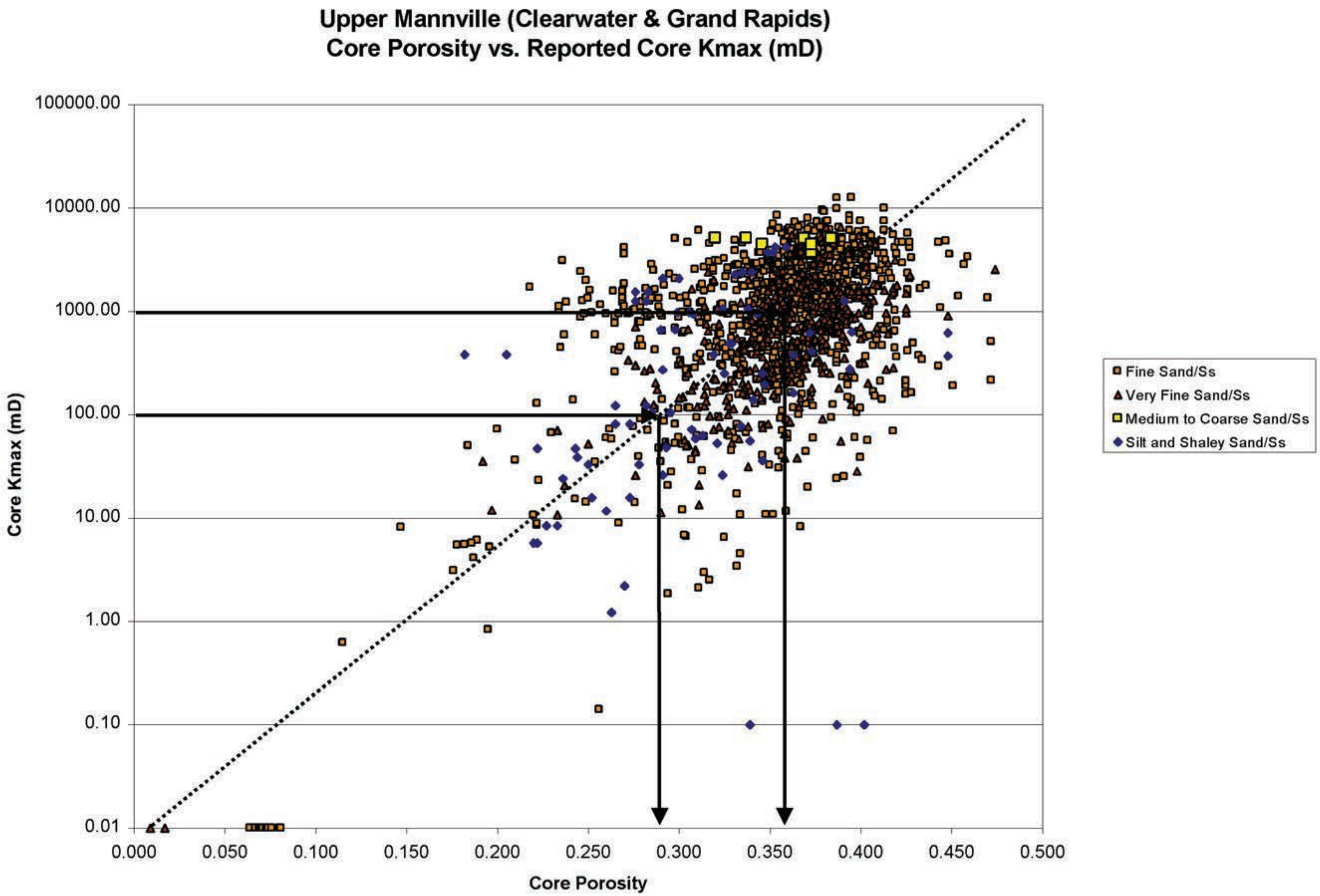


Figure 9.9. Core-measured porosity versus maximum permeability, sorted by reported grain size.

Table 9.3. Average Core-Kmax-Values (m/s) by reported grain-size.

Reported Grain Size	Number of Samples	Average of Reported K_{max} (m/s)	Coefficient of Variation
med sand	50	1.46E-05	0.954
fine san	558	1.80E-05	0.944
vf sand	289	1.07E-05	1.114
siltstone	5	9.78E-07	0.549
mudstone	3	7.53E-07	0.600
shale	7	9.74E-07	1.566

9.8 Chemistry of Upper Mannville Formation Water

Between 1999 and 2001 the Alberta Geological Survey conducted a water-sampling program in northeastern Alberta. Thirteen samples from Lower Cretaceous aquifers of the Upper Mannville, including, Colony, Grand Rapids and Clearwater formations were collected. Two Viking Formation water samples were also included for comparison.

The locations of the sampled Upper Mannville waters are in Figure 9.10. The wells were selected based on geographic area, penetration of a horizon of interest, well-completion quality, water production history and, where available, verification of completion interval using geophysical logs. Field measurements of temperature, pH, conductivity, dissolved oxygen, oxidation-reduction potential and alkalinity were made. The water samples were analyzed for major, minor and trace elements, extractable silica and silicon, chloride, bromide and iodide, $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{11}B$, $\delta^{34}S_{sulphide}$, $\delta^{34}S_{sulphate}$ and $^{87}Sr/^{86}Sr$. The protocols used for field determinations, sampling and quality control were developed based on those defined by the Geological Survey of Canada, the United States Geological Survey, the United States Environmental Protection Agency and the universities of Alberta, Calgary and Saskatchewan. The protocols are documented in Appendix 6. No acceptable water analyses were available from industry databases for the study area. All of the chemistries available to AGS from these sources had severe charge-balance errors (in excess of 5%) and thus are regarded as unreliable analyses of formation water.

9.8.1 Major Ion Chemistry

The total dissolved solids (TDS) values in the Upper Mannville wells vary between 2430 mg/L to 29600 mg/L. The samples all have TDS values less than the TDS of seawater, which is approximately 35000 mg/L (Drever, 1997, p. 345). Since some of the water samples were collected from gas wells, and since gas wells can produce water from condensation of fresher composition than nearby formation water, any water sample results less than 4000 mg/l total dissolved solids collected from a gas well need to be subjected to closer scrutiny.

The major ion chemistry is displayed on a Piper plot in Figure 9.11. The waters include mixed cation-HCO_3 type water, Na-HCO_3 type water, Na-Cl-HCO_3 type water and Na-Cl type water. The Na-Cl-HCO_3 and Na-Cl type water samples are from wells completed at the greatest depths while the mixed cation-HCO_3 and Na-HCO_3 type water are from the shallowest wells. These shallow wells are being used for domestic purposes or as water-supply wells. The various water types suggest that ion exchange has occurred to generate the mixed cation-HCO_3 and Na-HCO_3 type water, whereas the Na-Cl-HCO3 and Na-Cl type water in the deeper wells indicates that these samples come from the less flushed parts of the succession (Macpherson and Townsend, 1998).

A complete report of all chemical analyses is captured in Appendix 7.

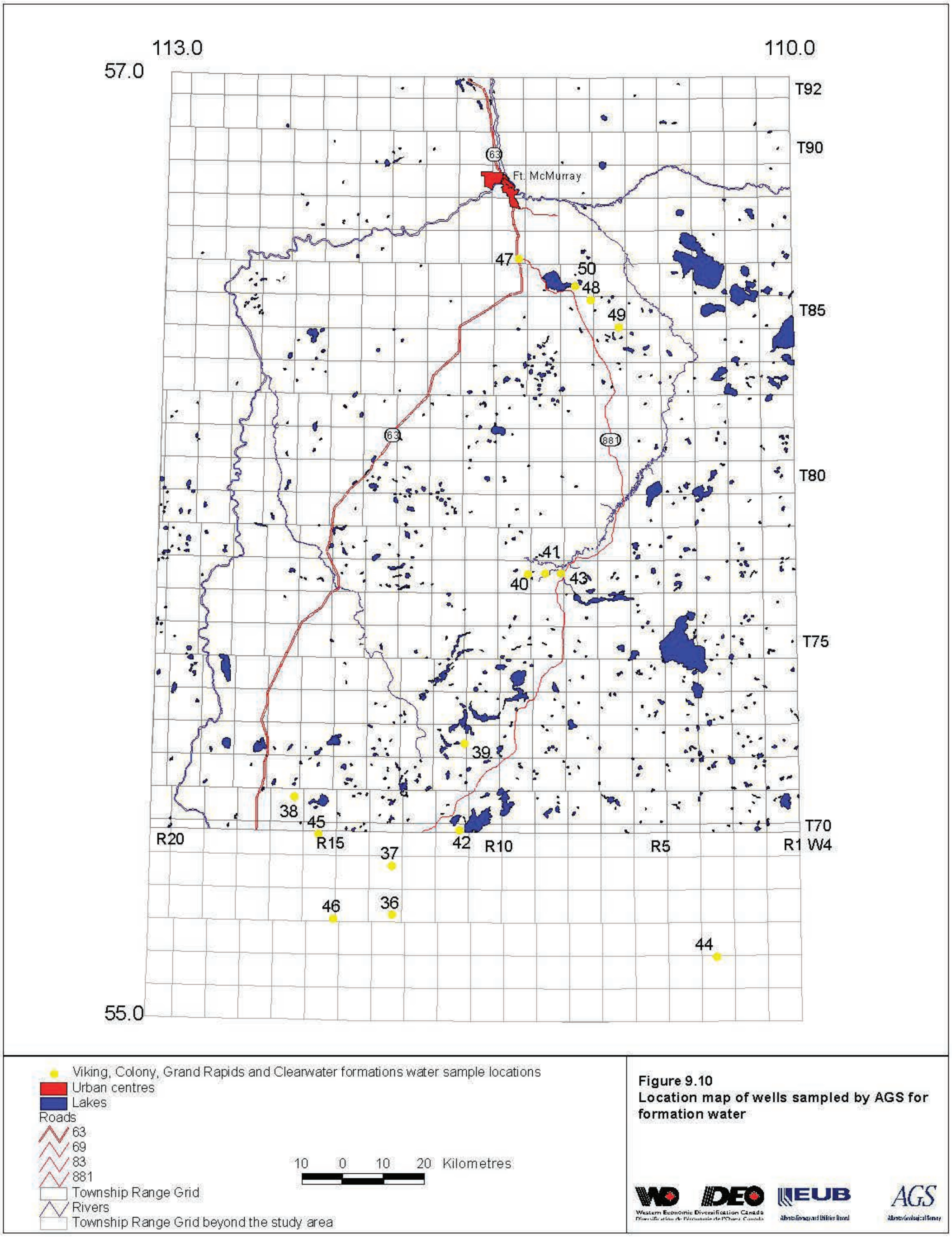


Figure 9.10
Location map of wells sampled by AGS for formation water

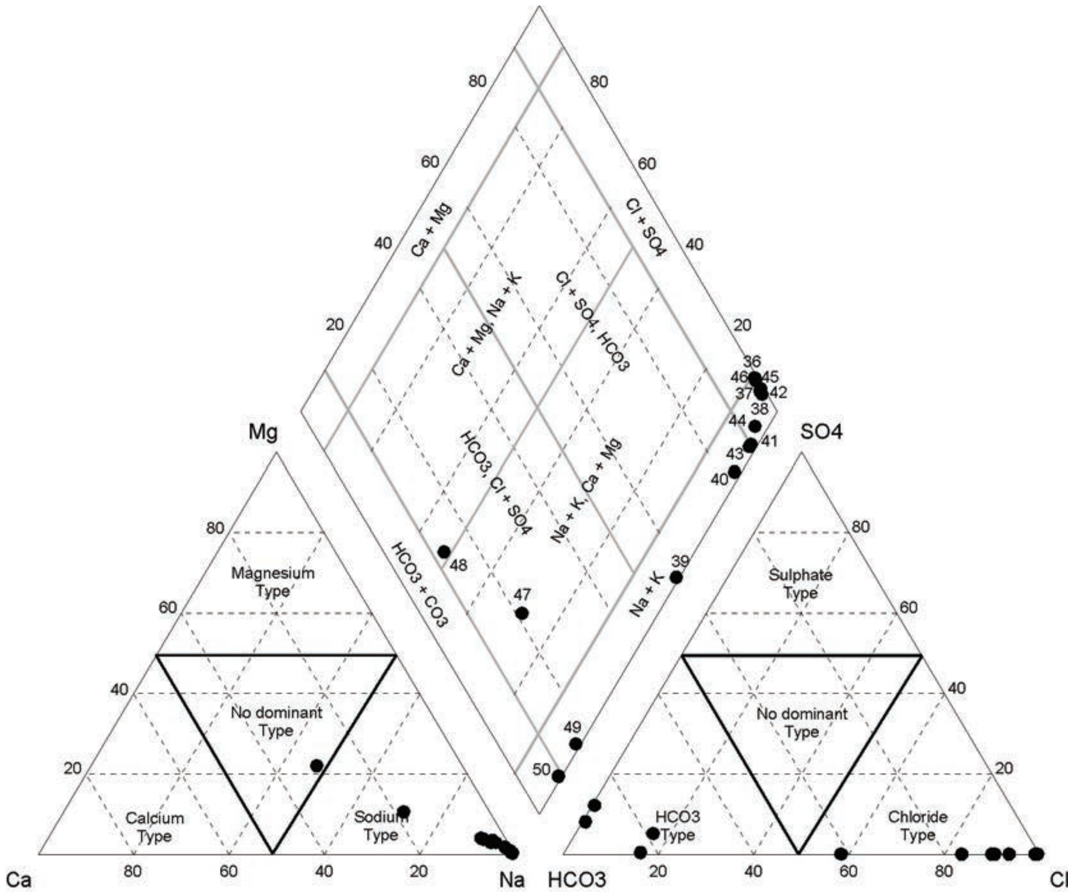


Figure 9.11. Piper plot showing major ion chemistry of formation-water samples.

9.8.2 Chloride/Bromide Mass Ratios

Bromide was analysed in each sample to detect if there has been any contribution of brines from dissolution of the underlying Devonian Prairie Formation evaporites to the water of the Upper Mannville. The salt-dissolution edge of the Prairie Formation passes north-south in the east half of the study area (Hamilton, 1971). Bromide analyses were done by neutron activation analysis to circumvent chloride-interference effects associated with bromide measurement by more common laboratory methods.

Davis et al., (1998) state that atmospheric precipitation will have Cl/Br mass ratios between 50 to 150, shallow groundwater between 100 and 200, and water affected by the dissolution of halite between 1000 and 10000. Seawater has a Cl/Br mass ratio of approximately 289. All of the calculated mass ratios for the Upper Mannville samples are less than 1000, suggesting that dissolution of halite is not contributing to the composition of the groundwater or formation water (Figure 9.12). Moreover, many of the Cl/Br mass ratio values within the intervals are consistent regardless of changes in Cl, suggesting that there is a single dominant source of chloride and bromide ions. Most of the waters have Cl/Br mass ratios close to that of seawater suggesting that this could be the Cl and Br source.

9.8.3 $\delta^{18}O$ and $\delta^{2}H$ Isotopes

The $\delta^{18}O$ and $\delta^{2}H$ values (Figure 9.13) of the samples are similar to the global meteoric water line of Rozanski et al., (1993). This similarity suggests that the water in the various aquifer units either has a

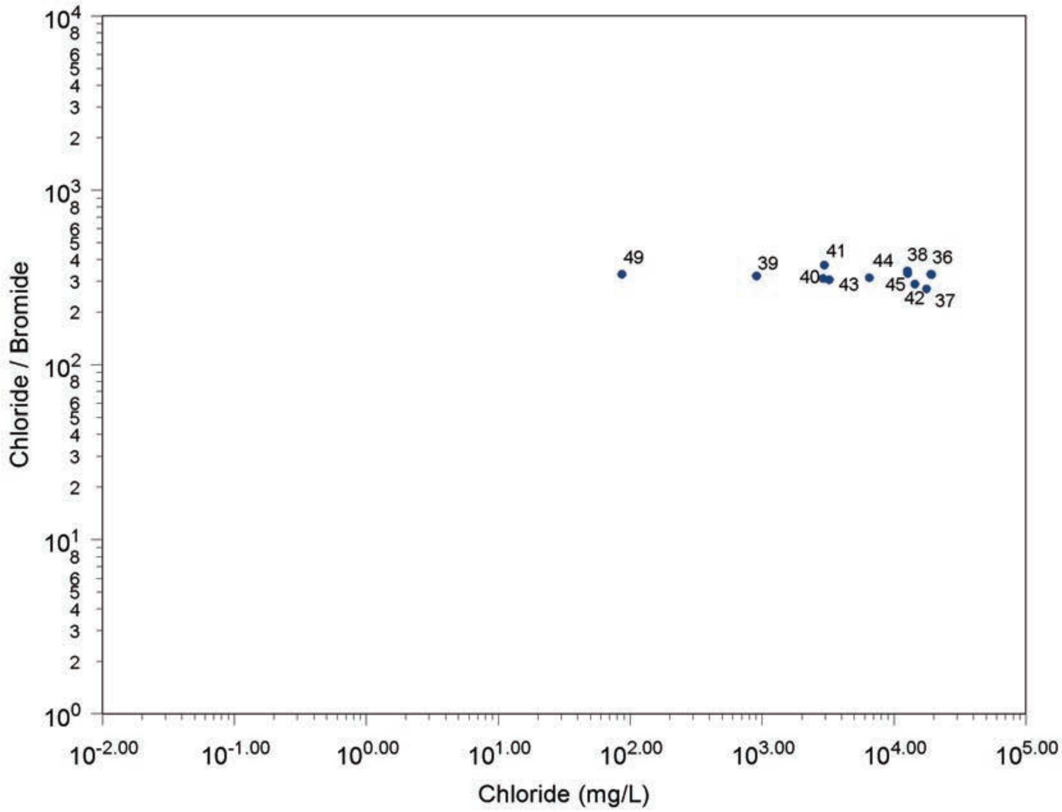


Figure 9.12. Chloride/Bromide ratio versus chloride, Upper Mannville Group and Viking Formation water samples.

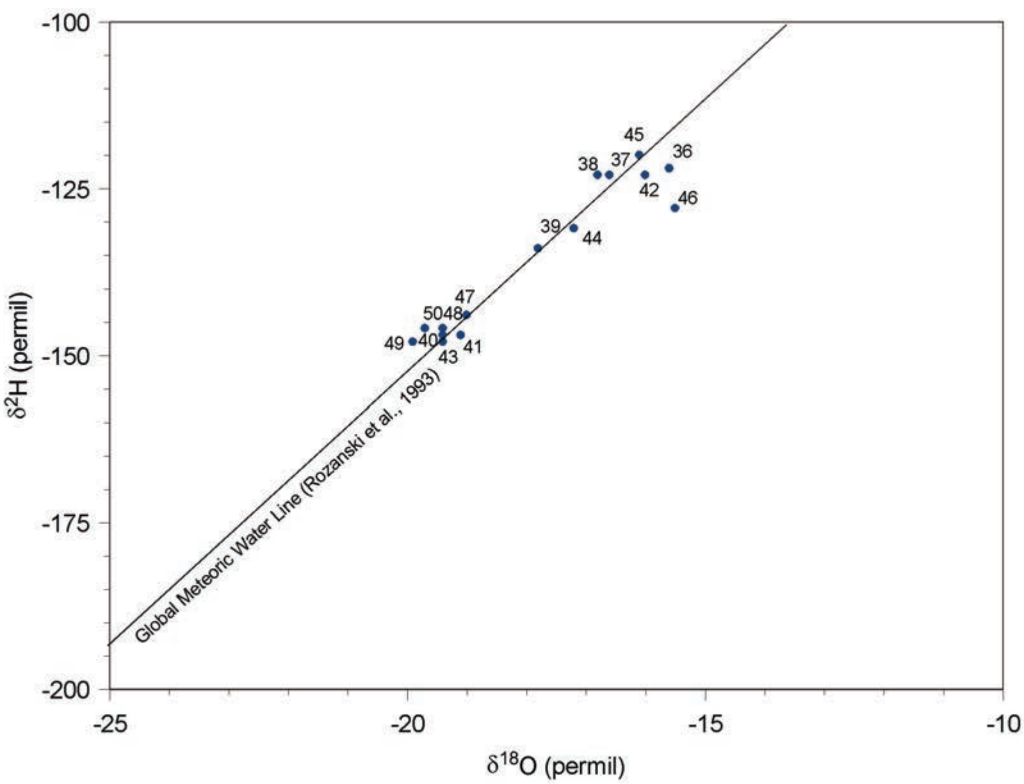


Figure 9.13. Oxygen-deuterium isotope plot comparing Upper Mannville Group and Viking water samples to the meteoric water line.

meteoric origin, or has mixed with meteoric water to give the observed isotopic values. Not all values plot directly on the line. Variation from the meteoric water line can be explained by differences in humidity shifting the data parallel to the line. Drier conditions shift the line upwards, while more humid conditions shift it downwards (Clark and Fritz, 1997, p. 44). Temperature changes can also affect the distribution of the data. Colder temperatures result in isotopic values that plot towards the more negative end of the line whereas warmer temperatures plot towards the more positive end of the line (Clark and Fritz, 1997, p. 64-65). Water samples from the Viking and Upper Mannville appear to have a bimodal distribution.

The group of points plotting along the upper portion of the meteoric water line correspond to sample locations southwest of the Mostoos Uplands. These same values have the highest TDS values. The isotopic values coupled with the lower TDS values of the samples from the study area north of the Mostoos Uplands suggest that the Upper Mannville Aquifers in the study area may be hydraulically decoupled from the Upper Mannville aquifers to the southwest, even though there is geological continuity of the Upper Mannville. This is a significant observation and will require future work to understand the hydrodynamic relationships.

A weighted annual average for Edmonton gives a $\delta^{18}O$ value of –17.1‰ and a $\delta^{2}H$ value of –131‰ at a mean annual temperature of 3.2°C (Rozanski et al., 1993). The majority of the data from north of the Mostoos Uplands have values for $\delta^{18}O$ and $\delta^{2}H$ less than the Edmonton value, suggesting colder temperatures of recharge than present-day during recharge, while the samples from south of the Mostoos Uplands have $\delta^{18}O$ and $\delta^{2}H$ values greater than the Edmonton values suggesting warmer temperatures than present-day during recharge. The isotopically "cold" values suggest mixing or infiltration of waters of cold meteoric origin, like snowmelt or glacial meltwater, into the Upper Mannville.

9.9 References

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10 McMurray Formation

The regional hydrogeology of the McMurray Formation is discussed in detail in Barson et al. (2001). They demonstrated how when bitumen is present, the McMurray Formation consists of three main hydrostratigraphic divisions:

- a regionally persistent upper aquifer occupied by natural gas and groundwater, called the "top water" by the oil-sands industry;
- a middle aquitard consisting of the bitumen zone but also containing groundwater at saturations above irreducible water saturation;
- a lower aquifer below the bitumen, often called the "bottom-water" by the oil-sands industry.

On the east side of the bitumen area, however, the McMurray Formation becomes a very thick regional aquifer. An isopach map of the cumulative thickness of water-bearing sand/sandstone in the McMurray Formation is shown in Figure 10.1. The distribution of sandstone is strongly controlled by the topography on the underlying Pre-Cretaceous unconformity surface. This surface represents the strongly weathered and karsted top of the underlying Devonian carbonate and calcareous shale formations. Details of the McMurray geology are found in Flach and Mossop (1985), Keith et al., (1988), Ranger and Pemberton (1997), and Wightman and Pemberton (1997).

The main issues with respect to the groundwater resources of the McMurray Formation are:

- the suitability of the McMurray Formation to provide brackish make-up water to SAGD operations;
- the suitability of the McMurray Formation to support aquifer-storage-and retrieval projects to help manage water balances at large SAGD operations;
- the long-term suitability of using isolated McMurray bottom-water lenses to dispose of waste waters by deep-well injection;
- the suitability of the McMurray Formation on the east side of the bitumen area to accept and contain waste-waters emplaced by deep-well injection, given the fact that it outcrops along the Christina, the Clearwater, and the Athabasca rivers on the north side of the study area;
- the long-term suitability of using future extinct SAGD chambers for produced water disposal.

Pressure interference by Wabiskaw and McMurray Formation gas production overtop commercially-attractive bitumen deposits amenable to in-situ recovery by SAGD is an ongoing regulatory issue (the gas-over-bitumen issue). Though this is a significant hydrogeological issue, but it is not a groundwater resource issue because the Upper McMurray aquifer is not used for either source water or injection.

The stratigraphic complexity of the McMurray Formation means that meaningful discussion of the issues listed above cannot be approached as part of a regional, baseline assessment. As well, at the time of this writing, a major EUB hearing into gas-over-bitumen issues is going on in Calgary. Companies involved in this hearing are presenting new data and new interpretations relevant to each of the five issues above. Many of the new data would not have been released into the public domain for many years had it not been for the hearing. Because of the cascading effect that these new data may have on the interpretations of Barson et al., 2001, new investigations into the groundwater resources of the McMurray are best postponed until the hearing is complete and the new data and interpretations are released completely into the public domain.

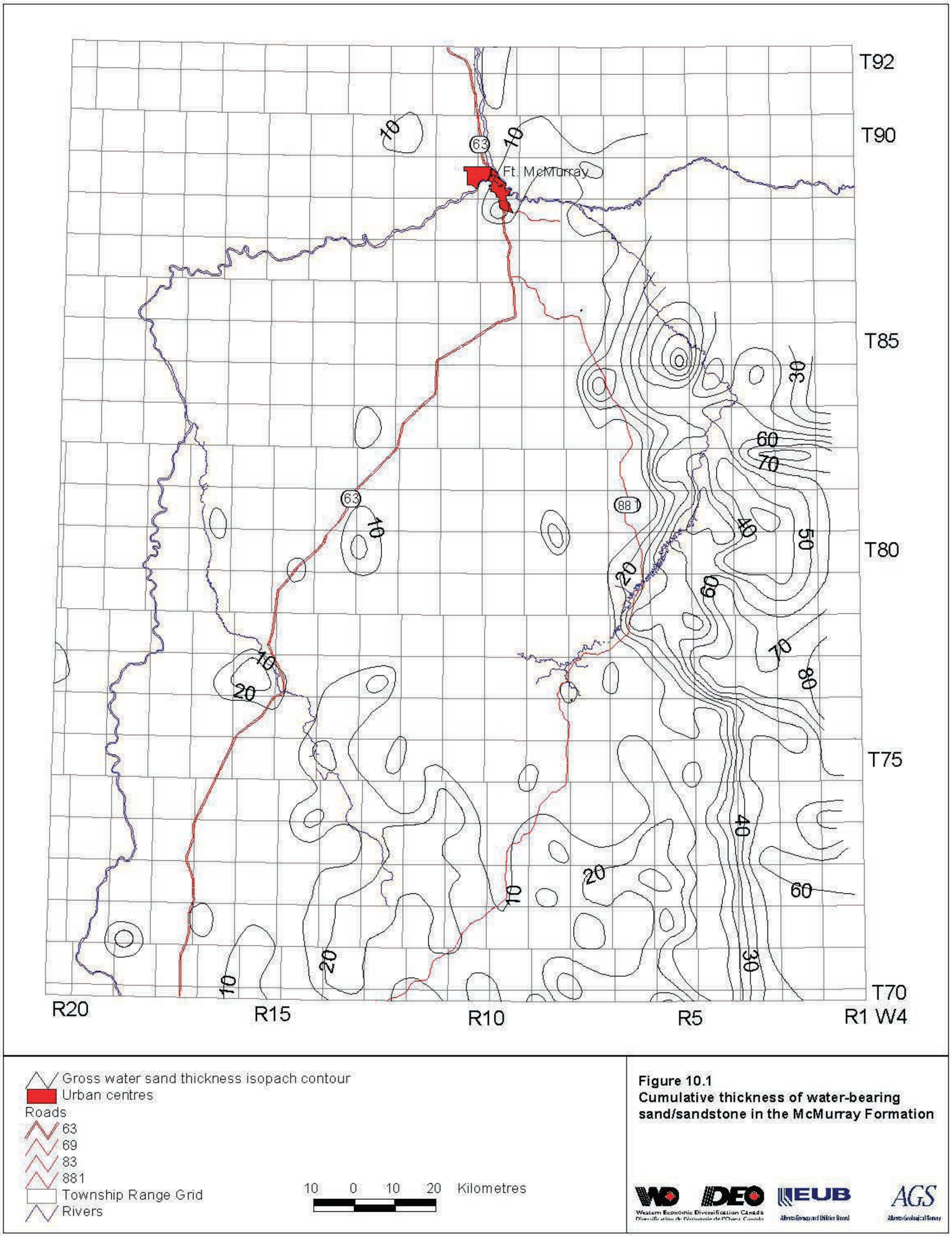

Figure 10.1
Cumulative thickness of water-bearing sand/sandstone in the McMurray Formation

But because of the need for baseline water characterization, four formation water samples were obtained from wells completed in the Wabiskaw and McMurray formations (see Figure 10.2). Data for an additional 3 wells completed in the McMurray Formation were extracted from historical records. The steps involved in selecting and sampling the wells are the same as described in Chapters 8 and 9. The results are presented in Appendix 7.

The total dissolved solids content ranged from 5434 to 25200 mg/l, which is saline but less saline than seawater. The $\delta^{18}O$ and $\delta^{2}H$ isotopic ratios are comparable to meteoric (Figure 10.3), which is consistent with the observations of Barson et al. (2001), who argue that the McMurray Formation water is receiving recharge from overlying sediments. The $\delta^{13}C$ of the three McMurray Formation water samples in the bitumen area all show substantial enrichment (Figure 10.4) relative to groundwater that has evolved through carbonate-mineral dissolution. This signature is consistent with bacterial methanogenesis (Clark and Fritz, 1997) and is consistent with the view that the McMurray oil sands are the biodegraded remnant of a conventional oil deposit (e.g., Deroo et al., 1974).

10.1 References

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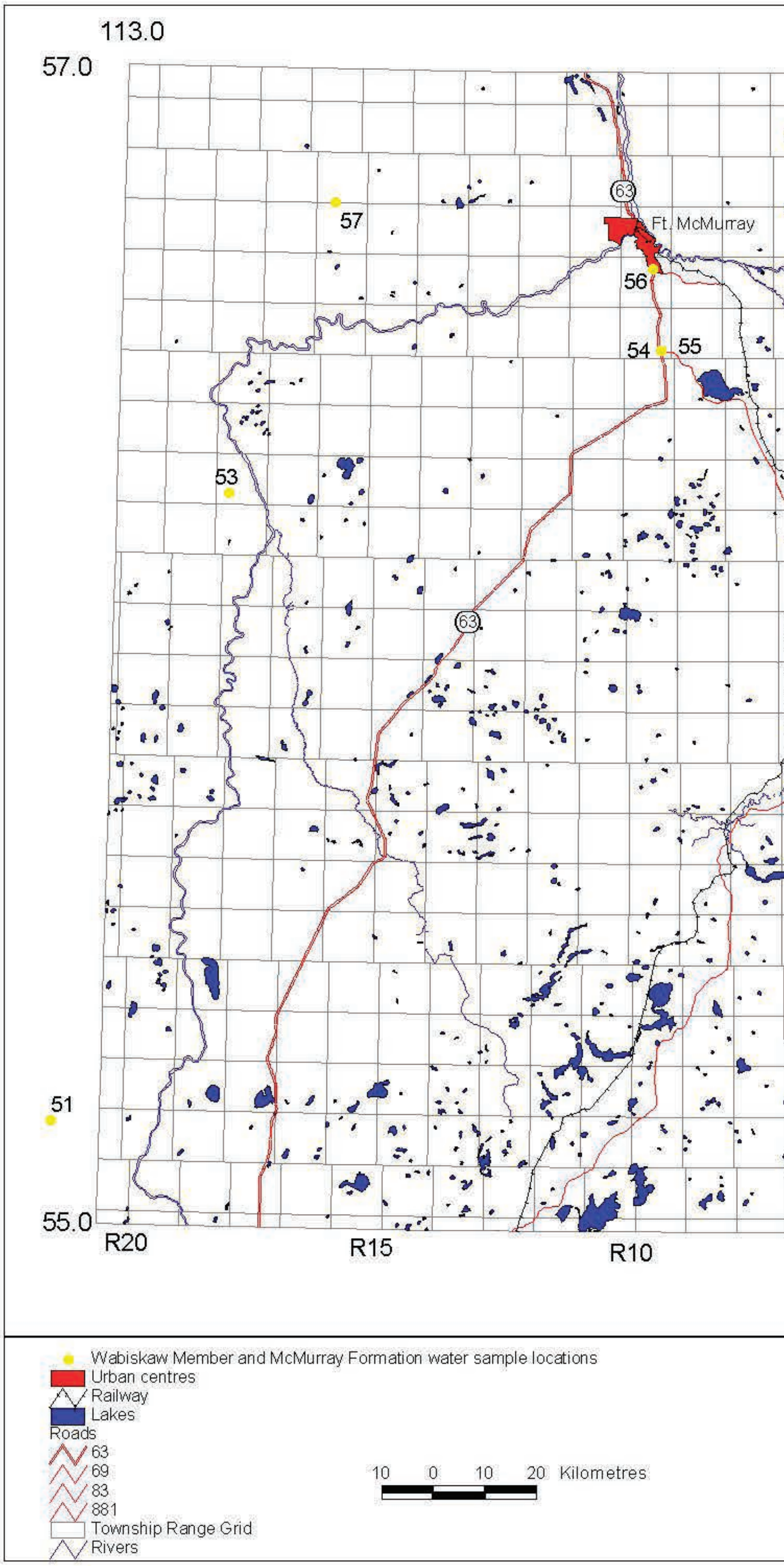

Figure 10.2
Location map of Wabiskaw Member and McMurray Formation wells

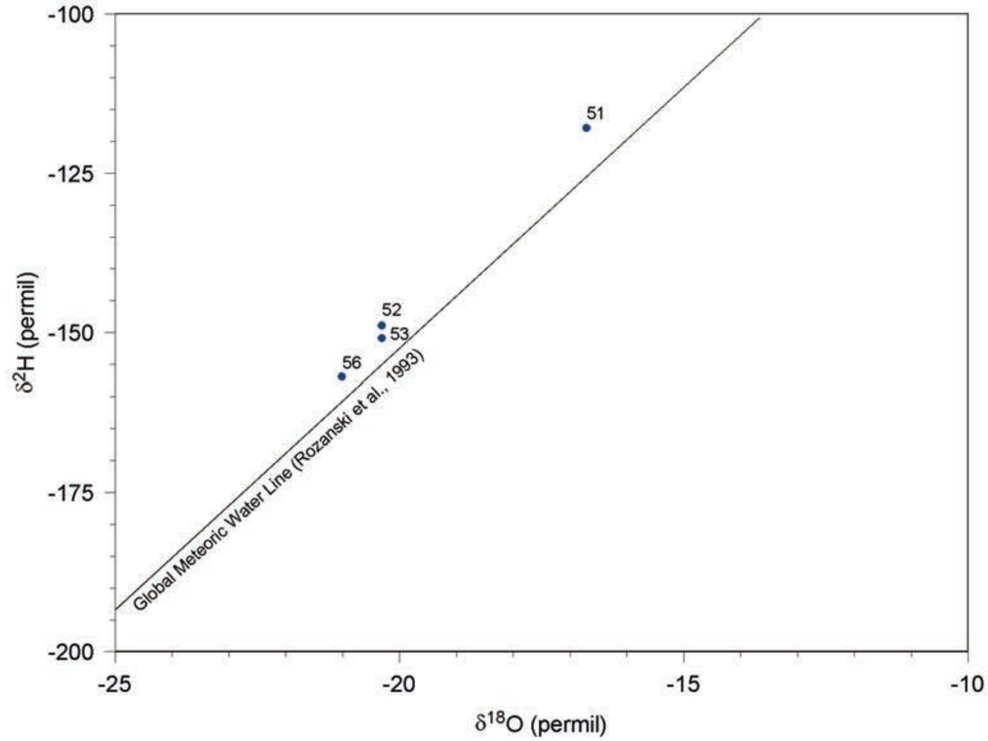

Figure 10.3. Oxygen-deuterium isotope plot comparing Wabiskaw Member and McMurray Formation water samples to the meteoric water line.

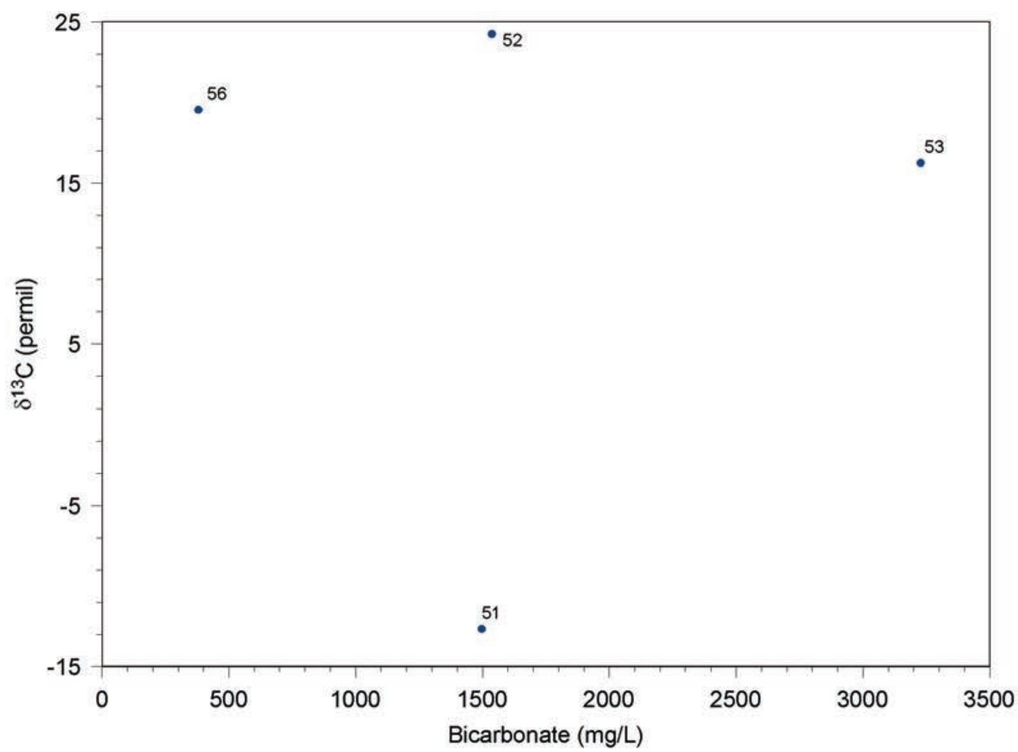

Figure 10.4. Carbon-13 isotope plot versus bicarbonate concentration in Wabiskaw Member and McMurray Formation water samples.

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Table A3-4: Geochemical analysis of samples from core hole WEPA99-2
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Appendix 4. Alberta Geological Survey Laboratory Grain-size and Carbonate-Content Analyses of Quaternary and Upper-Bedrock Samples

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Table A4-7: Matrix grain size and carbonate analyses, core hole WEPA00-4

Appendix 5. Alberta Geological Survey Water-Well Construction Details and Water-Level Information

Alberta Geological Survey water-well construction details
Tabular monthly water level elevations
Hydrographs of water level elevations, November 2000 to December 2001

Appendix 6. Field-Determination, Sample-Processing, and Sampling Protocols for Groundwater, Formation Water, and Surface Water.

Geonote 2002-09: Sampling of surface water and spring water in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 – A compilation of protocols and methods.
Geonote 2002-10: Sampling of groundwater from wells in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 – A Compilation of Protocols and Methods.
Geonote 2002-11: Sampling of formation water from wells in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 – A compilation of protocols and methods.

Appendix 7. Summaries of Groundwater Chemistry, Groundwater Isotope, and Groundwater Radiocarbon Analyses

Appendix 8. Guide to Recent Publications on Inorganic Water-Rock Interactions Relevant to Deep-well Wastewater Disposal in Carbonate-Evaporite Formations in the Athabasca Oil Sands Area, Alberta

Appendix 1. Surficial Geology Site Descriptions

NEQ96-Sec1 Longitude 110.62367 Latitude 56.367838

30 m high section on west side Christina River, July 29, 1996.

Unit 1: about 6m	Sand: upper 0.5m silty sand, massive; middle 1.5m medium grained, cross bedded; lower 2.5m horizontal bedded medium grained sand with 5cm thick silty clay beds; about 300 m north along section 1.5m horizontally bedded fine sand to silt and a few pebbles, well bedded over bank sediment overlying more than 1m of crossbedded medium sand.
Unit 2: > 3m	Till; clay loam texture; very dark grey to black; few pebbles or granules; unoxidized; friable; iron staining along fracture surfaces; weak reaction to HCL acid; at outcrop overlain by 20 cm thick very dark grey clay bed which also fractured and friable.
Unit 3: >5m	Grand Rapids Sandstone; fluvial sediment consisting of interbedded clayey silt and sand; well stratified, cross to planar bedded; hard iron cementing; weathers light grey; abundant muscovite flakes on weathered surface; abundant iron staining and some muscovite flakes along fracture an bedding planes; ironstone nodules in crossbedded sand.

NEQ96-Sec3 Longitude 110.69412 Latitude 56.414323

Fly stop along east side Christina River, July 29, 1996; DLS: 09-34-85-05W4; 10m high section above slump block to river level. 2 photos taken:

Unit 1: 2-2.5m	Diamicton (till-like); upper 1m uncertain; horizontal bedding or layers visible with sand layers about 10-30cm thick; numerous stones; grades downward into unoxidized till, with wavy contact defined by discontinuous sand layer.
Unit 2: 3m	Till; very dark grey exposed color; numerous stones; faint bitumen odor; greenish-grey colored bands near base of unit; thin wavy sand lenses and partings in horizontal wavy joints in till; moderate reaction to HCL acid.
Unit 3: 0.75m	Sand and silt; interbedded, well-sorted, glacial origin, silt reacts strongly to HCL acid.
Unit 4: >5m	Silt; uncertain origin; strongly jointed with strong iron staining along fractures; very dark grey; difficult to sample with hand pick; massive, no visible bedding; upper part of unit has bedrock appearance; interbedded with black silty clay beds (2-4 cm thick) about 0.5 m down from top of unit; strong groundwater discharge springs at base of slump face; mostly likely origin is Grand Rapids Formation bedrock.

NEQ96-Sec4 Longitude 110.792004 Latitude 56.489172

Fly stop along east side Christina River, July 29/96 DLS12-30-86-05W4; helicopter view indicates the following sequence:

1-2m Diamicton
5m Till
10m Glacial sand and gravel

NEQ96-Sec17 Longitude 110.354836 Latitude 56.668664

Fly view along east Edwin Creek, July 28/96 Numerous outcrops visible on east and west side of Edwin Creek Site 1: Crest of river valley; site described from helicopter only

Unit 1: 1m	Laminated lacustrine silt and clay; buff dark brown - no pink
Unit 2: 5-6 m	Till; columnar to massive till, has yellow brown oxidized color, but with grey veneer from overlying lacustrine colluvial veneer; wet stratified lenses and layers visible; a boulder pavement occurs at base of unit, one boulder thick, horizontal
Unit 3: 5-6m	Till; appears to have a less yellow brown and more grey brown color; at base is exposed a 1m thick deformed stratified unit; gradational contact between till and deformed stratified sedime
Unit 4: Colluvium	Bedrock not exposed; entire section appears to be drift, which is twice as thick as the drift in the outcrop to the north, towards the Clearwater River. 11 photos taken by LDA, photos RF96-1 #2-18 by M. Fenton.

Site 1 is located at crest of river valley and is not excessively eroded.
Sections exposed north of site 1.

1. Laminated silt and clay visible in adjacent outcrops but absent in subsequent outcrops to north.
2. The top 2-3 m of till is a layered sequence, which is gradational with underlying till.
3. At a couple of outcrops some indication of a boulder pavement; lenses of darker, coarser material within layered sequences (o.6-1m thick, 1-4m long).
4. Bedrock is visible in lower 1/2 of outcrop.
5. Large inclusions or blocks of what appear to be bedrock sandstone in the till unit - some are rounded, some angular.
6. The best outcrop to map is site 1. We did not see any intertill stratified sediment bu the lower part of site 1 was colluviated; therefore the major difference is that the drift is much thicker to the south and multiple tills are indicated.
7. Laminated silt and clay are present on the west side at northernmost end of Edwin Valley but not across valley on east side.
8. One outcrop on west side (south end of tributary) has what appears to be stratifie sediment (massive to poorly sorted) at base of till sequence (till is about 4-5 m thick), which correlates in elevation to the boulder concentration at site 1.

Section Revisited and sampled September 19, 1996.

Unit 1: 1m — Lacustrine silt and clay; light and dark grey rhythmites, each layer about 1cm thick, lighter silty layers and darker clayey layers.

Unit 2: 4m — Till; clayey-sand, soft, friable, very few clasts, some local sandstone cobbles, no iron staining, sharp upper and lower contact; boulder pavement directly below the lower contact; does not form shards; looking at a vertical cliff face one sees weakly developed horizontal joints with 2-5cm spacing. This unit 2 looks like the upper till at the OSLO site. Color grey brown.

	%MtxCO3	CO_2(ml/g)	%Sand	%Silt	%Clay
NAG96-660-2m	6.3	15.1	55	26	19
NAG96-661-4m	4.9	11.6	60	19	21

Unit 3: 6m — Till; silty sand; moderately hard, forms shards, non to very slight HCL reactions (however, cool day); more clasts than upper till; distinctly different from the upper till (harder, forms shards); medium to fine grained sand lenses which thicken to the top with 30 cm thick sand near the top; boulder horizon about 1/2 way down; grey color; till weathers a lighter color than above till even though fresh sample is grey and not grey brown as above unit 1.

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	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
NAG96-662-6m	5.2	12.5	58	34	8
NAG96-663-10m	4.2	9.9	62	28	10

Unit 4: >6m — Grand Rapids Sandstone?; fine sand to silt; some deformed 1mm to 1cm dark grey laminae; 2-4cm size ironstone nodules suggest that this is weathered bedrock; origin of sediment uncertain.

NEQ96-Sec22 Longitude 110.846948 Latitude 56.46861

Fly stop along Gregoire River, September 22, 1996.

Thick till section, difficult to land, check at lower water stage, Note! Most sections between here and the Christina River have about 4-6m of drift on bedrock; this section appears to have in excess of 20-25m of drift, but this is not confirmed

LA98-1 Longitude 110.51 Latitude 55.603336

Winefred River Section.

Unit 1: 0.5m Colluvium, roots .5 -

Unit 2: 1 - 1.5m Sand, stratified; well bedded

Unit 3: 1.5m Till; soft structureless, well oxidized olive brown, iron staining; sandy silt texture (loam); highly calcareous; manganese staining; 1% pebbles (some dolostone, granite); some high angle sand stringers; sample NATMAP 98-1 2.75m.

Unit 4: 0.15m Sand; subhorizontal, weakly bedded.

Unit 5: 0.1 m Sand and diamicton (till).

Unit 6: 0.65m Gravel with black diamicton; dirty, poorly sorted.

Unit 7: 2m Till; very dark grey, iron stained along fractures; moderately calcareous; 1% pebbles; clayey-sandy silt (sandy clay loam); bottom 0.5 m more clayey (heavy clay loam); black; weak to noncalcareous; till samples NATMAP 98-1 4.75m and NATMAP 98-1 6m.

Unit 8: 1.5m Shale; black, gypsum crystals; ironstone beds; block of displaced bedrock in till; sample collected.

Unit 9: 1.5m Till; similar to above till, sandy clay loam; strongly iron stained along fractures; moderately calcareous; faint bitumen odor; sample NATMAP 98-1 9m.

LA99-1 Longitude 111.6637 Latitude 55.036501

Approximately 15m outcrop on west side of Hwy 881.

Unit 1: 15 m Till; 3 till samples collected

LA99-1 3 m sample - clay loam; estimate 30% clay, 35% silt, 35% sand; moderate to strong reaction to HCL acid; color 2.5Y 3/2 very dark grey brown.

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
6.3	15	33.1	30.8	36.1

LA99-1 6 m sample - clay loam; 35% clay, 35% silt, 30% sand; siltier and less sand than above; weak to moderate reaction to HCL acid; color 10YR 3/2 very dark grey brown.

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
6	14.4	34.4	32.6	33

LA99-1 13m sample - clay loam; estimate 35-40% clay, 35% silt, 25-30% sand; clay (shale?) inclusions smeared within matrix; color 5Y 2.5/1 black to very dark olive grey; numerous Shield clasts throughout; some minor very rounded black chert and quartzite pebbles and cobbles.

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
4.6	11	44.6	24.5	30.9

Comments: Generally decreasing amount of carbonates in matrix with depth. About 50 m north of site is a 3 to 4m thick silty sand bed below the till. Silty sand bed undulates in north direction; a suggestion that this may be a block of sand incorporated within thrust moraine. If so, roadside stratigraphy is likely to be highly variable here due to thrust masses.

LA99-2 Longitude 111.635333 Latitude 55.042276

Unit 1: 3 to 4 m, Fine sand in roadcut through hummock; high relief topography in this area; sand almost has a preglacial appearance.

LA99-3 Longitude 111.453817 Latitude 55.159952

Unit 1: 3 m Gravelly sand in hummock along northwest side of Hwy 881; glacial origin, mostly granitic rock fragments.

LA99-4 Longitude 111.320533 Latitude 55.276967

Unit 1: 2.5 m Stony sand; hummock; collapse stagnant ice features around here may be composed of outwash/ ice-contact glaciofluvial sediment

LA99-5 Longitude 111.307467 Latitude 55.324454

East side of Hwy 881, next to DND Air Weapons Range.

Unit 1: Till; silty-clay texture, very little coarse sand; amorphous, iron-stained along joints; moderately calcareous; 1-2% pebbles, very few granules; estimate 20-25% sand, 40% silt, 30-35% clay; color 10YR 3/2 very dark grey brown; Note! This till is different from till at site LA99-1; it is similar to the Reita Lake till in Cold Lake, except it is more calcareous.

Sample LA99-5 2.5m.	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	15.2	36.5	24.5	36.6	38.0

LA99-6 Longitude 111.09891 Latitude 55.471701

Fresh road cut on west side of Hwy 881.

Unit 1: About 13 m of gravelly, stony sand; high relief hummock; ice-contact kame; a number of high relief knobs in area may also be kames; another kame sand outcrop at Longitude 111.09708 Latitude 55.479933 and at Longitude 111.0959 Latitude 55.5014; till outcrop about 400m north of site on east of Hwy 881.

LA99-7 Longitude 111.1247 Latitude 55.619729

Christina Creek Crossing.

Unit 1: 3 m Pebbly Sand, stratified, fine to medium grained, glacial, brown to grey-brow

Unit 2: 12 m, Till; clayey sand loam texture, estimate 45-50% sand, 35% silt, 15% clay; abundant medium to coarse
sand, hard, brittle, fractured, numerous pebbles, moderate to highly calcareous; looks like Marie Creek till without the abundance of 1-2mm sand and granules; upper 3 m slightly oxidized, becoming very dark grey to black at about 7 - 8 m down from top of section.

Sample LA99-7 4.5m Oxidized dark grey brown (2.5Y 3/2 very dark grey brown), very sandy and highly calcareous;

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
9.8	23.5	44.9	29.8	25.3

Sample LA99-7 6.5m Very sandy, oxidized 10YR3/4, highly calcareous, brittle, jointed, collapses when crushed between fingers

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
11.7	28.1	50.4	29.7	19.9

Sample LA99-7 7m	%MtxCO3	CO2(ml/g)	%Sand	%Silt	%Clay
	10.6	25.4	41.7	31.6	26.7

Sample LA99-7 9m Sandy clay loam, more clay than above, stiffer, black (5Y 3/1), highly calcareous, not too many granules or very coarse sand; dolostones on outcrop surface; iron staining along joints.

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
11.2	26.8	42.4	39.7	17.9

Sample LA99-7 11m Sandy clay loam, as above, with less clay; very brittle, jointed, black (5Y 3/1), slight iron-staining along joints; unoxidized sand lenses in till from 9 to 11 m.

%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
11.6	27.7	42.2	38.3	19.5

Sample LA99-7 13m	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	11.8	28	41	42.8	16.2

View across the road to the east shows wet, wavy silty sand beds in till, about 0.5 m thick; 5 photos taken of the outcrop and view on both sides of Hwy 881;
2 samples taken on east side of 881 at about 8.5 m and 11 m;
Sample LA99-7 8.5m
(East) till is highly calcareous; 2.5Y 4/4 olive brown

	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	10	23.9	49.8	28.8	21.4

Sample LA99-7 11m
(East) till is highly calcareous; 2.5Y 4/4 olive brown

	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	11.5	27.5	43.4	29.4	27.2

Comments: This appears to be a thick section of highly calcareous Marie Creek till, with abundant carbonates on the surface of the outcrop.

LA99-8 Longitude 110.976967 Latitude 55.730083

Unit 1: 1.5 m — Section of till near well site; sample at 1.3 m is silty-sand texture; loose, not much coarse sand or pebbles; sample in the C horizon is highly calcareous; soft, easy to dig, not indurated or consolidated like till at Christina Crossing outcrop; color 2.5Y 4/4 to 4/2, olive brown to dark grey brown.

	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
Sample LA99-8 1.3m	9.1	21.7	48.9	30.7	20.4

LA99-9 Longitude 110.713383 Latitude 55.815596

Cowper Lake Road; high relief, east bank of 1.5 km wide meltwater channel, south side of road.

Unit 1: 2 - 3 m — Till; silty-clayey sand texture, hard, brittle, iron-stained, very similar to till at Christina River crossing, but no reaction to HCL acid.

	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
Sample LA99-9 2.75m	0.3	73.9	25.8		

Unit 2: >1m — Black shale exposed in ditch on south side of road, 2 photos taken.

LA99-10 Longitude 110.46645 Latitude 55.836279

Unit 1: — Till; clay loam, sticky, not jointed or brittle, oxidized; not many pebbles, coarse sand or granules; non calcareous; mainly granite, quartzite, Athabasca Sandstone, no local rock types, very few carbonate rock types.

	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
Sample LA99-10 1.3m	1.1	2.5	48.1	18.2	33.7

SS1999-8 Longitude 111.09470 Latitude55.62036

Sand excavation pit; Aspen on edges of pit area.

SS1999-15 Longitude 112.37525 Latitude 55.48468

Clearing on west side of road; sandy-silty surface; small sand pit about 200 m from site.

SS1999-20 Longitude 112.14644 Latitude 55.65214

Sand pit along east side of road on the northern side of the House River crossing.

LA2000-1 Longitude 111.4653 Latitude 55.15233

Shallow road cut on the west side of Hwy 881, facing east. Hummocky to rolling, low to moderate relief; dominantly Black Spruce, minor Aspen, numerous organic depressions adjacent to hummocks.

Unit 1: 3m — Clayey-silt, little to no sand, no pebbles or granules in matrix; fissile to weakly bedded, bedding defined by dark clayey layers about 0.5cm thick; some cobbles and boulders on surface of roadcut; very moist; color 2.5Y4/4, olive brown; on north side of hummock a 0.3m thick fine sand bed overlies a 0.2m thick till bed, which overlies >0.1m thick clean, medium sand; 2 digital photos taken; unit interpreted as glaciofluvial or glaciolacustrine origin

LA2000-2 Longitude 111.3882 Latitude 55.18478

Road cut on the east side of Hwy 881, facing west; mixed spruce and Aspen, about 15m high; hummocky to rolling, low relief.

Unit 1: >2m Till; clay loam (clayey silt), little to no coarse sand or granules, cobbles on surface, <1% pebbles dominantly quartzite with some granites.

Sample	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
LA2000-02 2m	16.2	38.6	17.6	41.0	41.4

LA2000-3 Longitude 111.2233 Latitude 55.36358

Road cut on east side of Hwy 881; numerous pines, 6-10m high; rolling, low relief.

Unit 1: >3m Till; clay loam, estimate 30-35% fine sand, 40% silt, 25-30% clay; rilling on surface; 1% pebbles, metaquartzites; color 10YR3/3 dark brown; very weak reaction to HCL acid.

LA2000-4 Longitude 110.8433 Latitude 55.535

Helicopter stop on intersection of cut lines; hummocky, low relief; dominantly Jack Pine, minor spruce, abundant Caribou moss; wetlands cover about 50% of area; surface looks sandy; hand auger sampling.

Unit 1: 0.2m Ae soil horizon; loamy sand.

Unit 2: 0.4m Sandy loam; faint beds of clean, medium sand; estimate 65% sand, 30% silt, 5-8% clay; numerous cobbles in auger hole, Athabasca Sandstone, granite; material looks like very poorly sorted glaciofluvial sediment, with a till-like appearance (loamy sand diamicton); color 10YR5/4 yellow brown.

Sample	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
LA2000-04 0.2 – 0.6m	1.5	3.4	57.7	14.7	27.6

LA2000-5 Longitude 110.5943 Latitude 55.58902

Helicopter stop on edge of drill pad near gas well collector site; mix of spruce, Aspen, pine, and Labrador tea; hummocky moderate relief (5-6m), well drained with wetland depressions about 200m distance.

Unit 1: 0.4m Ae soil horizon; loamy sand with a few stones

Unit 2: >05m Sandy diamicton (till); estimate 50-60% sand, 30% silt, 10% clay; stiffer, more cohesive with depth; <1% pebbles; numerous Athabasca Sandstone boulders on surface, a few granites; color 10YR4/4 dark yellow brown.

Sample	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
LA2000-05 0.6-0.9m	0.9	2.2	46.6	20.7	32.7

LA2000-6 Longitude 110.4386 Latitude 55.61855 DLS 14-29-76-3W4

Helicopter stop at gas well site; mixed spruce and Aspen, 10-15m high; undulating, low relief; numerous Athabasca Sandstone boulders on surface, some granites.

Unit 1: 0.1m Moss.

Unit 2: 0.2m Ae soil horizon; loamy sand.

Unit 3: 0.55m Till; sandy loam, estimate 40-50% sand, 30-35% silt, 20-25% clay; 1-2% pebbles, very weakly calcareous at 0.8m from land surface; numerous white sand partings in till sample (these may be fracture infills with white loamy sand from Ae horizon above); color 10YR ¾ dark yellow brown.

Sample	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
LA2000-06 0.5-0.9m	0.9	2.2	44.8	20.9	34.3

LA2000-7 Longitude 110.2782 Latitude 55.59218

Helicopter stop on edge of north-south cut line; mix of Sphagnum moss, Black Spruce, and Labrador tea, with Caribou moss on surface; undulating low relief.

Unit 1: 0.1m Peat and organic soil.

Unit 2: 0.15m Ae soil horizon; loamy sand.

Unit 3: 0.65m Till; a few iron oxide blebs; some clay or shale clasts; more clayey than till at sites LA2000-5 and

LA2000-6; no reaction to HCL acid at 0.75m from land surface; color 2.5Y4/2 dark grey brown.

Relocate to site 10m to east
Unit 1: 0.1m Peat.
Unit 2: 0.6m Pebbly silt; minor sand; glaciofluvial origin
Unit 3: >0.1m Till.
Discontinuous veneer of glaciofluvial sediment on till

LA2000-8 Longitude 110.1082 Latitude 55.5268
Helicopter stop on old burn site; hummocky, moderate to high relief; 15-20 year-old Jack pine.
Unit 1: 0.15m Ae soil horizon; loamy sand, ashy white; oxidized rusty red at 0.15-0.2m down; boulder in auger hole.
Unit 2: 0.75m Silty to clayey-silt loam; 10YR4/4 dark yellow brown.

Sample	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
Sample LA2000-8a 0.7-0.9m	1.3	3	16.2	46.2	37.6

Unit 3: 0.2m Silty clay; clay rip-up clasts; no stones; color 2.5Y3/2 dark grey brown.
Unit 4: 0.25m Till; sandy clay loam, estimate 40-45% sand, 30-40% silt, 15-20% clay; some rusty iron oxide blebs, black carbonaceous blebs; 1-2% pebbles.

Sample	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
Sample LA2000-8b 1.1-1.25m	9.1	21.8	41.3	31.7	27

Comments: About 1m of glaciolacustrine or glaciofluvial sediment on till.

LA2000-9 Longitude 110.0775 Latitude 55.64543

Helicopter stop; shows evidence of old fire burn; undulating whaleback, low relief; pines on ridge and spruce in low areas; well drained site, Caribou moss on surface.
Unit 1: 0.2m Ae soil horizon; Sand; color 7.5Y7/2 pinkish grey.
Unit 2: 0.2m Bm soil horizon; Sand; medium to coarse, pebbly with cobbles.
Unit 3: 0.2m Sand; pebbly, medium to coarse sand; auger stopped on stones at 0.6m from surface; color 2.5YR4/6 red.
Comments: Augured three times and stopped on stones each time at about 0.7m down. Glaciofluvial deposit

LA2000-10 Longitude 110.1589 Latitude 55.79065
Helicopter stop at a logged burn site; undulating to rolling, low to moderate relief; dominantly Aspen with minor spruce and pine.
Unit 1: 0.05m LFH soil horizon.
Unit 2: 0.2m Ae soil horizon; sand, fine to medium, boulders at base of Ae horizon.
Unit 3: 0.95m Sand, fine, very well sorted, no pebbles, color 10YR6/4 light yellow brown

Relocated 10m north and augured new hole.
Unit 1: Ae soil horizon, sand, fine
Unit 2: Bm1 soil horizon, sand.
Unit 3: 0.2m Bm2 soil horizon (0.5m from surface); fine sandy silt
Unit 4: 0.1m Bm3 soil horizon, medium sand.
Unit 5: 0.1m Bm4 soil horizon, clayey diamictons.
Unit 6: 0.25m Bm5 soil horizon, fine to medium sand

Relocated 100m west on edge of logged area.
Unit 1: 0.05m LFH soil horizon.
Unit 2: 0.25m Ae soil horizon; stony loamy sand.
Unit 3: 0.5m Till; clay loam, with inclusions of fine to medium sand, clay clasts, and clay layer
Unit 4: >0.1m Till; mostly clay, looks like shale incorporated into till; mottled; a few pebbles; see site LA98-1 north

of Winefred Lake along Winefred River).

Sample LA2000-10 0.3-0.8m	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	1.5	3.4	43	12.9	44.1

LA2000-11 Longitude 110.2305 Latitude 55.98373

Helicopter stop in Black Spruce bog adjacent to pine-covered hummock, flat to very low relief, Labrador tea and Caribou moss.

Unit 1: 0.07m LFH soil horizon.
Unit 2: .63m Clayey silt with rounded black clay clasts 1-3mm in size; brown colored; 1 or 2 pebbles; no coarse sand or granules
Unit 3: 0.4m Clay; black; numerous rounded clay clasts.

Sample LA2000-11
Comments: This is either a lacustrine silty clay deposit with debris flow rip-up clasts of cla , or it is till derived from black shale with comminuted rounded clasts of shale and a few sandstone, quartzite and granite pebbles.

Relocated to nearby bog.
Unit 1: 0.5m Of soil horizon; fibrous peat
Unit 2: 0.1m Sandy clay loam; lacustrine sediment?

LA2000-12 Longitude 110.501 Latitude 55.95375

Helicopter stop at the Cowper Tower air strip; elevation 546m; high point on major upland ridge
Unit 1: 0.2m Ae soil horizon; sand, fine to medium
Unit 2: 0.3m Bm soil horizon; sand, fine, color reddish-brown
Unit 3: 0.7m BC soil horizon; sand, fine, well sorted, color light yellow brown
Comments: Glaciofluvial deposi

LA2000-13 Longitude 110.5094 Latitude 55.88207

Helicopter stop at cleared gas well site; Black Spruce, flat to low relief, boulders at surface
Unit 1: 0.2m Ae soil horizon; fine sand
Unit 2: 0.7m Sand; fine, grading to loamy sand with depth
Unit 3: >0.1m Till; sandy clay loam; soft and very sandy.
Comments: Glaciofluvial veneer on till

LA2000-14 Longitude 110.5568 Latitude 55.77337

Helicopter stop at recent burn site; flat to undulating low relief; numerous boulders on surface (lag?), Athabasca Sandstone, gneisses
Unit 1: 0.07m LFH soil horizon.
Unit 2: 0.13m Ae soil horizon; medium sand, cobble concentrations at base of Ae.
Unit 3: 0.8m Sand, pebbly, medium, moderately well sorted; wet at bottom of hole.
Comments: Glaciofluvial deposit

LA2000-15 Longitude 110.7464 Latitude 55.77563

Helicopter stop along pipeline; hummocky to rolling, low to moderate relief, mixed Aspen and spruce.
Unit 1: 0.07m LFH soil horizon.
Unit 2: 0.28m Ae soil horizon; sand, color pinkish light grey.
Unit 3:).55m Bm soil horizon; sand, medium, very well sorted, color yellow brown; no pebbles or granules
Comments: Glaciofluvial? Aeolian?

LA2000-16 Longitude 110.8775 Latitude 55.72173

Helicopter stop along right-of-way on road to gas plant; hummocky moderate relief.

Unit 1: 0.05m LFH soil horizon.

Unit 2: 0.3m Ae soil horizon; sand, medium, one or two pebbles.

Unit 3: 0.25m B horizon; sand, medium well sorted, a few pebbles.

Unit 4: >0.4m Till; sand loam to sandy clay loam; crumbles when crushed between fingers; estimate 60-70% sand, 20-30% silt, 10% clay; <1% pebbles.

Sample LA2000-16 0.7-1.0m	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	0.9	2.1	35.5	32.7	31.8

LA2000-17 Longitude 111.2518 Latitude 55.84347

Helicopter stop on very sharp relief ridge, 3-4m high, with organic bog to east and west of site; 6m drop-off on east side of ridge; lowland on west side of ridge may be a glacial meltwater channel; spruce in lowland, Aspen on slopes, pine on ridge.

Unit 1: 1m Sand; fine, silt , no granules or pebbles; color 10YR5/6 yellow brown.

Unit 2: 0.25m Till; sandy clay loam; estimate 45% sand, 30% silt, 25% clay; brittle; abundant coarse sand and limestone and dolostone granules; calcareous matrix, with moderate to strong HCL reaction; iron oxide blebs; color 2.5Y4/3 olive brown; looks like till at Christina River crossing on Hwy 881 (see LA99-7); similar to Marie Creek till in Cold Lake area.

Sample LA2000-17

Relocated to bog east of site

Unit 1: 0.5m Of soil horizon; fibrisol

Unit 2: 0.7m Silty loam; recent lacustrine deposit; black organic rich zone (Ohg) from 0.5 to 1m down from surface; sand lenses in bottom 0.2m of hole.

LA2000-18 Longitude 111.2929 Latitude 55.90562

Helicopter stop at a cleared well site; site is a poorly drained flat Sphagnum-Black Spruce bog with Caribou moss and minor Aspen

Unit 1: 0.15m Peat.

Unit 2: 0.4m Sand; silty, medium, grading to fine with depth; a few pebbles and cobbles (gneiss); gleyed, iron oxide blebs.

Unit 3: 0.45m Till; sandy clay loam, estimate 45% sand, 35% silt, 20-25% clay; very moist, soft; 1% pebbles; a few local bedrock siltstone clasts; iron oxide and black carbonaceous (manganese?) staining; no reaction to HCL acid; color 2.5Y4/2 dark grey brown.

Sample LA2000-18 0.55m	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	0.9	2.1	43.5	22.6	33.9

Comments: Glaciofluvial veneer on till

LA2000-19 Longitude 111.1825 Latitude 55.9881

Helicopter stop at gas well lease site; undulating to rolling, low relief; moderately well drained; dominantly spruce, minor birch, pine, Aspen; Caribou moss at surface; auger hole at edge of lease, in trees.

Unit 1: 0.07m LFH soil horizon.

Unit 2: 0.68m Silty loam to very fine sandy loam; a few pebbles; color 10YR4/4 dark yellow brown; interpreted as a fluvial or lacustrine unit

Sample LA2000-19a 0.07-0.75m	%MtxCO3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	0.9	2.1	52.8	25.4	21.8

Unit 3: 0.45m Till; sandy loam, estimate 70% sand, 20% silt, 10% clay; abundant 1-2mm thick sand lenses giving unit a stratified appearance; <1% pebbles; iron oxide blebs; color 2.5Y4/2 dark grey brown;

extremely sandy till (Gipsy till?).

Sample LA2000-19b 0.75-1.2m	%MtxCO_3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	0.9	2.1	56.3	19.6	24.1

Relocated 40 m east of site.

Unit 1: 0.6m Sand, pebbly, loamy, massive; looks like till; Athabasca Sandstone, granite boulders on surface of lease.

LA2000-20 Longitude 111.1365 Latitude 56.07765

Helicopter stop at gas well lease site; flat, wet, poor drainage; dominantly Black Spruce and Sphagnum

Unit 1: 0.75m Of; fibric organic soil profil

Unit 2: 0.25m Oh; humic organic soil profile

Unit 3: 0.25m Silty clay; gleyed, noncalcareous; sticky; recent lacustine sediment.

LA2000-21 Longitude 111.003 Latitude 56.14838

Helicopter stop at abandoned gravel pit, excavated at least 5m deep; hummocky moderate to high relief; 12-15m high pine, some Aspen Labrador tea on ground surface; auger site is about 40m west of gravel pit on side of hummock; well drained.

Unit 1: 1m Silty loam; faint bedding on auger-flyt samples; 1 or 2 pebbles near top of unit; glaciofluvial deposit

Unit 2: Till; Silty clay loam; very soft, sticky; not much coarse sand; some iron and manganese oxide blebs; <<1% pebbles; color 2.5Y 4/3 olive brown; appears to be gradational contact between silty loam and till.

Gravel Pit Description

Unit 1: 2-3m Sand; well stratified; fine to medium; normal faulting visible in horizontal beds, some deforme beds; dark beds of loamy sand with iron oxide concretions

Unit 2: >3m Gravel, coarse; digital photo taken, 5 35mm slides.

Comments: Ice-contact glaciofluvial kame deposi

LA2000-22 Longitude 111.1611 Latitude 56.26458

Helicopter stop at gas well site; hummocky, moderate to high relief; dominantly Aspen; many large boulders on surface, some limestone; well drained, with mossy ferns on surface.

Unit 1: 0.1m LFH soil horizon.

Unit 2: 0.55m Till; sandy loam; stony layer at the Ae-Bm soil contact

Sample LA2000-22 0-0.65m	%MtxCO_3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	0.9	2.1	36.4	28.1	35.5

Unit 3: 0.5m Sand; medium, well sorted, 1 to 2 pebbles.

Unit 4: >0.1m Till; sandy loam; estimate 70% sand, 20% silt, 10% clay, 1% pebbles; Ck soil horizon, strongly calcareous; color 2.5Y4/3 olive brown.

Comments: Sandy gravelly surface of lease site and nearby pipeline suggests this area may be an ice-contact glaciofluvial map unit.

Relocate 100m west of lease along pipeline.

Unit 1: >1m Sand, medium, pebbly; granite clasts; interpreted as ice-contact glaciofluvial kame complex

LA2000-23 Longitude 111.4535 Latitude 56.22528

Helicopter stop at gas well lease site; undulating, low relief; mainly spruce; moderately well drained, creek to west.

Unit 1: 0.1m Peat.

Unit 2: 0.55m Silty loam; clast free; soft, color 2.5Y5/4 light olive brown.

Unit 3: 0.25m Silty clay; mottled, color dark grey brown to olive brown; clay clasts in clay matrix.

Unit 4: 0.15m Till; sandy clay loam, estimate 50-60% sand, 25% silt, 15% clay; <1% pebbles; iron oxide blebs; color 2.5Y4/3 olive brown.

Sample LA2000-23 0.9m	%MtxCO$_3$	CO$_2$ (ml/g)	%Sand	%Silt	%Clay
	0.9	2.1	36.4	28.1	35.5

Unit 5: 0.15m Silty clay; stratified, well defined, finely bedded laye eigen shaped clay lenses 2mm thick.

Comments: Complex looks like water-laid sediments including diamicton (till); interpreted as a glaciolacustrine sedimentary complex.

LA2000-24 Longitude 111.5858 Latitude 56.13798

Helicopter stop at gas well lease site; old burn site; undulating, low relief, shallow hummock (4m relief) about 100m to east; stones on surface, new growth pine, Black Spruce; poorly drained site.

Unit 1: 0.08m LFH soil horizon

Unit 2: 0.27m Bm soil horizon; silty loam; no pebbles, color yellow brown

Unit 3: 0.65m Till; silty clay loam, estimate 50% sand, 25-30% silt, 15-20% clay; numerous sand lenses, abundant clay (shale?) clasts; <1% indurated pebbles; iron and manganese oxide blebs; very moist, soft.

Sample LA2000-24 0.5-1m	%MtxCO$_3$	CO$_2$ (ml/g)	%Sand	%Silt	%Clay
	1.1	2.6	33.7	31.2	35.1

Comments: Glaciolacustrine veneer on till.

LA2000-25 Longitude 111.6072 Latitude 56.03908

Helicopter stop in a naturally cleared old burn site; 2-3m tall pines, spruce in wetlands nearby; shallow hummock about 1-1.3m high, surrounded by Black Spruce bog, numerous cobbles and boulders at surface.

Unit 1: 0.45m Sand; medium, with 1 or 2 pebbles; bedded; iron oxide concretions; color 10YR5/8 yellowish brown

Unit 2: 0.15m Sandy clay loam; diamicton; dark grey brown; iron oxide nodules in upper part; 1% pebbles and granules.

Unit 3: 0.65m Sand; coarse, glacial, very well sorted, some clayey silt lenses 0.5cm thick; wet; oxidized to bottom of interval.

Comments: Glaciofluvial deposit, possibly near glacier source (diamicton layer

LA2000-26 Longitude 111.8526 Latitude 55.94457

Helicopter stop at logged burn site; rolling low relief.

Unit 1: 0.03m LFH soil horizon.

Unit 2: 0.3m Aeg soil horizon; gleyed silty sand.

Unit 3: 0.25m Btj soil horizon; silty loam; a few coarse clasts.

Unit 4: 0.4m Till; clay loam, estimate 30-35% sand, 30-35% silt, 25-30% clay; dense, stiff; abundant local siltstone fragments, some clay (shale?)-rich clasts; iron and manganese oxide blebs; 1-2% pebbles and granules, some granite, local bedrock; color dark grey brown.

Sample LA2000-26 0.5-0.9m	%MtxCO$_3$	CO$_2$ (ml/g)	%Sand	%Silt	%Clay
	1.1	2.6	35.9	26.4	37.7

Comments: Glaciolacustrine veneer on till.

Relocate 150m east of site along logging trail.

Unit 1: 0.4m Silty loam; some pebbles and cobbles at base of unit; color olive brown

Unit 2: 0.1m Till; clay loam; stiff.

Comments: Glaciolacustrine veneer on till.

LA2000-27 Longitude 111.7134 Latitude 55.83442

Helicopter stop at well site; rolling, low relief; mix of Aspen, spruce, pine, some Birch

Unit 1: 0.25m Peat, thin (3-5cm) Ae soil horizon at base of interval

Unit 2: 0.4m Silty sand; till?; a few pebbles; possibly a transition between soil horizons A&B; no Bt horizon observed.

Unit 3: 0.2m Till; sandy clay loam; sandier than till at site LA2000-26; 1-2% pebbles; a few thin sand lenses; iron oxide blebs.

LA2000-28 Longitude 111.7745 Latitude 55.73723

Helicopter stop at north end of well site; undulating to hummocky, moderate relief, dominantly spruce and pine; well drained

Unit 1: 0.03m LFH soil horizon.

Unit 2: 0.03m Ae soil horizon.

Unit 3: 0.59m Bm soil horizon; sand; fine to medium, some silt; compact structure; iron oxide concretions; color 10YR5/8 yellow brown.

Unit 4: 0.5m BC soil horizon; sand; well sorted, fine to medium, no pebbles or granule

Comments: Well sorted medium sand – glaciofluvial? aeolian

LA2000-29 Longitude 111.5751 Latitude 55.68902

Helicopter stop at intersection of pipeline and well site; flat; Black Spruce bog; we

Unit 1: 0.6m Peat

Unit 2: 0.1m Aeg soil horizon; sandy loam

Unit 3: 0.3m Till; sandy clay loam; 1% pebbles; abundant sand in matrix; stiff, plastic; gleyed

	%MtxCO_3	CO_2 (ml/g)	%Sand	%Silt	%Clay
Sample LA2000-29 0.7-1m	1.3	3	47.4	19.6	33

LA2000-30 Longitude 111.5234 Latitude 55.58447

Helicopter stop at intersection of cut lines; flat, poorly drained; mix of Black and White Spruce, Larch, some pine, and Caribou moss on ground.

Unit 1: 0.1m Peat.

Unit 2: 0.1m Ae soil horizon; sandy loam, pebbles at contact with B horizon.

Unit 3: 0.6m Btjg soil horizon developed on till, silty-clay loam texture, estimate 70% sand, 20% silt, 10% clay; some stones; manganese oxide blebs.

Unit 4: 0.3m Sand; medium to coarse, silty, gritty.

Comments: Till veneer on glaciofluvial outwash

LA2000-31 Longitude 111.6918 Latitude 55.142083

Roadside outcrop.

Unit 1: 5m Sand; medium to coarse, cobble horizon 2.5m down from top of unit

Comments: Glaciofluvial deposit

LA2000-32 Longitude 111.714917 Latitude 55.1514333

Abandoned gravel pit; ridged to hummocky topography.

Unit 1: >6m Sand and gravel; 1cm to 4cm sized gravel; medium to coarse sand, some granules

Comments: Looks like an esker ridge, ice-contact glaciofluvial deposit

LA2000-33 Longitude 111.00611 Latitude 55.6004

Road cut exposure; 2-3 m high Aspen and pine growth; 1 photo taken.

Unit 1: >2.5m Sandy diamicton and sand; poorly sorted, dirty glaciofluvial deposit with well sorted sand lenses

LA2000-34 Longitude 110.98249 Latitude 55.5957

Road stop at old drill site; clover covered; hand auger sample description.

Unit 1: 0.4m Silty sand; pebbly; glaciofluvial deposit

LA2000-35 Longitude 110.97531 Latitude 55.58727

Road stop at large cleared well site; hand auger sample description; 1 digital, 1- 35mm photo.

Unit 1: 0.4m Till; sandy loam, estimate 60% sand, 30% silt, 10% clay.

LA2000-36 Longitude 110.87767 Latitude 55.51328

Clover-covered site, Aspen and spruce nearby; hand auger sample description; 1- 35mm photo

Unit 1: 0.5m Sand, fine, pebbl , loose, soft; glaciofluvial deposi

LA2000-37 Longitude 110.8434 Latitude 55.45875

Abandoned sand pit on south side of road; very well drained; 1- 35mm photo; looks like ice-contact glaciofluvial kame deposit.

LA2000-38 Longitude 110.727933 Latitude 55.464467

Outcrop along east side of road; organic areas nearby.

Unit 1: 5m Sand, silty, grading to silty coarse sand at base of unit; glaciofluvial deposit

LA2000-39 Longitude 110.719917 Latitude 55.473483

Outcrop on east side of road, about 400m north of Kirby Gas Plant, at junction with east-west road.

Unit 1: 3.5m Till; sandy loam, estimate 70% sand, 20% silt, 10% clay; a few sand lenses about 0.5-1cm thick.

Sample LA2000-39 1.3m	%MtxCO_3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	10	23.9	50.8	24.7	24.5

LA2000-40 Longitude 110.70645 Latitude 55.472433

Abandoned drill site on northeast side of road; alfalfa and clover covered; 1- 35mm photo.

Unit 1: Gravelly sand exposed in outcrop on southwest side road; pebbly medium sand; glaciofluvial deposit

LA2000-41 Longitude 110.6459 Latitude 55.455583

Outcrop along east side of road.

Unit 1: 1m Clayey silt; weathers buff brown; glaciolacustrine deposit.

Unit 2: 0.15m Silty clay; very dark grey brown to black; glaciolacustrine.

Unit 3: 1.35m Till; sandy loam, estimate 70% sand, 20% silt, 10% clay, 1% pebbles.

Comments: Glaciolacustrine veneer on till.

LA2000-42 Longitude 110.6097 Latitude 55.364933

Clearing on south side of road; 2-3m Aspen and pine growth; hand auger sample description

Unit 1: 0.3-0.4m Loamy sand; cobbles.

Unit 2: 0.2m Till; sandy clay loam; coarse lag veneer on till surface.

LA2000-43 Longitude 111.039767 Latitude 55.7275

At approach west of Hwy 881, along a logging trail adjacent to the Christina River; 15-20m tall Aspen; hummocky, moderate relief.

LA2000-44 Longitude 110.917233 Latitude 55.746883

Aggregate stockpile site 60m east of Hwy 881, on Talisman Road (North Winefred); 1- 35mm photo; looks like till in outcrops.

LA2000-45 Longitude 110.761 Latitude 55.627433

Gravel stockpile site and pit along the north flank of the Christina meltwater channel complex; digital photo taken

LA2000-48 Longitude 111.2772 Latitude 55.66806

Grassy, clover clearing on east side of road; gentle incline to north, low relief; silty sand exposed at surface; 1 digital photo, 1- 35mm slide.

LA2000-49 Longitude 111.41625 Latitude 55.598383

Hummocky, low relief; spruce and pine on hummocks.
Unit 1: 0.7m Sand; silty, medium grained, stony
Unit 2: 0.2m Diamicton and sand; sandy clay diamictons (till?) bed.
Unit 3: 0.2m Sand; medium grained.
Comments: Ice-contact glaciofluvial deposit

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LA2000-50 Longitude 111.361333 Latitude 55.6981

Gas lease site; 6m high outcrop on southwest side of lease, along meltwater channel.
Unit 1: 6m Silty clay with iron oxide nodules.
Comments: Interpreted as glacially displaced block of shale

Relocate to outcrop about 300m east along road; Longitude 111.3576 Latitude 55.6979
Unit 1: 5m Shale; bedded, dark brown to black silty clay with pale olive (5Y 6/4) layers (0.5cm) of bentonite; beds are discontinuous in outcrop, mostly horizontal; a few pebbles and cobbles on surface of fresh outcrop (rounded quartzite, quartz sandstone); 2 digital photos, 3- 35mm photos.

Sample LA2000-50 3m	%MtxCO_3	CO_2 (ml/g)	%Sand	%Silt	%Clay
	1.1	2.6	1.7	80.8	17.5

Comments: Interpreted as glacially displaced block of shale bedrock.

LA2000-51 Longitude 111.239033 Latitude 55.683983

2m high outcrop along east side of road.
Unit 1: 2m Till; clay loam; dark grey brown; much more clayey and darker colored than the till east of Conklin community; possibly enriched with shale and siltstone on the top of Stony Mountain.

LA2000-52 Longitude 111.32955 Latitude 55.450966

Adjacent to abandoned railroad siding at Margie; well drained, undulating to hummocky, low relief, clover covered.

LA2000-53 Longitude 111.324266 Latitude 55.446683

Road side outcrop
Unit 1: 1.5m Till; clay loam to loam; numerous sand lenses; olive brown; less clayey and more olive brown colored than till at LA2000-51.

LA2000-58 Longitude 110.796867 Latitude 55.8157

Road side outcrop; 1- 35mm photo.
Unit 1: 0.3m Discontinuous boulder lag on surface.
Unit 2: 1.1m Sand, well bedded, pebbly, moderately well sorted, medium grained; oxidized.
Unit 3: 0.15m Sand; fine, darker grey than above, bedded
Unit 3: 0.65m Sand; medium grained, bedded as above, fining with depth
Unit 4: 0.4m Sand; medium to coarse, pebbly, stony; oxidized; poorly bedded; some boulders.
Unit 5: 0.4m Till; fine sandy loam; wav , irregular contact with overlying sand; abundant lenses and inclusions of fine sand and silt; very weakly calcareous; 1% pebbles; possibly thick sand bed beneath till, but covered by colluvium.
Comments: Interpreted as ice-contact glaciofluvial and morainal complex (kame-moraine)

LA2000-59 Longitude 110.697433 Latitude 55.820666

Outcrop on north side of road; rolling, moderate relief; Aspen.
Unit 1: 0.6-2.5m Till; loam to fine sandy clay loam; 2.5 4/2 dark grey brown; irregular contact with underlying sand.
Unit 2: 0-2.2m Sand; medium grained, a few stones.

LA2000-60 Longitude 110.6615 Latitude 55.815633

Observation along logging trail.

Unit 1: 0.6m Sand; fine to medium grained

LA2000-61 Longitude 110.556167 Latitude 55.815633

Abandoned construction camp; sandy surface; well drained, slopes to the east; 2 digital photos

Unit 1: 0.6m Boulders, sand, cobbles

Unit 2: 0.8m Till; sandy clay loam; soft moist, sticky; <1% pebbles and granules; color 2.5Y4/2 dark grey brown

Sample LA2000-61 0.6-1.4m	%MtxCO$_3$	CO_2 (ml/g)	%Sand	%Silt	%Clay
	1.3	3	44.8	27.3	27.9

LA2000-62 Longitude 110.415167 Latitude 55.8596

Observation of outcrop along south side of newly constructed road

Unit 1: 3-4m Sand, stony.

LA2000-63 Longitude 110.34265 Latitude 55.866767

Observation of outcrop on north side of newly constructed extension of Cowper Road.

Unit 1: 10m Gravelly sand; outcrop dressed with till with prevent erosion of underlying sand.

LA2000-64 Longitude 110.3194 Latitude 55.860233

Borrow pit on north side of road.

Unit 1: 3-4m Till; no sand visible.

LA2000-65 Longitude 110.28035 Latitude 55.850583

Undulating to rolling, low relief; dominantly spruce; large boulders on surface.

Unit 1: 0.45m Ae soil horizon; sandy loam to loamy sand.

Unit 2: 0.4m Till; fine sandy clay loam; color 2.5Y4/2 very dark grey brown; mottled, gleyed; pebbles <1%; sticky, plastic, moist; abundant clay in matrix.

Sample LA2000-65 0.85m	%MtxCO$_3$	CO_2 (ml/g)	%Sand	%Silt	%Clay
	1.1	2.6	47.6	17.1	35.5

Comments: Not like the sandy Gipsy till that L. Bayrock described in the region in the early 1970's.

LA2000-67 Longitude 110.999183 Latitude 56.091483

Gravel pit exposed in hummock on the north side of road; 1 digital photo.

Unit 1: 4-5m Gravel; cobbly.

LA2000-68 Longitude 111.033167 Latitude 56.0991

Observation along road; hummocky; 1 digital photo.

Unit 1: Gravel; boulders; poorly sorted; glaciofluvial deposit

Comments: Glaciofluvial gravel observed along road from LA2000-67 to 68

LA2000-69 Longitude 111.0514666 Latitude 56.10425

Gravel pit and stockpile; 2 digital photos, 5- 35mm photos.

Unit 1: 8-10m Sand and grave; boulders.

Comments: Similar to site LA2000-21 to the north of this site; ice-contact glaciofluvial deposit

LA2000-70 Longitude 110.875017 Latitude 56.150583

Reclaimed sand pit, flat to rolling; well drained; glaciofluvial deposi

LA2000-71 Longitude 111.0269 Latitude 56.38615

Borrow pit on east side of Hwy 881; 1 digital photo.

Unit 1: 3m — Shale; Clearwater Formation?; black, silty clay; fissile; olive brown to grey silt partings; locally capped by 1m thick indurated silty sand (sandstone?) which forms 'mini hoodoos'; some granite pebbles on surface suggest unit may be glacially modified, or possibly displaced, shale and sandstone.

LA2000-72 Longitude 110.966883 Latitude 56.318117

Recently cleared construction staging site on west side of Hwy 881; flat; poor to moderate drainage; 1 digital photo; looks like clayey till at surface.

LA2000-73 Longitude 110.955967 Latitude 56.30245

Gravel stockpile on west side of Hwy 881; well drained, flat; 1 digital photo; no visible geolog .

LA2000-74 Longitude 110.921383 Latitude 56.245283

Small clearing on north side of road; clover, small Aspen; 1 digital photo; sandy surface.

LA2000-76 Longitude 110.95875 Latitude 56.228567

About 10 hectare gravel pit and stockpile area; 1 digital photo.
Comments: Looks like same glaciofluvial sand and gravel complex as seen at LA2000-21, and LA2000-68

LA2000-77 Longitude 110.8863 Latitude 55.567467

Outcrop section along south side of lease road.

Unit 1: 4m — Silty sand; medium grained; bedded with sandy diamicton layers; very poorly stratified to massive outcrop appearance.

Comments: Interpreted as either very poorly sorted glaciofluvial outwash deposit, or very sandy till

LA2000-78 Longitude 110.9079 Latitude 55.55555

Outcrop along west side of road; described from mid point of section

Unit 1: 5-6m — Till; sandy clay loam, estimate 45-50% sand, 30% silt, 20% clay; fractured with iron staining along fracture faces;

LA2000-79 Longitude 110.8544 Latitude 55.462417

Outcrop on north side of road; pine, spruce, minor Aspen.

Unit 1: 2.5m — Till; sandy loam to sandy clay loam, estimate 50% sand, 25-30% silt, 15-20% clay; soft, easy to dig.

LA2000-80 Longitude 110.737117 Latitude 55.458817

Outcrop along road.

Unit 1: 2.5m — Sand; gravelly with large inclusions of very dark grey brown sandy loam diamicton (till?); ice-contact glaciofluvial deposit

LA2000-81 Longitude 111.28765 Latitude 55.761667

Outcrop on west side of road; mixed Aspen and spruce.

Unit 1: 1.5m — Silty clay; very dark brown to black with beds of very dark brown clayey silt; discontinuous beds overlying till(?).

Comments: Site interpreted as glacially displaced shale and siltstone (see site LA2000-50).

LA2000-82 Longitude 111.315417 Latitude 55.8039

Outcrop along east side of road

Unit 1: 2.3m Gravelly sand; till inclusion at base of unit (sandy clay loam, estimate 50-60% sand, 25-30% silt, 10-15% clay)

LA2000-83 Longitude 110.7619 Latitude 55.627533

Esker ridge oriented parallel to Christina Lake meltwater channel complex; about 20 digital and 35mm slide photos taken.

Unit 1: 10-12m Gravel; collapse structures in flanks of esker gravel indicate ice-contact glaciofluvial origi

LL2000-1 Longitude 111.46675 Latitude 55.1519

Shallow outcrop on west side of road; flat to rolling, low to moderate relief; dominantly Black Spruce, minor Aspen.

Unit 1: 2-3m Clayey silt; faintly bedded; color 2.5Y4/4 olive brown.

Comments: North part of outcrop displays beds of sand, fine to medium grained, well sorted, as well as blocks of diamicton (till) with very few granules or pebbles. Site interpreted as ice-contact glaciofluvial deposit

LL2000-2 Longitude 111.08665 Latitude 55.616267

South flank of meltwater channel directly west of Christina Lake; 3-4 m relief; mixed Aspen and spruce, with sedges and Black Spruce in floor of channel

Unit 1: 3-4m Sand; medium to fine, massive, oxidized; <1% pebbles to granule size clasts; glaciofluvial deposi

LL2000-3 Longitude 111.046667 Latitude 55.6123

Outcrop on south side of road, on upper part of meltwater channel near site LL2000-2; mixed Aspen and spruce; gently undulating, low relief.

Unit 1: 2.5m Sand; fine to medium, massive; unoxidized; moist; very few stones; rare cobble and boulde .

Unit 2: Till; sandy loam; very few stones (<1% granules, pebbles); some limestone and sandstone boulders; pebbles include Athabasca Sandstone, limestone, granite, gneiss.

Comments: Glaciofluvial outwash on till

LL2000-4 Longitude 110.956983 Latitude 55.5821

Site along road side; flat, low relief; mainly spruce, some pine

Unit 1: Sand; medium grained, massive; slightly oxidized; no pebbles or granules; glaciofluvial deposit

LL2000-5 Longitude 110.908983 Latitude 55.556683

Site along road side; gently undulating to rolling, low relief; mix of Aspen, spruce, some pine.

Unit 1: Till; sandy loam; color 2.5Y4/4 olive brown; 1-2% granules; pebbles and cobbles on surface (sandstone, granite, some limestone, rounded to sub angular).

LL2000-6 Longitude 110.886183 Latitude 55.5091

Site on northwest side of road; rolling, low to moderate relief; mostly Aspen, some spruce.

Unit 1: Till; sandy loam; 1-2% granules; pebbles and cobbles on weathered surface.

LL2000-7 Longitude 110.8747 Latitude 55.478816

Observation along road side; hummocky, moderate relief (5-6m).

LL2000-8 Longitude 110.901383 Latitude 55.473433

Observation on west side of road; flat to gently undulating, low relief; mostly spruce, some pine and Aspen; located on small knob that lies above adjacent organic area.

Unit 1: Sand; medium to coarse, trace of silt, no pebbles; glaciofluvial deposit

LL2000-9 Longitude 110.7357 Latitude 55.3753

Observation on southwest side of road; rolling to hummocky; open pine forest with patchy Caribou moss; pines up to 10m high.

Unit 1: Sand; medium; oxidized, color 10YR5/8 yellowish brown; no stones; glaciofluvial deposit

LL2000-10 Longitude 110.515683 Latitude 55.432833

Near shoreline of Winefred Lake; rolling topography; mostly spruce, some Aspen; shovel pit.

Unit 1: Sand; fine to medium, some silt, no pebbles; glaciofluvial deposi

LL2000-11 Longitude 110.455033 Latitude 55.39295

North shore of Grist Lake; flat to rolling; mix of spruce, pine, Aspen, birch.

Unit 1: Sand; medium with discontinuous lenses of black (charcoal?) and more oxidized sand; glaciofluvial deposit

LL2000-12 Longitude 110.456133 Latitude 55.393783

Auger sample description at base of small hummock, northeast side of road; rolling to hummocky, low relief (<3m); spruce, pine, a few Aspen, some willow and birch.

Unit 1: 1m Sand; medium; glaciofluvial deposit

LL2000-13 Longitude 110.459433 Latitude 55.396117

North side of road on 6-8m high ridge, trending 247^0, steep side on north face; mix of Aspen and spruce.

Unit 1: 6-8m Till; loam; 1-2% coarse fragments; a few pebble-size clasts; color 2.5Y4/4 olive brown.

Comments: Sand excavated in flank of ridge, medium grained, massive, no stones. Feature looks like esker ridge

LL2000-14 Longitude 110.5107 Latitude 55.41025

Observation on north side of road; undulating to rolling, low to moderate relief; mix of Aspen and spruce.

Unit 1: 0.3m Sand; medium to coarse, massive; slightly oxidized; a few large pebbles; sharp, undulating contact with underlying till.

Unit 2: 0.7m Till; loam; 1-2% pebbles.

Comments: Glaciofluvial veneer on till

LL2000-15 Longitude 110.581667 Latitude 55.3728666

South facing exposure, hummocky to rolling moderate relief; burned area, pine and spruce about 8-10m high.

Unit 1: 0.25m Till; loam; <1% pebbles, massive

Unit 2: 0.25m Sand; coarse to gravelly, fining with depth; glaciofluvial origi

Comments: Other shovel pits dug into hummock show sand at surface in some places and till in others.

Comments: Interpreted as till and sand morainal complex.

Appendix 2. Log Descriptions of Alberta Geological Survey Core Holes

Appendix 2a: Lithology of Core Hole WEPA99-1

Appendix 2b: Lithology of Core Hole WEPA99-2

Appendix 2c: Lithology of Core Hole WR99-1

Appendix 2d: Lithology of Core Hole WEPA00-1

Appendix 2e: Lithology of Core Hole WEPA00-2

Appendix 2f: Lithology of Core Hole WEPA00-3

Appendix 2g: Lithology of Core Hole WEPA00-4

Appendix 2a: Lithology of Core Hole WEPA99-1

PROJECT: **WEPA Hydrogeology**	DATA NO: **WEPA99-1**	LOGGED BY: S. Stewart	DATE: Sept.17, 1999
DRILLER: Layne- Christiansen	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 660.92 m
LOCATION: LSD 03 SEC 08 TP 77 R 14 W4	LATITUDE: 55.6517371°	LONGITUDE: 112.1468557°	Source: Surveyed
COMMENTS ON LOCATION: Alberta Transportation sand pit on east side of HWY 63, against the trees on south side of clearing.			

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0.0	1.5	cuttings	0.60	Sand	Med. Sand.
		cuttings	0.30	Sand	Silty med. Sand.
		cuttings	0.10	Silty sand	Silty sand, poorly sorted, dark brown (10YR4/3).
		cuttings	0.50	Sandy silt	Clayey loamy sand 5% clay, quartz pebbles.
1.5	3.0	0.00		Sandy silt	No recovery.
3.0	3.6	0.15	0.15	Silty sand	Possible reclaimed material, organic stain, rootlets, dark grey brown (2.5Y4/4).
3.6	4.3	0.23	0.23	Silty sand	Fine silty sand, bedded, dark carbon flecks, some iron staining, dark grey brown (10YR3/2), fin low-angle bedding planes.
4.3	4.9	0.00		Silty sand	No recovery.
4.9	5.5	0.40	0.40	Silty sand	Interbedded clay layer (6 cm), fine silty sand; 12cm silty sand; 6cm clayey silt; fine sand-silty fi sand unoxidized base of clay layer (5Y3/1) very dark grey.
5.5	7.0	0.00			No recovery.
7.0	8.5	0.90	0.90	Sand	10cm coarse sand, coal flakes, mottled, iron staining, unoxidized, massive to weakly bedded, bedding planes 5-10° , differential oxidation on bedding planes, med-coarse grained with coarser beds more oxidized, rusty brown.
8.5	10.3	0.30	0.30	Silty sand	Interbedded clay, sand beneath clay zone; mottled with oxidized and unoxidized zones, poorly sorted deformed bedding planes, mottled silty clay.
10.3	11.9	0.36	0.36	Sand	Poorly sorted medium sand, some carbon flecks (10YR4/3) dark brown, dirty sand
11.9	15.8	0.40	0.40	Sand	Poorly sorted medium sand, weakly bedded 1 cm silt beds, iron oxide precipitation at sand contact (siderite); coal flecks, dark brown matrix; grey clay clasts

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
15.8	18.9	1.65	1.65	Sand	Medium to coarse poorly sorted sand, dark brown, weakly stratified; carbonaceous streaks along bedding planes, fairly uniform from top to bottom (10YR4/3) dark brown.
18.9	21.9	0.15	0.06	Sand	Fine-medium sand (6 cm thick) mottled, iron oxide staining.
			0.01	Siderite	1 cm thick siderite zone at sand/till contact.
			0.08	Till	Very dark grey till, non-calcareous, 30% clay, 35% silt, 35% sand, pebbles, 7cm sandstone cobble in ???, pebbles <1%.
21.9	25.0	0.70	0.06	Sand	Recovery from bottom 70 cm of cored interval (from 24.3 m to 25 m depth); medium sand lense; sharp contact with till below; 50% sand, 15% clay, 35% silt, brittle, gritty Iron oxide stained; 5% coarse sand granules.
			0.64	Till	Dark grey till, 35% clay, 45% silt, 20% sand; Iron oxide staining at base of sample; 1-2 cm thick dark olive grey silt at base of sample.
25.0	25.9	0.35	0.20	Till	Bedding planes, iron oxide cementing (1-1.5 cm thick) rusty brown; dark olive grey weakly bedded iron oxide along partings.
			0.15	Stones	Base- well rounded granites and dolostones.
25.9	26.2	0.30	0.30	Gravel	Large sandstone boulder, granitic rocks; small amount of till, non calcareous, slight Fe stain, very dark grey/brown, 2.5Y 3/2; gravel contains quartz, feldspar (very angular), 3-4mm.
26.2	27.4	0.00		Cobbles	Large cobbles, quart and igneous .
26.8	27.4	0.60	0.60	Gravel	Very angular, igneous and quart (grab sample).
27.4	28.0	0.60	0.60	Cobbles	Igneous and dolostone.
28.0	28.3			Cobbles	Sandstone cobbles, trip out- rock bit, catch samples.
28.3	29.2	cuttings		Cobbles/ boulders	Poor cuttings from rock bit, ~1cm size, no sample, igneous, quartzite, angular.
29.2	29.5	cuttings	0.30	Till	Poor cuttings from rock bit, ~1cm size, no sample. Ream hole to 30.5m.
30.5	33.5	0.95	0.95	Till	No recovery of upper 2m. Drilled like till, granite boulder at top of hole, weak HCl reaction, sandy clayey silt, 2-3cm pebbles of granite, sandstone and carbonates 5Y2.5/1 black. 40%silt, 35%clay, 25% sand, ~5-2% pebbles.
33.5	36.2	0.00		?	No recovery, driller says rock stuck in bit-trip out. Driller unsure about material.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
36.2	36.5	0.20	0.20	Till?	No recovery, some till stuck to bit, plastic, stiff, clayey silt, some sand, black, very little coarse material.
36.5	37.4	0.00		Till	Large sandstone rock in shoe.
37.4	39.3	0.00		Till	Boulder in shoe- no recovery.
39.3	39.9	0.57	0.15	Till	Silty, clayey, 2% pebbles, stiff, black, non-calcareous, 5Y2.5/1.
			0.42	Till	Sandy, silty, clayey, 2% pebbles, stiff, black, noncalcareous, 5Y2.5/1.
39.9	41.4	0.80	0.80	Till	Sandy silty clay till, very fine sandy partings, sti f, black (5Y2.5/1), 2% pebbles, some organic flecks, 35%silt, 30%sand, 35%cla , 2cm twig.
41.4	42.7	1.22	1.22	Till	Weakly calcareous, sandy silty clay, 2% pebbles 5Y2.5/1, black, 40% clay, 35% silt, 25% sand, less plastic than previous till.
42.7	44.2	1.55	1.30	Till	Black, sandy silty clay, <1% pebbles 5Y2.5/1, apparent washouts, 40%silt, 25% sand, 35% clay, limestone clasts, weakly calcareous, very stiff.
			0.20	Till	45% clay, 35% silt, 20% sand, black..
			0.05	Till	40% silt, 25% sand, 35% clay.
44.2	45.7	0.66	0.66	Till	Black, silty, sandy clay, with sand partings, weak to noncalcareous, 40%clay, 35%silt, 25%sand, o.5cm sand enrichment, <1%coarse/ pebbles.
45.7	47.2	0.00		Sand?	No recovery.
47.2	48.0	1.25	0.45	Till	This section from previous run- clay till, mottled, very stiff, waxy, black, 55%clay, 30%silt, 10-15%sand, section goes from 10cm clay rich to heavy clay till back into clay.
			0.90	Till	Alternating clay and heavy clay till, dry, brittle, siltstone?, ~3cm thick inclusion or bed, noncalcareous, some sand.
48.0	48.7	1.22	0.90	Till	Silty clay till, sandy zones ~2cm thick, coarse sand partings, shale clast inclusions, very faint oil odour, waxy black, 10%sand, 30%silt, 55-60%clay alternating clay/silt contents, 15%sand, 45-50%clay, 35%silt.
			0.32	Till	Sandy clay till, 25%sand, 35-40%clay, 35%silt.
48.7	50.2	1.35	1.35	Till	Sandy clay till, 40% sand, 40%silt, 20%clay, oxidation zones @20cm, noncalcareous, 2% pebbles, medium grained sand partings @22cm, oxidation colour = 10YR 3/6, dark yellow brown, at 80cm there are siltstone clasts.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
50.2	51.8	1.76	1.76	Till	Clayey, sandy, silt till, very dark grey, noncalcareous, 3-4% pebbles, 45-50%sand, 35%silt, 10% clay. Munsell colour= 5Y2.5/1, black, some shale clasts.
51.8	54.8	3.00	3.00	Till	Black, silty sandy clay till, mostly same as above, 1-2% pebbles, 4cm thick calcareous cemented brecciaed mudstone? @2.15m, gypsum nodule? @2.95m.
54.8	57.9	2.80	2.80	Till	Clay sandy silt, 40%sand, 40% silt, 20%clay, 1-2% pebbles, evidence of local bedrock fragments, @80cm, a 5cm thick zone of clay enrichment in matrix (35%sand, 35%silt, 30%clay, <1% pebbles).
57.9	61.0	0.80	0.80	Till	Stone in shoe (poor recovery), black, 35%sand, 35%silt, 30%clay, <1% pebbles.
61.0	64.0	2.95	0.90	Till	Black clay sand silt till, 35% sand, 35%silt, 30%clay, 1-2% pebbles, large stone @ 50cm (sandstone).
			1.15	Bonneville till?	New till, sharp contact, 5Y4/3 olive oxidation pervasive entire matrix, sandier, bedrock clast inclusions, coal flecks, non-weakly calcareous, 5% pebbles, 45-50%sand, 35-40%silt, 15-20%cla .
			0.80	Till	Oxidation following paleo fractures, 45-50% sand, 15-20%clay, 25-30% silt, noncalcareous, coal flecks
64.0	67.0	---		Till	Rock in bit, likely still in till.
67.0	68.6	1.40	0.80	Till	3-4% pebbles, oxidation fractures, 45-50% silt, 40%sand, 20%clay, 2cm granite clast on oxidation zone, matrix very dark grey to black, very sandy along fracture planes, abundant granules.
			0.60	Till	Lose oxidation completely, ~5% pebbles, very weakly calcareous.
68.6	70.1	1.75	1.75	Till	5% pebbles, 2-3% coarse sand and granules, 40-45%silt, 45%sand, 15%clay, clayey sandy silt till, very dark grey to black, very weakly calcareous, 5Y2.5/1.
70.1	73.2	2.60	2.00	Till	As above, weak-moderately calcareous, sand partings, shale clasts, silt clasts.
			0.60	Till	>% fine sand, ~50% increase in sand in bottom 60cm, clay-silt sand
73.2	76.2	3.02	0.12	Till	As above, >% clay , <sand, clayey silt till, shale and silt clasts.
			0.83	Till	Clayey sandy silt till, abundant granules, weak to moderately calcareous.
			0.13	Very fine san	Fine silty sand.
			1.94	Till	4cm stones, abundant pebbles, clayey sandy silt till, weak to moderately calcareous, very dark grey to black.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
76.2	79.2	2.60	2.60	Till	Weak to moderately calcareous, clayey sandy silt till, abundant pebbles and granules, very dark grey to black, 45-50% silt, 40%sand, 15% clay , ironstone granules, shale clasts, granites, sandstone pebbles (3cm).
79.2	82.3	2.15	0.45	Till	45-50%sand, 40-45%silt, 10-15%clay, abundant pebbles, no bedrock clasts, driller hit stone, possibly sand: 'water sand'.
			1.65	Till	Vuggy (wash out sand?), moderately calcareous, bedrock clasts, black, quartz and granite pebbles.
82.3	84.3	0.10	0.10	Till and stones	Driller says rocks and gravel, only drilled 2.0m @82.3m-84.3m, coarse gravel, limestones, granites, very angular, some till (5cm) recovered at bottom of bit, clay sandy silt till, weakly calcareous, abundant pebbles.
					Last 2.0m, drill chatter all the way down, felt like stones and rocks.
84.3	84.9			Boulders	Driller says 'very rocky 60cm', trip out and put on rock bit, rocks are very angular, granitic, Athabasca sandstone.
84.9	86.5	bag sample	0.70	Boulders and gravel	Rocks, very angular, as above, sandstone, granite, chert.
		cuttings	0.90	Till	No sample, described from small rock bit cuttings, clayey sandy silt.
86.5	87.0	---	---	Till	Driller says stone in bit.
87.0	88.3			Till	Clayey sandy silt till, shale clasts, 2-3% pebbles, weakly calcareous, 40% silt, 35-40% sand ,20-25% clay, 5Y2.5/2, abundant coarse granules.
88.3	89.6	0.03		Till	Hit rock, disturbed core, stiff, black, sandy clayey silt, weakly calcareous, abundant granules and coarse sand, 1-2% pebbles, 40%silt, 30-35%clay, 25-30%sand.
89.6	90.6	1.17	0.60	Till	Hit boulder, 3% pebbles, clayey sandy silt till, 45% silt, 30-35% sand, 30-35% clay, black, 2-3% granules, some coarse sand (2%), weakly calcareous, unoxidized, stiff.
			0.10	Silt and till	0-10cm of silt inclusion (not a bed) same as above.
			0.47	Till	Same as above, 3-4 large pebbles.
90.6	92.6	1.26	1.26	Till	Black, clayey sandy silty till, same as above, 3-5% pebbles (sandstone and granite), large shale clast @91m, very weakly calcareous, 5Y2.5/1, abundant granules (coarse sand), stiff (cracks when broken), siltstone inclusions.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
92.6	94.8	0.75	0.75	Till	Black, clayey, sand, silty till, as above, rock at 75cm, no more recovery to 94.8m, rocks (granite and athabasca sandstone), some sandstone inclusions, very small and minor.
94.8	96.6	1.33	1.00	Till	Black, as above, very weakly calcareous, rock at contact with below.
			0.06	Till	Dark olive grey, 5Y3/2, clayey sandy silt till ,stiff, 3-5% pebbles, weakly calcareous, 40% silt, 35% clay, 25% sand.
			0.27	Till	Black, weak to moderately calcareous, 40% silt, 35-40% clay, 20-25% sand, chert pebble, 3-5% pebbles, more CaCo3, more clayey.
96.6	98.1	1.71	1.71	Till	Black, sandy clay silt till, more bedrock clasts, siltstone, sandstone, shale, chert, >5% pebbles, moderately calcareous, interval enriched with local bedrock.
98.1	98.7	0.25	0.25	Till	Black, sandy clay silt till, bedrock clasts, moderately calcareous, dense, stiff, ~5% pebbles, abundant shale, siltstone, rock @98.1m (gneiss).
98.7	100.3	1.70	1.70	Till	Black (5Y2.5/1) clay sandy silt till, enriched with local bedrock, >5% pebbles, 2-3% granules/ coarse sand, moderately calcareous, very stiff, abundant quartz sand (2-3%).
100.3	103.0	2.49	1.03	Till	Black, moderately to strongly calcareous, abundant local bedrock clasts, 5% pebbles, sandy clayey silt, 30% clay, 35-40% sand, 35-40%silt.
			0.94	Till	Interbedded clay till and sand clay silt till with inclusions of clay silt ~10-15cm thick @60cm, highly calcareous zone- silt lense, higher silt= >CaCo3, bottom 30cm is noncalcareous (below silt lense).
			0.52	Clayey silt	Black, clayey silt, silt partings <<1% pebbles, angular clay clasts, non calcareous, sharp contact with clayey sandy silt till above, a few coarse sand and granule clasts (quartz).
103.0	106.0	2.13	0.70	Clayey silt	Black, silt to clayey silt, as above, increasing granules with depth, lignite inclusion, high angle contact of clay silt with unit (clay sandy silt till) below, noncalcareous.
			0.94	Till and silt	Black, clayey sand, silt, moderately calcareous, lots of dolomite pebbles, 8% pebbles, abundant carbonate pebble clasts.
			0.38		Interbedded clay sand, silty till and clay silt. clay silt has high angle, vertical bedding.
106.0	106.5	1.43	1.43	Till and silt	Recovered core lost from previous run. Clayey sandy silt till with inclusions of weakly calcareous silt at high angle, abundance of calcareous pebbles, moderately calcareous matrix, black, silt inclusions from 5-15cm thick.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
106.5	109.6	1.11	1.11	Till	Driller said drilled easy, like sand to 108.8m, clayey sandy silt with inclusions of clay (5-15cm), weakly calcareous, sandy inclusions (5Y2.5/1), black, 3-5% pebbles, local bedrock, pebbles abundant, 40%silt, 30-35%sand, 25-30%clay.
109.6	111.3	1.10	1.10	Till	Sandy clay silt, abundant pebbles (3-4%), gritty, 35%sand, 25-30%clay, 40%silt, numerous local bedrock clasts (black shale), very weak to noncalcareous, dense, 2-3% coarse sand, 5cm quartzite cobble at bottom of core.
111.3	112.5	1.33	1.33	Till	Sandy clay silt, very gritty, as above but more pebbles (4-5%), 1-1.5cm shale clasts, no inclusions or beds, siltstone, igneous, local sandstone, shale, very weakly calcareous, a few fine sand partings 20cm from top of core, large cobble at end of run.
112.5	115.2	2.85	2.85	Till	As above, silty clay inclusion at 36-41cm, waxy, sandy silty clay, more clay in matrix, abundant shale clasts up to 1-1.5cm, occasional fine sand partings, 20%of clasts are local bedrock, mostly black clay stone, very weakly calcareous, 5% pebbles increase in pebbles in bottom 0.5-0.75m of core, gritty till, 30-35%sand, 35%clay, 35-40%silt.
115.2	116.4	0.85	0.85	Till	Sandy clay silt, about 5% more clay in matrix, very stiff, numerous shale clasts, fewer pebbles than above core interval, 3% pebbles, 30%sand, 35%clay, 35%silt, lignite clast (rusty brown), very weakly calcareous.
116.4	118.5	1.66	1.26	Till	Sandy silty clay, clay enrichment due to shale clast inclusions, 6cm shale clast at 12cm from top, very weak to noncalcareous, 35-40%clay, 35%silt, 25-30%sand, large shale clast orientation vertically on long axis.
			0.40	Till	Sandy clay silt, more silty, fine sand, less clay in matrix, fewer shale clasts, very weakly calcareous, 1-2%pebbles, gritty when cut with knife, 30-35%clay, 35%sand, 35-40%silt.
118.5	121.6	3.00	1.70	Till	Sandy silty clay, dense, abundant shale inclusions, 1-2% pebbles, weak to noncalcareous.
			0.02	Sand	Coarse sand lense in till.
			1.28	Till	More pebbles than above 1.7m, more silty, sandy clay silt, weak to noncalcareous, 3% pebbles, (large limestone cobble at 30cm from top of core, Athabasca sandstone cobble in core), gritty till, till still contains abundant coarse sand and granules/pebbles equal% sand and clay, silt dominant, fewer shale clasts in bottom1.28m of core.
121.6	123.7	2.20	0.55	Till	Sandy clay silt, 3% pebbles, gritty , 30%sand, 30-35%clay, 35%silt, stiff, dense, noncalcareous.
			0.75	Silty clay	Sharp contact with above till, irregular wavy silt partings, nearly vertical, some silty partings throughout, black clay (shale?) clasts (3mm), about 45^{o} angle contact with till below, sharp contact, 80^{o} angle deformed, dark black clay streaks, possibly block of mudstone in till.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.90	Till, minor sand lenses	Sandy clayey silt, some fine sand lenses near base of interval, 10cm interval of fine sand at abou 60-70cm down in the interval, 4-5% pebbles, sandstone, shale, quartzite, gritty till when cut, 35-40%silt, 30%sand, 30%clay, weak to noncalcareous.
			0.90	Till, minor sand lenses	Sandy clayey silt, some fine sand lenses near base of interval, 10cm interval of fine sand at abou 60-70cm down in the interval, 4-5% pebbles, sandstone, shale, quartzite, gritty till when cut, 35-40%silt, 30%sand, 30%clay, weak to noncalcareous.
			0.90	Till, minor sand lenses	Sandy clayey silt, some fine sand lenses near base of interval, 10cm interval of fine sand at abou 60-70cm down in the interval, 4-5% pebbles, sandstone, shale, quartzite, gritty till when cut, 35-40%silt, 30%sand, 30%clay, weak to noncalcareous.
123.7	124.7	0.72	0.72	Till	Sandy clayey silt, 30-35%sand, 30-35%clay, 35-40%silt, 2-3% pebbles, weak to noncalcareous, fine sand parting @45cm from top, rotten sandstone pebble
124.7	127.7	2.97	2.97	Till	Sandy clay silt, same texture as above, 3% pebbles, gritty abundant coarse sand and granules, some 2cm, shale clasts (2cm), sandstone, noncalcareous, numerous Athabasca sandstone pebbles, particularly the larger pebbles.
127.7	130.8	2.50	2.50	Till	As above, 2-3% pebbles, amount of clay in matrix varies as the amount of shale clasts in the till, numerous shale pebbles, sandy clay silt texture, gritty, very weak to noncalcareous, very dense and hard till, 1 chert pebble, abundant local siltstone, sandstone, core breaks on very thin discontinuous sand partings (2 breaks).
130.8	133.8	2.77	2.25	Till	As above, sandy clay silt, 2-3% pebbles, enrichment of sand in matrix @ 95-110cm from top of core, possibly incorporation of sand, noncalcareous.
			0.10	Sand	Fine sand, soft, unoxidized, no bedding visible, 60cm thick unit, driller said soft, easy from 132.9m to 133.5m.
			0.42	Till	As above, sandy clayey silt (30-35%sand, 30-35%clay, 35-40% silt), abundant local pebbles.
133.8	136.9	2.55	1.00	Till	Sandy clayey silt, as above, very dense, 2-3% pebbles, noncalcareous.
			0.55	Till? (sand)	Very sandy, soft till (?), silty sand with pebbles, easy drilling, very poorly sorted diamicton.
			1.00	Till	Two sand partings, each about 3cm thick, fine to medium @ 160cm from top of core @175cm from top of core, sandy clay silt till, numerous bedrock fragments, very weakly calcareous @ 190cm from top, 7cm thick Athabasca sandstone boulder cored @136.6m.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
136.9	139.9	3.20	3.20	Till	As above, sandy clay till, 3-4% pebbles, gritty, very sandy diamicton inclusion @ 25-25cm from top core, dense, weakly calcareous (more than @ 120-135m), estimate 30-50% of pebbles are local bedrock clasts, core breaks on very thin discontinuous fine sand and silt partings (occasional, not common).
139.9	143.0	3.14	3.14	Till	Sandy clay silt, as above, 3-4% pebbles, ~50-60% pebbles are local bedrock clasts, no carbonate clasts evident (haven't seen carbonate clasts for last 15-20m), Athabasca sandstone and granites present, weakly calcareous, fine sand partings @ 55cm of top core
143.0	146.0	2.45	2.45	Till	Sandy clay silt, 30%sand, 25-30% clay, 40-45% silt, 3-4% pebbles, 6-7cm calcite-cemented sandstone boulder @ 140cm from top of core, white calcite vein about 1cm thick in grey sandstone (grand Rapids sandstone?), weakly calcareous, abundant local bedrock.
146.0	148.4	2.95	2.95	Till	As above, gritty, sandy clay silt, 3-4% pebbles and granules, abundant local bedrock clasts (4cm black shale clast), weak to moderately calcareous, increase in carbonate in matrix, local bedrock clasts ~60-70% of pebbles, very fine sand parting @55cm from top of core, clay % varies with amount of shale clasts.
148.4	149.0	0.47	0.47	Till	Increase in clay in the matrix, sandy silty clay, (30%sand, 35%silt, 30-35%clay), a few granite pebbles, 70% of pebbles of local bedrock origin - shale, siltstone, Ironstone, weak to moderately calcareous, 4-5% pebbles and granules, gritty till.
149.0	150.3	1.25	0.86	Till	As above, sandy clay silt, dense, abundant pebbles, local bedrock, weak to moderately calcareous.
			0.20	Silty sand	Poorly sorted silty sand, massive to poorly bedded with discontinuous fine sand partings, weak to moderately calcareous, dense, stiff.
			0.19	Sand and silty sand	Medium sand interbedded with dense silty sand, ~4-6cm thick, unoxidized, weak to moderately calcareous.
150.3	152.7	2.30	2.30	Till	Sandy silty clay, 70-80% local bedrock clasts, some round chert, few igneous shield clasts, gritty ~5% pebbles, moderate to strongly calcareous along cut surfaces, no visible limestone or dolostone, black, stiff, dense, 30-35%sand, 30-35%clay, 35-40%silt.
152.7	153.8	1.45	1.08	Till	Sandy silty clay, 5% pebbles, siltstone, Athabasca sandstone, igneous, more shale clasts, moderate to strongly calcareous, siltstone.
			0.37	Silty clay	Discontinuous silt partings, high angle, almost vertical, silt partings are very weakly calcareous, claystone appearance, possibly displaced block, 10cm block of till within half diameter of core, weak slickensides.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
153.8	154.5	0.00		Till?	Till at end of core barrel, thin cutting sand clay silt, gritty, lost core.
154.5	155.1	0.00		Bedrock? shale?	Lost core, changing core catcher, driller says he can feel the core at the bottom of the hole, tripped down again, but nothing in the core barrel again.
155.1	156.2	1.67	1.67	Mudstone (shale) (shell fragments)	Silty clay, claystone, weakly bedded with silt partings along bedding planes, clam shell (fossils (2-3cm) @ depth of 156m (147cm from top of core), recovered 60 cm of core from above drill interval as well as 1.1m of core in this drill interval, shell fragments along bedding plane, possibly dark brown fish scales (8mm) at about 155.5m depth (100cm from top of run)
156.2	158.2	2.00	0.50	Claystone	Bedded clay silt and silty clay, bedding interval from 3mm to15mm spacing, calcite crystals (Aragonite?) needle-form, along bedding plane, calcite veins along fracture.
			0.05	Bentonite	2.5Y 4.5/0 grey to dark grey, pyrite nodules, 1cm in size, micro crystals.
			1.45	Claystone	Mudstone to claystone, well bedded as above bentonite layer, very dark (black) with lighter coloured bedding, silt partings in lighter layers, looks like dark brown fish scales? along partings, unsure if shell fragments or carbonate deposition from groundwater. Aragonite crystals suggest these.
158.2	160.5	3.10	3.10	Mudstone (silt and silty clay)	Bedded, 1-2cm thick beds of alternating black and very dark grey beds, white calcium carbonate in fill along bedding planes @ 305cm from top of core (160m depth), high angle fractures in core result of too much core jammed in barrel, barrel expanded as core sheared inside and jammed barrel inside core tube - 1 hour to pull out core, calcite smells like H2S with 10% HCl, too much core, have to adjust above depths to account for the 75 cm of core lost at 154.5m to 156.2m. This run captured lost 75 cm of core. Elongated dendritic black patterns on silt parting faces - common on a number of faces.
160.5	161.2	0.00	0.00		Core remained in hole (0.5m).
161.2	162.8	0.68	0.68	Mudstone (or claystone?)	Drilled 1.5m, but only recovered 69 cm, weakly bedded mudstone or claystone?, moderate to strongly calcareous (only on light coloured silt? partings), presence of entire shells (2-3cm) possibly some fish scales present as well
162.8	164.3	1.90	1.90	Claystone or mudstone	Numerous silt partings, shell fragments perhaps recrystallized to aragonite, weekly bedded, moderately calcareous (on silt partings), fish scales present on partings, photos taken
164.3	165.8	0.00	0.00		
165.8	166.4	1.64	1.64	Mudstone	Well-bedded and regularly bedded spacing from 3 to 10mm, core breaks easily along the silt partings, 115cm from top of core Inoceramus (sp?) (shell), frequent occurrence of shells in the lower portion of the core, especially high HCl reaction, moderate on silt partings, offset in bedding at 156cm from top of core, 3 photos taken (of this offset).
166.4	167.3	0.00	0.00		No recovery ~3m of core left at the bottom of the hole. Depth to core ~164.2m . TD = 167.3m.

Appendix 2b: Lithology of Core Hole WEPA99-2

PROJECT: **WEPA Hydrogeology**	DATA NO: **WEPA99-2**	LOGGED BY: T. Lemay	DATE: Sept.23, 1999
DRILLER: Layne- Christiansen	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 583.07m
LOCATION: LSD 13 SEC 12 TP 74 R 17 W4	LATITUDE: 55.3985831°	LONGITUDE: 112.4932875°	Source: Surveyed
COMMENTS ON LOCATION: Flat area adjacent to bog and next to the access road.			

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0	3.1	0	0		1.8 m of sand 1.25 m of harder material to drill based on driller's comments. In 1.8 m soil profile, 1.5 m of sand with clay beds and 0.3 m of clayey till from soil survey done 30 m NW of hole.
3.1	4.0	0.26	0.6	Till	Zone of mottled 10YR - dark yellow brown and 2.5Y 4/2 dark greyish brown clayey silt till with trace sand, massive, sharp contact with the till below, soft and plastic.
			0.20	Till	2.5Y 4 to 5/2 greyish brown to dark greyish brown clayey silt till with trace sand, silt component may be greater than in the above till, no reaction with HCl, Fe-oxidized irregular fractures and granules, hard and non plastic.
4.0	4.6	0.16	0.16	Till	Dark grey brown clayey silt till with some sand and mudstone and sandstone (Athabasca?) pebbles, pebbles range in size from 1cm to 3 cm along the long axis, zones of Fe-oxidation present in fractures and partings, material is brittle and stiff, quartzite.
4.6	4.9	0.20	0.20	Till	5Y 3/1 to 2.5/1 very dark grey to black, very dark brown, clayey silt till, Fe-oxidized with an irregular pattern to the oxidation, granule fraction appears to be less than in the above till, pebble content less than 1%, no reaction to HCl.
4.9	5.8	0.45	0.45	Till	Very dark grey clayey silt till, signs of Fe-oxidation, weak HCl reaction, presence of shale clasts, granule poor, pebbles make up 2 to 3%, most pebbles shale and sandstone, smaller percentage of igneous, metamorphic and limestone pebbles.
5.8	7.31	0.75	0.75	Till	Very dark grey to black clayey silt till, 3% pebbles predominantly shale, lesser amount of igneous, metamorphic and sandstone pebbles, also present a sand stringer 23 cm from top of core, sand was medium fray and fine textured, coal fragments found, till massive and rigid
7.3	8.8	1.15	0.80	Till	Same as above.
			0.25	Silt	Dark grey silt, massive, soft, may be coarsening upwards, presence of trace pebbles.
			0.10	Silt	Dark grey sandy silt to a mud, massive, firm and rigid, trace pebbles

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
8.8	9.4	0.50	0.50	Till	5Y 3/1 to 2.5/1 very dark grey to black, very dark brown, clayey silt till, local bedrock pebbles make up the greatest fraction, pebbles 3%, HCl reaction very weak, shale clast 7.6 cm in diameter at bottom of core interval.
9.4	11	1.00	1.00	Till	Same as above.
11	12.5	0.82	0.20	Till	Same as above but moderately calcareous.
			0.06	Silt till	Same as above but with greater clay content.
			0.56	Till	5Y 3/1 to 2.5/1 very dark grey to black, very dark brown, clayey silt till, local bedrock pebbles make up the greatest fraction, pebbles 3%, HCl reaction moderate, large igneous and quartzite cobbles at 40 cm from top of core and 82 cm from top of core.
12.5	14	1.05	0.20	Till	Same as above.
			0.10	Gravel and sand	Made up predominantly of local bedrock fragments, also contains igneous, quartzite and chert pebbles, largest pebble size 3 cm, smallest 0.20 cm, sand is poorly sorted.
			0.75	Till	5Y 3/1 very dark grey, sandy silt till, pebble content 3% predominantly local bedrock, some oxidized granules, in the lower 20 cm several horizontal sand stringers and lenses were found, two of which are oxidized, the lens of sand is coarse-grained, presence of green sandstone pebbles, some clasts and granules react moderately to HCl.
14	15.5	1.07	0.83	Till	Same as above, but no sand stringers, lenses or green sandstones observed.
			0.24	Silt	5Y 3/1 very dark grey silt with some pebbles and perhaps trace granules, no HCl reaction.
15.5	18.6	1.15	0.58	Silt	Same as above, but with some wavy bedforms?, non calcareous, some fine sand or silty streaks
			0.10	Till	5Y 3/1 very dark grey, sandy silt till, pebble content 3% predominantly local bedrock, some oxidized granules, some clasts and granules react moderately to HCl, irregular high angle contact with the silt below.
			0.10	Silt	5Y 3/1 very dark grey silt with some pebbles and perhaps trace granules, no HCl reaction, gradational contact with the till below.
			0.37	Till	5Y 3/1 very dark grey, clayey sandy silt till, coarse sand fraction has increased over previous tills, non calcareous, pebble content 1% predominantly local bedrock, soft and easy to cut, limestone clast near the bottom of the core interval.
18.6	20.1	0.60	0.60	Till	Same as above with a sand lense near the top the of the core interval in the split section, large quartzite cobbles prominent especially at the base of the core interval.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
20.1	21.6	0.17	0.17	Till	Same as above, three large cobbles/pebbles found, largest 7cm along the long axis possibly granite, mid sized pebble 3cm possibly diorite, smallest 2cm possibly quartzite.
21.6	22.3	0.32	0.32	Till	Same as above, with less local bedrock in the pebble fraction, ironstones found, fewer of the large pebbles found.
22.3	22.7	0.62	0.62	Till	Same as above with slight increase in pebble content.
22.7	23.6	0.76	0.76	Till	Same as above, local bedrock content continues to decrease.
23.6	24.7	0.28	0.28	Till	Same as above, Athabasca sandstone cobble at the base of the cored interval, cobble the diameter of the core.
24.7	25.5	0	0		
25.5	25.6	0	0		
25.6	26.5	0	0		Till cutting recovered Same as above.
26.5	27.1	0	0		
27.1	27.7	0	0		
27.7	28.3	0.28	0.28	Till	Same as above, sand fraction decreased to where sand and clay appear equal.
28.3	29.2	0.59	0.59	Till	Same as above, igneous, metamorphic pebbles range in size from 1cm to 3cm, clay content variation of about 5% occurs in the upper portion of the core for about 10 to 15cm.
29.2	30	0.92	0.92	Till	Same as above, HCl reaction moderate, silt still dominant with sand and clay fighting it out for second place.
30	31.1	0.84	0.84	Till	Same as above, silt fraction may be increasing slightly, weakly moderate HCl reaction.
31.1	31.7	0.23	0.7	Sand	2.5Y 4/0 dark grey, medium to fine grained sand, no reaction to HCl
			0.16	Till	Same as above with flat tabular coal striated on both flat surface
31.7	32.8	0.90	0.90	Till	Same as above, coarse sand fraction increasing, silt still dominant, glacial sand lenses, shale pebbles found along with cherts, igneous and metamorphic pebbles, pebble content 1 to 2%.
32.8	33.8	0.90	0.90	Till	Same as above, lower 7cm of the cored interval a silty sand till, shale pebble found.
33.8	35.4	0.70	0.70	Till and sand	Till becoming lighter in colour 5Y 4/1 dark grey, sand fraction increasing, clay down to about 10%, silty sand till and silty sand have a strong to moderate reaction with HCl.
35.4	36.1	0.46	0.46	Till and sand	Same as above with some coarser sand lenses.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
36.1	36.9	0.15	0.15	Till and sand	Same as above but siltier, sand lenses contain finer sand than above
36.9	37.8	0.54	0.54	Till and sand	Same as above sand lenses and partings may be coarser than above.
37.8	38.6	0.41	0.10	Till and sand	Same as above.
			0.21	Sand	Medium to light grey brown fine-grained sand
			0.10	Silt	5Y 3/1 very dark grey clayey silt, presence of some pebbles, sand lenses and partings, bedding in convoluted and possibly deformed, contact with the sand above is at an angle of approximately 45°.
38.6	39.9	1.00	0.12	Silt	Same as above, convoluted bedding ends 8cm from the top of the core, weakly bedded below 8cm.
			0.10	Sand	Medium to light grey brown fine-grained sand
			0.56	Till	5Y 4/1 dark grey silty sand till, shale, chert, igneous and metamorphic pebbles found, pebble content 1 to 2%, moderate HCl reaction.
			0.10	Sand	Dark grey silty sand with clay.
			0.12	Silt	Grey brown massive silt with faint bedding, moderate reaction with HCl.
39.9	40.8	0.94	0.08	Gravel	Glacial gravel, pebbles from 2mm to 1.5cm, presence of silt and sand within the gravel.
			0.42	Silt	Dark grey silt, clay content high, faint contorted bedding in the lower halt of the interval, no pebbles or granules, strong reaction to HCl.
			0.44	Silt	Very dark grey to black silt, faint contorted bedding, pure quartz pebbles found, quartzite and granite pebbles found in the lower 2cm.
40.8	41.5	0.47	0.14	Silt	Very dark grey massive clayey silt.
			0.33	Till	5Y 4/1 dark grey silty sand till, shale, chert, igneous and metamorphic pebbles found, pebble content 1to 2%, concentration of pebbles found 30cm from top of core interval, moderately weak HCl reaction.
41.5	42.1	0.75	0.75	Till	Same as above with weak reaction to HCl.
42.1	43.3	1.12	0.32	Till	Same as above with greater pebble 2 to 3% and granule content, slow weak reaction to HCl.
			0.90	Till	Same as above, possible increase of silt may make this till a sandy silt till rather than a silty sand till, few pebbles, some shale clasts, weak reaction to HCl, green sandstone found.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
43.3	46	2.82	2.82	Till	Same as above, upper 50cm has more pebbles than the lower 232cm, stiff and rigid, shale pebble content may be increasing.
46	49.1	3.10	3.10	Till	Same as above, zone from 50cm to 104cm from top of core may be more pebble rich than above or below, sand lense at 40cm from top of core, presence of Fe-oxidized sandstone and siltstone.
49.1	52.1	2.87	2.87	Till	Same as above, presence of large quartzite and Athabasca sandstone pebbles within the till
52.1	52.7	0.95	0.08	Till	Same as above, contact with unit below is distinct.
			0.08	Till	Colour as above, clayey silt till, shale fragments, no reaction to HCl, some igneous pebbles, contact with unit below distinct.
			0.10	Till	Lighter brown than above, sandy silt till, reaction to HCl moderate, contact with unit below distinct.
			0.69	Till	5Y 4/1 dark grey clayey silt till, appears to have a greater clay content than the first clayey silt till in this cored interval, pebble content and HCl reaction similar.
52.7	53.6	0	0		
53.6	53.9	0	0		
53.9	54.6	1.77	0.79	Till	Same as above, but with some bands of clay rich material.
			0.28	Till	Dark brown to black, silty clay till, no reaction to HCl, pebbles of sandstone present, massive.
			0.70	Till	Same as above, with Fe-oxidized pebbles.
54.6	56.1	0.79	0.79	Till	Same as above, but clay and sand contents seem to vary throughout the cored interval, generally more clay rich near the top and sandier near the bottom.
56.1	57	1.55	1.55	Till	Same as above, clay content varies throughout the cored interval making zones of clay rich and clay poorer till, coal fragment 1cm across found in the lower portion of the cored interval.
57	58.2	1.37	0.05	Till	Same as above, perhaps grading (?) into a finer till belo .
			1.17	Till/Silt	Very dark brown to black, convoluted bedding with and alternation of light and dark beds (?), no HCl reaction, pebbles present and large granite cobble near the top of the interval, grain size may be getting finer near the bottom
			0.15	Silt	Dark grey , massive silt, no pebbles present, no HCl reaction.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
58.2	61.3	2.26	2.26	Silt	Same as above with zones of fine sand that show regular bedding, at the base of the sand rich areas clay content appears to increase to almost equal the silt content, more sand rich to more clay rich areas almost appear to alternate, this trend especially visible in the lower portion of the silt.
61.3	64.3	2.81	1.65	Silt	Same as above, spectacular convoluted bedding of fine sand, 15cm of sand silt till near the middle of the silt unit, some of the beds appear to be truncated by upper beds, photos taken.
			1.16	Till	Same as above 5Y 4/1 dark grey clayey silt till.
64.3	67.4	3.10	3.10	Till	2.5Y 3/2 very dark greyish brown sandy silt till, 2 to 3% pebbles, igneous, quartzite and green sandstone pebbles found, weak to moderate HCl reaction, sand and silt partings found.
67.4	70.4	3.26	3.26	Till	Same as above, Fe-oxidized sandstone pebbles, green siltstones, pebble content may be increasing slightly, large limestone cobble found.
70.4	73.5	0.90	0.90	Till	Same as above, some shale clasts, weak reaction to HCl.
73.5	76.5	2.90	2.90	Till	Same as above, some sand and silt partings, the large pebble (2 to 5cm) fraction appears to be increasing as does the silt content.
76.5	78	1.89	1.89	Till	Same as above, silt content appears to be fluctuating, large clasts still present, clasts composed of sandstone and quartzite, plate of purple material 3mm by 2mm noted and location indicated on the core box.
78	79.6	1.44	1.44	Till	Same as above, starting to lose the larger clasts.
79.6	81.1	1.48	1.48	Till	Same as above.
81.1	82.6	1.55	1.55	Till	Same as above, with at least one shale clast, no HCl reaction, sand content appears to have increased, continued trend of less large pebbles.
82.6	85.6	2.81	2.81	Till	Same as above, sand still seems to be increasing, shale clasts found, large pebble size fraction content remaining constant.
85.6	88.7	3.10	3.10	Till	Same as above, numerous Fe-oxidized 10YR 6/8 brownish yellow sandstone clasts, weak reaction to HCl near the top of the interval increasing to a moderate reaction depth, more abundant shale clasts, limestone clast noted, presence of green siltstone, large pebbles still present (2-3cm long axis).
88.7	91.7	0.31	0.31	Till	Same as above, silt content may be increasing slightly, small shale clasts, moderate reaction to HCl.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
91.7	94.8	3.02	3.02	Till	Same as above, dolostone pebble with an iron-stained rind, shale clasts more common, chert pebble found.
94.8	97.8	2.82	2.82	Till	Same as above, shale clasts more common, large clasts content increasing, silt content may be increasing near the top, sand lenses located near the core top, sulphide coated pebble located 20cm from the base of the core, limestone pebble found.
97.8	100.9	3.15	3.15	Till	Same as above, silt content appears to be increasing, may even be a sandy silt till now, 3cm thick clayey silt bed (?) at 130cm from the top of the core reacts strongly with HCl, cobble sized quartzite and igneous fragments found.
100.9	103.9	2.12	2.12	Till	Same as above, harder to split and break.
103.9	105.5	2.80	2.80	Till	Same as above.
105.5	107	1.28	1.28	Till	Same as above, large shale or clayey silt clast near the bottom of the cored interval had a strong reaction to HCl, pebble content may be decreasing.
107	110	3.00	3.00	Till	Same as above, recovered an 8cm diameter quartzite cobble near the bottom of the cored interval, igneous pebble content appears to have decreased, pebble content has remained at about 2%.
110	113.1	2.84	2.84	Till	Same as above, HCl reaction increasing with depth, shale clasts varying in size from 2mm to 2cm, green sandstone found.
113.1	116.1	3.10	3.10	Till	Same as above, numerous clasts of quartzite, sandstone and igneous rocks, shale content may have decreased slightly, sand content appears to have increased.
116.1	119.2	2..80	2.80	Till	Same as above, dolostone clast found, pure quartz pebbles found, larger shale clasts found near the base of the cored interval, sand content does appear to have increased.
119.2	122.2	3.05	3.05	Till	Same as above, 2 to 3cm wide silty medium-grained sand lenses, pebble content has decreased to 1 to 2%, sand lenses react moderately to strongly with HCl.
122.2	125.3	2.97	2.97	Till	Same as above, greater concentration of shale clasts, clasts 1 to 3cm in length, greatest concentration of clasts near the bottom of the interval, bottom 20cm looks like a mixture of clayey silt and till units, sand partings present and non reactive to HCl.
125.3	128.3	2.51	2.51	Till	Same as above, sand lens present, shale clasts more abundant in the upper portion of the till, clayey silt lenses present, strong to moderate reaction to HCl, easier to break.
128.3	129.8	1.12	1.12	Till	Same as above, pebble content continues to drop 1%, clayey silt zone ends 10cm from top of core, definitely cuts more easil , sandier.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
129.8	131.4	0.85	0.85	Till	5Y 3/1 very dark grey, sandy silt till. Moderate reaction to HCl, pebble content less than 1%, mainly local bedrock, some chert, sand stringers found within the till, contact with till above not well observed, looks like sand was lost at the bottom of the core.
131.4	132.9	2.75	2.75	Till	Same as above, pebble content increasing 225cm from top of core, abundant clayey silt beds, some seem to show weak bedding, HCl reaction increases from moderate near the top to strong near the base, sand lenses present, shale clasts, core breaking along silt parting
132.9	134.4	1.32	0.87	Till	Same as above.
			0.10	Sand	Dark grey fine to medium grained sand, strong reaction to HCl
			0.35	Till	As till above.
134.4	137.5	2.85	1.10	Till	Same as above with a clayey silt rich zone 73cm from the top of the core, weak bedding present with the clayey silt.
			0.75	Sand	5Y 3/2 dark olive grey fine to medium sand, reacts moderately to HCl, presence of a massive 5cm wide clayey silt bed that reacted moderately with HCl, massive silt and clay also present.
			0.18	Silt	Very dark grey to black clayey silt with high angled contorted bedding, moderate reaction to HCl.
			0.82	Sand	5Y 3/2 dark olive grey fine to medium sand, reacts strongly to HCl, massive silt and clay also present.
137.5	140.5	2.20	0.36	Sand	Same as above.
			0.25	Silt	Clayey silt as above, highly deformed bedding.
			1.10	Silt	Very dark grey to black clayey silt with highly contorted bedding, moderate reaction to HCl
			0.49	Silt	5Y 3/2 dark olive grey fine grained sandy silt, massive, hint of low angled bedding, weak reaction to HCl.
140.5	142.3	2.40	0.60	Silt	Same as above, clayey silt with convoluted bedding marks the base, coal fragment found 60cm from the top of the core.
			1.80	Silt	5Y 3/2 dark olive grey fine grained sandy silt, massive, hint of low angled bedding, weak reaction to HCl, presence of irregular polygons of sand on some of the ends of the broken core.
142.3	143.6	1.45	0.53	Silt	5Y 3/2 dark olive grey clayey silt with high angled contorted bedding, moderate reaction to HCl abundant slickensides.
			0.92	Silt	5Y 3/2 dark olive grey fine grained sandy silt, massive, weak reaction to HCl

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
143.6	146.6	2.82	0.90	Silt	5Y 3/2 dark olive grey clayey silt with contorted bedding, moderate reaction to HCl, slickensides.
			0.52	Sand	2.5Y 3/2 very dark greyish brown, medium to fine grained silty sand, abundant coal fragments and what looks like a coal stringer or bed (?), moderate reaction to HCl.
			1.40	Silt	5Y 3/2 dark olive grey clayey silt with contorted bedding, moderate reaction to HCl, slickensides.
146.6	148.7	0.94	0.26	Silt	Same as above with a 5cm thick 2.5Y 3/2 very dark greyish brown medium to fine grained sand 15cm from the top of the core.
			0.45	Silt	5Y 3/2 dark olive grey sandy silt with clayey silt beds that show contorted bedding, moderate reaction to HCl.
			0.23	Silt	2.5Y 3/2/1 very dark greyish brown to very dark grey, clayey silt, slickensides very prominent, contorted bedding very distinct, moderate reaction to HCl.
148.7	149.7	1.64	1.18	Silt	2.5Y 3/1 very dark grey clayey silt, contorted bedding very noticeable, clasts of shale present, clay does not react with HCl, silt appears to react moderately, slickensides prominent.
			0.46	Silt	2.5Y 3/1 very dark grey, clayey silt, extremely contorted bedding that shows offsets and dislocations (photos taken), silt seems to react to HCl moderately, clay no reaction.
149.7	152.7	2.50	0.60	Silt	Same as above but only the top 15cm shows convoluted bedding, remainder is more massive and perhaps contains more silt, top portion reacts moderately to HCl, lower portion (below 15cm) reacts moderately to strongly to HCl.
			1.02	Till	5Y 3/1 very dark grey clayey sandy silt till, weak HCl reaction, local bedrock clasts and igneous pebbles make up 1%, clayey silt blocks within the till from 4 to 9cm wide, 2cm of dark grey medium to fine grained silty sand at the base of the till, coarse to medium grained sand lenses present in till.
			0.88	Silt	2.5Y 3/1 very dark grey clayey silt, some evidence of bedding, strong reaction to HCl, shale clasts found as individual clasts within 0.5cm to 1cm thick beds (?), lower 35cm appears to be more silt rich, bottom 10cm contains shale partings (?).
152.7	155.4	3.20	2.30	Silt	Same as above, till partings, 10cm thick till bed found 123cm from the top of the core, till is a 5Y 3/1 very dark grey clayey sandy silt till, weak HCl reaction, local bedrock clasts and igneous pebbles make up 1%, fine to medium grained sand with silt found 175cm
			0.90	Till	5Y 3/1 very dark grey clayey sandy silt till, moderate HCl reaction, local bedrock clasts and igneous pebbles make up 1%.
155.4	158.2	1.42	1.42	Till	Same as above, with limestone clasts and coal.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
158.2	159.4	0	0		
159.4	160	0	0		
160	160.5	3.23	0.91	Till	Same as above.
			2.32	Mudstone	5Y 3 to 2.5/1 very dark grey to black mudstone, irregular bedding in the upper 160 cm of the interval, regular bedding begins 200 cm from the top of the interval, deformed bedding present in the lower 72 cm of the interval, HCl reacts only with the silt? in the mudstone; What may be bentonite found 124 cm from top of interval; colour 5Y 6/2, light olive grey; more regular bedding found ~2 m from the top of the interval.

Appendix 2c: Lithology of Core Hole WR99-1

PROJECT: **WEPA Hydrogeology**	DATA NO: **WR99-1**	LOGGED BY: J. Pawlowicz, L. Andriashek	DATE: Dec. 7th, 1999
DRILLER: Layne- Christiansen	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 663.76 m
LOCATION: LSD 7 SEC 36 TP 77 R 15 W 4	LATITUDE: 55.7143976°	LONGITUDE: 112.1878725°	Source: Surveyed
COMMENTS ON LOCATION: Abandoned well site west side of HWY 63, 30km south of Marianna Lake. Use 14.3 cm (5 5/8”) insert bit, 20.7m casing depth.			

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0	1.8	Bag sample		Fill	Sandy clay till, fill
				Peat	Peat- organic; fibrisol, wood fragments, black (5Y2.5/2)
1.8	3.4	Bag sample		Silt	Lacustrine, sandy-clayey silt; unoxidized, some coarse sand and pebbles at 4m, rig chatter.
3.4	4.9	Bag sample		Till?	Strong- either a very sandy soft till, or clayey fine gravel; some cuttings of sandy-clay till.
4.9	6.4	Bag sample		Sand	Mainly coarse, pebbly, dirty sand; pebbles <1cm. Sand in last 60cm of drill run (5.8m) glacial, unoxidized, limestone clasts.
6.4	7.9	Bag sample		Sand	Poorly sorted, more silty-clay in matrix; some sandy-clay till cuttings in pan, no HCL reaction.
7.9	9.4	Bag sample		Till	Good cuttings; sandy-clay loam; unoxidized; no HCL reaction; till contact @ 7.6m; black (5Y 2.5/1).
9.4	11	Bag sample		Till	As above; sandy clay loam; not many granules; abundant pebbles in pan; black (5Y 2.5/1).
11	12.5	Bag sample		Till	Stone- boulder @11.9m; as above; no HCL reaction; si-cl sand texture.
12.5	14	Bag sample		Till	Silty-clayey sand; soft, plastic; no HCL reaction; as above.
14	15.5	Bag sample		Till	As above; no change; a few stones in this interval.
15.5	17.1	Bag sample		Till	Rocky, hard drilling from 15.8m - 16.6m; granite rock cuttings in pan; till is more stiff; @16.6m.
17.1	18.6	Bag sample		Till	Stiffer, more consolidated, little change from above; no HCL reaction; angular rock fragments; peat fragments likely from above.
18.6	20.1	Bag sample		Till	Driller says stiff drilling; poor cuttings (very small); hit boulder @19.8m; some black rounded shale fragments; feldspar, quartz.
20.1	20.7	Bag sample		Till	Some well-rounded pebbles (0.5cm) suggests gravel layer, but driller says stiff till; a few limestone clasts; quartzite; crystalline; no HCL reaction, sa-clay till; moderately soft, plastic; few stones.
					End of rotary hole, set casing and cement, set up BOP and rig substructure.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
					Rig set-up on substructure with BOP. Casing set to 20.7m and cemented.
20.7	22.6	---		Till	Drilled out with rock bit, same till as above.
22.6	25.6	1.40	0.70	Till	Black (5Y 2.5/1), stiff and plastic sandy clay loam, unoxidized, moderately pebbly, non-calcareous, shale clasts present.
			0.22	Silt	Black (5Y 2.5/1), clayey, massive, few pebbles, very soft, recovery likely lost in this unit.
			0.48	Till	Same till as above, 2cm silt bed 10cm from top, massive.
25.6	28.7	0.90	0.90	Till	Black, sandy clay loam, massive, unoxidized, stiff, quartzite, igneous, limestone, lost recovery probably due to large quartzite cobble at top of run.
28.7	31.7	1.72	1.72	Till	Same as before, very slightly calcareous, minor very fine grained sand lense, poorly bedded silt, moderately pebbly, well rounded quartzite pebbles to angular granites, minor black shale, greenish-grey siltstone, carbonaceous shale.
31.7	34.7	1.25	1.25	Till	Large rock @ 34.4m; 6-7cm dolostone pebble; 6-8cm Athabasca sandstone; 10cm quartz sandstone cobble; cl-si sand; soft, easy to cut; 1% pebbles, few granules; weak to very weak HCL reaction; a few dolostone pebbles; black (5Y 2.5/1); cobbles mostly at 0-15cm part of core; quartz sandstone cobble in shoe.
34.7	37.8	2.85	2.85	Till	As above; si-cl sand; few pebbles; some cobbles- Athabasca sandstone at top of core (from 34.4m); a few greenish sandstone clasts; no HCL reaction; moderately stiff; easy to split (breaks along apparent fracture planes), weak HCL reaction @ 2.6m (0.9-1.8m wrapped up in plastic for pore water sample).
37.8	40.8	2.7	2.7	Till	Rocks @ 39.3m, 40.2m; same as above; a few black rounded shale clasts; no HCL reaction at 2.4m; very minor reaction @ 1.5m.
40.8	43.9	3.1	0.70	Till	As above becoming much more clayey in texture at contact with lacustrine.
			2.40	Silt and clay	Lacustrine, rhythmically bedded; clay laminae ~4-5mm thick, silt laminae 12-20mm thick; silty beds are extremely finely laminated (0.25-0.5mm thick), noncalcareous, from 2.9-3.1m finely bedded loosing rhythmite structure (about 25-30mm between clay beds); very dark grey to black (5Y2.5/2).
43.9	46.9	2.87	2.44	Cl-silt and clay	As above, but becoming more clayey; clay laminae 3-5mm; silty layers 15-35mm thickness; not as well finely laminated as above; dropstones
			0.43	Diamicton	Very clayey beds with till beds (poorly defined), more stones; non calcareous; becoming more till like from 2.6m-2.87m.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
				Till and Clay	Oxidized bleb @ 2.6m, ~5mm size; mostly till with 20mm thick clay layer, till cl-si sand like above; noncalcareous; 3 photos taken, photos of bedded lacustrine sediments, some brown siltstone/ very fine sandstone clasts in till
46.9	50.0	2.4	0.30	Till and Clay	As above, some clay beds mixed with till.
			2.10	Till	Clayey silty sand, similar texture to till above; appears to have more local bedrock fragments, mostly soft sandstone; pebbles ~1%, a few dolostone, chert clasts; granules 2-3%; very weak to no HCl reaction, calcareous limestone nodule reacted strongly; black (5Y 2.5/1); Athabasca sandstone clasts, rocky from 49.1m-50.0m Athabasca sandstone boulder.
50.0	53.0	2.93	2.93	Till	Athabasca sandstone boulder at top of core; silty clay sand; 2% granules; 1-2% pebbles; no change from above; no HCL reaction; some gneissic cobbles; not any significant amount of local bedrock clasts.
53.0	56.1	1.52	1.52	Till	Hit rock at 54.6m- only 1.5m core recovery (53.0m-54.5?); stiffer drilling at 55.2m; granite at 53.0m at top of core; till same as above, few more pebbles (2%); 10cm quartzite cobble at 1.0m; clayey silty sand.
56.1	59.1	1.0		Till	No core but driller said ~30cm-60cm till then hit sand.
				Sand	No sample in core; driller said hit at least 1.5m sand.
			0.20	Till	As above; siltstone cobble- buff coloured.
			0.10	Silty sand	Dirty, poorly sorted lense in till.
			0.70	Till	Large buff coloured siltstone cobble at top of core; granite cobble at top of this interval; numerous iron oxide blebs in this interval; lost core 56.1m-58.1m.
59.1	62.2	2.57	2.57	Sandy till	Athabasca sandstone cobble at top of core; granite cobbles at 1.7m-1.8m interval; this run appears to have more granitic rock fragments than previous runs; silt parting at 0.45m; texture same as above, clay silty sand; becoming more consolidated; some local sandstone clasts; no HCL reaction at 1m, no HCl reaction at 2.3m; bottom 0.5m very sandy, fewer granules.
62.2	65.2	1.47	1.47	Sandy till	Core recovered from 62.2m-63.7m; sandstone boulder at 63.7m; lost core from 63.7m to 65.2m; slightly clayey silty sand texture, very sandy; no HCL reaction; driller says slightly harder drilling, less clay in matrix (>15%); brittle; silt content also higher.
65.2	68.3	1.25	1.25	Till	Poor recovery- numerous stones in hole; cobble partially filling shoe but some curls of till squeezing by; granite cobbles at 0.9m in core; clay silty sand; more clay in matrix than previous runs (5% or more); granite cobble in shoe at 1.25m.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
68.3	71.3	2.72	2.72	Till	As above; abundant granite clasts; granules 2%; coarse sand 2-3%; no HCL reaction; some limestone clasts; clayey silty sand texture; more consolidated; sample fractures when core split; medium sand parting at 1.3m.
71.3	74.4	3.0	3.0	Till	Boulder at 72.8m; softer drilling 72.8m-73.5m; Athabasca sandstone boulder at 72.8m in core; till same as above; pebble % increase 2-3%; clayey silty sand; core much stiffer, harder to break; more silt in matrix; clayey sandy silt, a few limestone clasts, numerous granite.
74.4	77.4	0.55	0.55	Till	Lost core from 75m to 77.4m (sand at 75.9m- no core recovery), as above.
				Sand	Sand at 75.9m; fine sand in sieve; glacial; a few carbonaceous shale (coal?) fragments (2mm)
77.4	80.5	0.07	0.07	Till and clay	Till in bottom of core shoe; large silty clay clast in till (8cm); silt parting in clay is non-calcareous, looks like shale clast but could be lacustrine clay inclusion; ~60cm of this according to driller.
80.5	83.5	0.42	0.15	Clay	Silt partings, massive to very weakly bedded.
			0.18	Till	Same till as above.
			0.09	Clay	Clay, massive, rounded clay clasts; some pebbles - clay diamicton.
				Sand	Glacial, medium to coarse in 60 mesh sieve; granitic fragments, some black coal- carbonaceous shale clasts.
83.5	86.6	1.0		Sand	Sand drilled from 83.5m to 85.0m.
			1.0	Clay (shale?)	Bedded silty clay, almost rhythmically; noncalcareous; almost has shale appearance; hard; light silty partings (highly calcareous); black clayey partings and fragments; clay sample from 85.0m-86.0m.
				Sand	Driller says sand from 86.0m to 86.6m.
86.6	89.6	0.55		Sand	86.6m to 87.5m- no sample.
			0.25	Silt	Massive; brittle; moderately dense.
			0.30	Cl-si sand	Sand, diamicton; very poorly sorted, muddy glacio-fluvial deposit; pebbles; has sandy till-like appearance; can be cored.
				Sand	Sand at 88.1m- 90.5m.
89.6	92.7	0.55	0.15	Till (?)	Till at 90.5m, ~15cm thick; sandstone boulder at 90.8m (Athabasca sandstone).
			0.15	Boulder	13cm thick in core; Athabasca sandstone.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.25	Till and sand	~30cm sandy till and sandy diamicton (fluvial) mixed; gneiss, granite rock fragment at 0.4m down in core; could be sand from 91.1m-92.4m.
					Bag sample of fine to medium sand from 91.1m-92.7m; rock at 92.4m (till)
92.7	95.7	2.7	2.7	Till	Pore water core sample from 93.0m-93.7m; much more silty till than tills above; cl-sa silt; dense; stiff; breaks brittle; very weak HCl reaction; some local siltstone/ sandstone clasts; more sandy with depth around 2.3m; no HCL reaction at 2.6m; 1-2% pebbles and granules.
95.7	98.8	3.18	0.65	Till	Sandy clay silt till.
			0.10	Fine sand	10cm of silty fine sand
			0.55	Silt	Massive, with rip up clasts of finely bedded silt ~3-4cm size
			0.20	Silt	Finely bedded silt and clayey silt with highly deformed, contorted bedding suggesting dewatering structures; noncalcareous.
			0.60	Silt	Massive, with occasional bedded silty clay and silt layers (~5cm thick); noncalcareous.
			1.08	Silt and clay	Bedded silt and clay with increasing clay bed thickness at bottom 40cm; noncalcareous; clay is black, silt is very dark grey; finely laminated, fissil
98.8	101.8	0.93	0.93	Clay	Lost 3m of core down hole- ran back down and retrieved 0.9m, running back down hole to retrieve remainder of core. Minor silt laminae, moderately well bedded; at 0.1-0.4m, high angle (10°) and some deformed silt beds; dark black clay beds from 2-5cm thick; noncalcareous; bottom 30cm finely bedded clay with silt partings (~1-2mm thickness of laminae)
101.8	103.6	0.65			Hard drilling at 100.6m, 101.8m- drilled 1.8m, only recovered 0.9m.
			0.15	Clay	Weakly bedded clay, poor sample.
			0.15	Clay and silt	Well-bedded clay with silt laminae.
			0.35	Clay	Weakly bedded clay with occasional 3mm thick silt laminae; still chasing 3m of core; driller says some of the missing 3m has been ground up by the bit and is cuttings in the tank; some of this missing core may show up in the next run.
103.6	104.9	0.52			Driller indicated sand at 104.5m to 104.9m.
			0.22	Clay	Black (5Y 2.5/2), same as above, weakly bedded; massive appearing; stiff; waxy; upper 10cm disturbed by redrilling; noncalcareous; pictures: R2/23-25.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.30	Clay	Same as above but well bedded; abundant fine silt/ very fine-grained sand laminae ~1mm thick noncalcareous.
				Sand and gravel	104.5m-104.9m - no recovery-driller comment. Sample collected from mud tank flow; medium to coarse grained sand; abundant angular black grains.
104.9	106.4	0.10			Lost recovery; drillers comment sand and gravel.
			0.10	Clay	Black; highly broken and deformed; clay or shale (?) clasts; minor fine-grained sand (grey); noncalcareous; possibly deformed bedrock.
106.4	107.9	0.3	0.13	Silt	Very dark grey; soft, clayey; deformed; noncalcareous.
			0.12	Clay	Black; massive; faintly mottled; deformed with slickensides; noncalcareous.
			0.05	Silt	Very dark grey with black clay laminae; highly contorted and deformed; noncalcareous.
107.9	109.4	0.48	0.48	Clay	Black; deformed clay with silt; stiff; noncalcareous; silt beds deformed, also appears fractured throughout.
109.4	110.9	0.89	0.89	Clay	As above with slickensides; fewer silt beds; upper 50cm highly fractured; lower 39cm hard and very stiff; driller is thinning drilling mud to try and improve recovery.
110.9	114	0.53	0.53	Clay	As above; less hard and stiff; massive; waxy in appearance; very few granules, quartzite and granite; minor silt; noncalcareous.
114	115.5	1.38	1.38	Clay and silt	Very prominent rhythmic bedding; very dark grey silt and black clay interbeds (varved?); occasional pebbles; top 20cm: 2-3cm silt beds, 0.5cm clay beds; horizontal bedding, undeformed; noncalcareous; next 60cm: undeformed, 1cm silt, 0.5cm clay couplets, one 10cm silt bed, noncalcareous; next 20cm: same rhythmic bedding; some deformation with fractures and minor offsets, noncalcareous; next 38cm: undeformed; 0.5cm silt, 0.5cm clay; bottom of core: contains sand beds; slightly calcareous (photos R2/ 31-34).
115.5	117	1.53	1.53	Clay and silt	As above; rhythmic bedding; most silt beds ~1cm wide; dark grey in colour; 0.5cm black clay beds; horizontally bedded, undeformed; some of the thicker silt beds seem to show cross bedding; only the top 10cm is slightly calcareous; fairly stiff; presence of some pebbles, some bedding planes are sandy.
117	120.1	0.23	0.05	Clay and silt	As above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.18	Silt	Number of bedded, very dark grey and black silts; slightly calcareous; darker beds contain more clay than lighter silt beds.
120.1	123.1	0.92	0.10	Silt	Dark grey; same as above.
			0.10	Silt	Dark grey; massive; saturated; soft and loose; water bearing; possible loss of recovery.
			0.72	Silt	Minor clay interbeds and laminae; slightly deformed bands; stiff; noncalcareous.
			bag sample	Sand	Drillers comment: hit about 1.5m of water bearing sands from base of run; sand and fine gravel (igneous pebbles).
123.1	124.7	0.04	0.04	Clay	Black; massive; silty; hard; stiff; thin clay interbeds.
124.7	126.2	0.00			No recovery- likely sand.
126.2	129.2	0.35		Boulders and cobbles	Drillers comment: hit rock about 4' from bottom, chased it down the rest of the way.
			0.05	Silt	Black; massive; plastic; noncalcareous.
			0.10	Silt and cobbles	Chert, granite; sub angular to sub rounded; up to 5cm in diameter.
			0.20	Boulders	Dark grey and green igneous rock; cut with a diamond bit.
129.2	132.3	0.35	0.35	Sand	Dark grey; very fine to coarse-grained sand; disturbed from drilling, drilling through a number of stones; 10cm quartzite cobble at top; *faint olive grey oxidation bands ~ 1cm thick; finer grained sands show some bedding and become more prominent near the base.
132.3	133.8	0.00	Bag sample	Sand	Fine grained-very coarse grained; igneous, quartz, chert grains; rounded to sub angular; few pebbles.
133.8	135.3	0.00			Driller comment: still in sand.
135.3	138.3	0.45	0.45	Sand	Very dark grey; silty; very fine grained; silty clay interbeds; fine, wavy carbonaceous lamina (minor); light grey calcareous lense 3cm x 0.5cm.
138.3	141.4	0.60	0.60	Sand/ silt	Very fine grained; same as before; lower portion of core recovery shows minor deformation of the laminae; soft; slightly calcareous.
141.4	144.5	0.00		Sand	Sieve sample in bag- mostly fine grained
144.5	147.5	1.00	0.70	Clay	Silty; very dark grey; grey silt laminae, horizontal; stiff; broken up from drilling; noncalcareous.
			0.15	Clay	Silty; massive; dark grey; stiff.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.15	Silt	Sub horizontal clayey interbeds; slightly calcareous. NOTE: drilling mud very sandy. Fines circulating and possibly contaminating screened samples. Need to empty mud tank. Also, likely affecting core recovery.
147.5	149	0.60	0.60	Sand	Grey- dark grey; fine to medium; loose; water bearing; clean; some dark silt interbeds; presence of some pink, angular igneous fragments, mostly well rounded quartz, some well rounded cherts.
149	152.1	0.90			Drillers comment: seem to be drilling through alternating beds of sand and clay.
			0.05	Sand	Same as above.
			0.08	Clay	Silty; very stiff; slightly calcareous; very dark grey.
			0.12	Silt	Massive; saturated; loose.
			0.55	Sand	Brownish grey; fining up water from coarse to very fine grained; saturated; loose; some wel rounded quartzite pebbles up to 2cm.
			0.10	Diamicton	Clayey sand; massive with pebbles up to 4cm, noncalcareous.
152.1	153.6	0.00			Drillers comment: still in sand, most likely.
153.6	156.4	0.00		Gravel	Driller says 2.7m gravel; rig chatter; pan sample of angular fragments of mudstone (green-grey), local sandstone, crystalline gneiss, quartzite; bag sample (core box 20); 4 cobbles at bottom of core shoe, 7cm across, broken, 3 gneissic, 1 pink quartz sandstone; bag sample in core box 21.
156.4	159.7	0.00		Pebbly sand	Driller says stones in sand; sand is medium grained; quartz sand with feldspar; black grains- possibly rock fragments or chert(?); well rounded, carbonaceous shale clasts, bag sample in core box 21.
159.7	162.2	0.00		Gravelly sand	Driller reports rocks all the way down; sand is medium grained; quartz with 25% dark fragments, tabular shale fragments; bag sample in core box 21. Change to rock bit.
162.2	165.2	0.00		Sand	Medium grained; angular, tabular; dark grains (shale?); rounded quartz grains; moderately well sorted; some pink fragments (feldspar?); some tabular, light collared grains; very coarse fraction as caught in hand strainer absent; sample taken.
165.2	168.2	0.00		Sand	As above; 2 samples taken, finer fraction #1, coarser fraction #2; abundant local bedrock present (siltstone, shale).
168.2	171.3	0.00		Sand	As above; 2 samples taken: #1, #2; abundant local bedrock present (siltstone, shale).

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
171.3	174.3	0.00		Sand	Dominantly quartz; 10% igneous, 10% black, local bedrock, greenish igneous; quartz- well rounded to angular, frosted and clear; Ironstone.
174.3	177.4	0.00		Sand	As above.
177.4	180.4	0.00		Sand	As above.
180.4	183.5	0.00		Sand or till?	Sand fraction as above but now contains noticeable clay balls with grains at 182.9 m; possibly till; clay smeared onto granules; clay not seen alone.
183.5	186.5	0.00		Sand or till?	Same as before.
186.5	189.6	0.00		Sand or till?	As before- drilling with tricone rock bit. Driller comments: softer drilling since 180.4m.
189.6	192.6	0.00		Clay/ silt/ sand	Likely interbeds of clay silt and sand; soft drilling; very few larger clasts and granules; glacial sand; 2% pink feldspar, abundant pink quartz, 10% black mafics and cherts; angula , fine grained sand; clay ball still present; number may be increasing in coarse fraction.
192.6	195.7	0.00		Sand/ clay?	Same as before; but less clay balls; drilling change: harder, more coarse and fine fraction- likely interbeds; abundant pink, green igneous clasts, minor sulphides, some local bedrock, mostly quartz; 10% black grains.
195.7	198.7	0.00		Sand	Same as before; minor clay balls; fine grain sample- mostly quartz with increasing black grains; green grains; very few pink coarse fraction- quartz, black grains, few igneous, pink.
198.7	201.8	0.00		Sand	Same as before; minor clay; mostly quartz; angular to rounded grains; fine to coarse grained; 10% igneous, 10% black mafics; Fine grain fraction: 30% black grains, few pink coarse fraction: minor sulphide rods.
201.8	204.8	0.00		Sand	Fine to coarse grained; fine grain- salt and peppe , mostly quartz, 30% black, green, few pink grains, minor yellow coarse grain fraction; quartz, igneous grains, 10% black, minor siltstone, minor brown tabular grains fossil? or Ironstone?; minor mica.
204.8	207.9	Bag sample		Sand	Little sample recovered; likely fine grained; same sand as above
207.9	210.9	Bag sample		Gravel	Moderate sized; rock bit is chattering but still going down; no sample recovered; loss of circulation; mixing 9 more bags of mud.
210.9	214	Bag sample		Gravel	Cobble size (?); mostly quartzites; white, yellow, grey; abundant black chert- well rounded; minor igneous; very few pink igneous clasts; some crystalline quartz- rose, white; minor sandstone clast; limestone clast (HCl reaction).
214	217	Bag sample		Gravel	Same gravel as above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
		Bag sample		Sand	Driller note: out of gravel at 214.6m; drilling like same sand as above gravel.
217	220.1	Bag sample		Sand and gravel	Fine gravel with sand; mostly quartz, quartzite, white, grey, and yellow-brown; 20% black chert, >1% pink igneous- might be circulating from above; few larger stones.
220.1	223.1	Bag sample		Sand and gravel	As above; presence of clay/silt balls? make up less than 1% of sample.
		Bag sample		Sand and gravel	As above; no clay/silt balls.
		Bag sample		Sand and gravel	As above; finer gravel fraction increasing
		Bag sample		Sand and gravel	As above; occasional large stone.
232.3	235.3	Bag sample		Gravel	Coarse; slow drilling. Driller reports clean mud; still drilling through rocks (233.2m-234.1m); sample wash fines from bottom of sample wash bucket; sample bag in box 21; driller reports fine gravel 234.1m; sample returns improving; driller reports back into rocks at 234.4m; drill break out of rocks, into hard drilling; driller suspects sandstone; first appearance of soft, white tabular cuttings.
232.3	235.3	Bag sample		Sand and gravel	Fine gravel with sand; rock fragments, quartz, abundant well-rounded black chert pebbles, white and smoky yellow quartz, rare green and rare pink igneous rock fragments, rare calcareous rock fragments, rare cemented quartz sandstone (medium grained, brown), very rare and very soft white tabular platy fragments, no HCL reaction, (anhydrite?).
235.3	236.8	Bag sample		Sandstone with bentonite interbeds	Drilling break; hard smooth drilling; 4100 kgs on bit ; metal shavings starting to appear in cuttings; at 236.2m, hard drilling for 15cm, driller says may be fracture bit; at 236.5m seeing more sandstone; rare bentonite (grey, tabular, soft, smearing- greasy) fragments in cuttings; at 236.7m, hard chatter. Lower medium to upper fine grained; medium brown to greenish brown; well sorted; quartoze with minor chert grains (sub rounded to sub angular); quartz cemented; porosity>5%. Bentonite- small; tabular; white-grey; greasy, soft cuttings; black and grey chert pebbles and fragments abundant in sample but origin unknown. Core point chosen at 236.8m. *NOTE: Driller called break at 235.3m but he was not at the drill; K.P and G.J and drillers helpers noted break at about 234.7m; plus, first sandstone and bentonite appeared in samples 232.3m-235.3m.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
236.8	238.4	1.45	0.15	Sandstone	Upper fine grained to lower medium grained; well rounded; well sorted; light brown; silica content; quartz with 10% well rounded black chert pebbles (0.5cm), elongate; possible low angle cross bedding; tight (no porosity) [Sandstone].
			1.30	Shale	Black; soft; moderately fissile; non-calcareous with abundant light gre , wispy silt laminae, partings and blebs; occasional fine quartz sand on partings, non-calcareous; pyrite; recognizable horizontal burrows (planolites?) infilled with silt; one fossil ~3mm long found in place on a shale parting, not identified, light grey-brown [Bioturbidated Silty Shale]
238.9	240.8	2.4	2.4	Shale	As above but with 1-3cm interbeds of dark green to grey very fine grained quartz sandstone; very soft to unconsolidated sand with parallel to low angle fine cross lamination (glauconite?) and minor chert; sub rounded grains [Bioturbidated Silty Shale with glauconitic very fine sand/sandstone interbeds].
240.8	243.5	2.54	2.54	Shale	As above but with rare greenish very fine grained sandstone interbeds; still silty but silt becoming perhaps more interbedded or interlaminated with shale as opposed to wispy, bioturbated with occasional horizontal burrows in upper half of core; returning to more bioturbated silty shale in bottom; very fine green sandstone in burrows observed as well as silt
243.5	245.1	1.64	1.64	Shale	As above; bioturbated silty shale with very fine grained, green sandstone
245.1	248.1	1.93	1.93	Shale	Black; blocky; with minor silt partings (less than above unit); orange brown concretion (15cm) below top of core (BTOC), siderite?; subhorizontal fractures, 30° from horizontal; 60, 94, 110, 140 cm BTOC; may be slickensided but muddy- too hard to tell; incipient concretion at bottom of core, jammed in shoe, and twisted off; assume core below fell out; sandstone- 3cm at base of core, medium to coarse grained, moderately hard.
248.1	249.6	0.27	0.27	Shale	Black; hard; solid; numerous tight intersecting fractures, 30° angle clay filled fracture; tried to retrieve 1.2m of core from last run, but unsuccessful.
249.6	249.9	0			Tried to recover shale core in hole; different core catcher- finger; core slipping out
249.9	250.2	0			Different core catcher- spring toggle; no luck, core still slipping out.
250.2	250.7	2.54	2.54	Shale	As above; 2cm sandstone bed 62cm from base of core, depth might be 250.1m; sample is very hard and makes a dull ringing sound when struck; low angle bedding (5-10°) planes; few burrows are sand filled; minor sulphide nodules, occasional dark red-brown fish scale
250.7	253.4	1.43	1.43	Shale	As above; parting planes appear to be subhorizontal; tight fractures; sulphides present as nodules and along fractures; bioturbation has decreased.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
253.4	253.7	0.45	0.45	Shale	As above; drilled 30cm, and was only able to recover a portion of 1.2m core down the hole; broken up from drilling; end in Joli Fou Shale.
					T.D. at 253.7m. -Finished coring at 1:00am, Dec. 12/99. -Circulating for 30min. -Hole in good condition for logging. -Century logger on site. -Run 4 tools: 1st. Magnetic Susceptibility. 2nd. Sonic. 3rd. Density Combination. 4th. Neutron Combination.

Appendix 2d: Lithology of Core Hole WEPA00-1

PROJECT: **WEPA Hydrogeology**	DATA NO: **WEPA00-1**	LOGGED BY: T. Lemay	DATE: Sept 28, 2000
DRILLER: McAuley Drilling Ltd.	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 667.64 m
LOCATION: LSD 06 SEC 33 TP 74 R 09 W4	LATITUDE: 55.4514162°	LONGITUDE: 111.3298313°	Source: Surveyed
COMMENTS ON LOCATION: At Margie railroad crossing, north end of clearing, east side of tracks, west of hwy 881.			

DRILLED DEPTH (m) from	DRILLED DEPTH (m) to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0.0	0.8	0		Till	Sandy silt till, (from cuttings)
0.8	1.8	0.18	0.18	Till	Sandy silt till, 2.5Y 4/3, granite clasts and some quartzite clasts, unoxidized grey blebs, thin sand partings, oxidation occurring along the partings, soft.
1.8	2.8	0		Till	No recovery.
2.8	3.7	0.50	0.50	Till	Sandy clay loam, abundant iron oxide blebs and lenses along fractures, iron oxide halos, clay content increasing, 2.5Y4/2, large clasts absent, granules 1%, very weak to weak HCl reaction, soft, moderate HCl reaction with iron oxides.
3.7	4.6	0.98	0.98	Till	[redacted]
4.6	5.3	0.18	0.18	Till	Till, as above, large clasts of igneous and sedimentary (clay and dolomite origin), oxidation decreasing, soft.
5.3	6.3	1.00	0.90	Till	Sandy clay loam, streaks of oxidation, some vertical, some horizontal, presence of unoxidized zones, some with unoxidized cores at the center of oxidized haloes, large clasts absent, soft.
			0.10	Till	Sandy clay loam, 5Y 3/1, moderate HCl reaction, granules 1%, large granite clasts at base of recovered core.
6.3	7.8	1.03	0.74	Till	Sandy clay loam, oxidation along sand lenses, moderate to weak HCl reaction, siltstone and clay clasts, large metamorphic clast at the top of the recovered core, soft, oxidation streaks at high angle with moderate HCl reaction.
			0.10	Sand	Silty sand, fine grained, abundant oxidation
			0.19	Till	Silty sand, fine grained, 5 4/3, weak to no HCl reaction, oxidation at the base of this run, soft, till as above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
7.8	9.4	0.30	0.30	Till	Clay loam, 5Y 3/1, very dark grey, moderate to strong HCl reaction, sand parting about 25° from horizontal, fine sand 10cm from top of the recovered core, soft, large clasts present but not abundant, massive, shale clasts observed.
9.4	10.5	1.75	1.75	Till	Collected additional 60cm from previous run, Sandy clay loam, 5Y 3/1, moderate HCl reaction, granules 1%, massive, soft, presence of sand particles.
10.5	11.5	0.75	0.75	Till	Till, as above, medium grained sand partings.
11.5	13.5	1.70	1.70	Till	Till, as above, high angled fine grained sand partings, weak HCl reaction, few large clasts found, some dolostone clasts, pebbles <1%, granules <1%.
13.5	15.5	1.90	1.90	Till	Till, as above, sandy, high angle (45°) sand partings still abundant, wear HCl reaction periodic, sand rich zone from 0.7m to 0.85m from top of recovered core, sand partings have moderate HCl reaction, core breaks along partings, till becoming firme , bedding (?) planes of sandy diamictons up to 3.0cm thick, irregular, very calcareous, alternation between light and dark bedding, bottom 10cm -20cm clayey sand.
15.5	17.5	0		Sand	Sand content increasing with depth in the till above, could be causing the recovery problem.
17.5	18.5	0		Sand	Drill break at 20.5m, driller indicated we are out of the sand.
18.5	20.5	0		Sand	No recovery.
20.5	21.5	0.36	0.19	Slough	Mix of material from above the current material.
			0.17	Clay	Clay with silt beds, *rip-up clasts* present, alternation of light and dark beds, irregular in shape, weak reaction with HCl, 3 photos taken, firmer than above tills
21.5	22.5	0.85	0.23	Silt	Clayey silt, frequent irregularly bedded silt and clay, weak to moderate HCl reaction.
			0.57	Silt	Clayey silt, massively bedded, evidence of some vertical bedding, weak to moderate HCl reaction.
			0.05	Sand	Silty (dirty) sand.
22.5	23.5	0.46	0.46	Till	Sandy clay loam, dark grey, very weak HCl reaction, thick sand bed about 10cm thick, 20cm from top of core recovered, large clasts forming a bed (?) near top of the interval, firm, zone of oxidation (dark olive color 2.5Y 3/2) 5cm from base of interval.
23.5	24.9	1.5	1.5	Till	Sandy clay loam, 0.6m to 0.65m zone of oxidation, very dark grey, oxidation appears to occur along fractures, pebbles 1%, granules 1%, weak to very weak HCl reaction, coloration of oxidized zones changes with depth from rust to olive brown, moisture content appears to have decreased.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
24.9	26.1	1.2	1.2	Till	Till, as above, 0.2m from top of core contains more signs of oxidation, carbonaceous shale clasts noted, weak HCl reaction, large sandstone clast about 40cm from top of recovered core, occasional fine grained sand lense
26.1	27.6	0.58	0.58	Till	Till, as above, with siltstone clasts, weak HCl reaction, large sandstone clast at the base of the recovered core, more massive till.
27.6	29.6	1.86	1.86	Till	Clay loam, stiff, very weak HCl reaction, large gneiss clast 20cm from top of recovered core.
29.6	31.9	0.15	0.15	Till	Sandy loam, fine grained, very weak HCl reaction, poor recovery due to rocks in the shoe, large igneous and metamorphic clasts present.
31.9	32.5	0.40	0.10	Till	Sandy loam, as above, fine grained
			0.30	Till (#3?)	Clayey silt till, weak to moderate HCl reaction, dense and stiff, very dark grey, sulphur smell evident, igneous clasts, bitumen smell also present in core (sulphur smell noted after the addition of acid).
32.5	33.7	0.34	0.34	Till	Till, as above, bitumen smell still present in core, large clast of Athabasca sandstone, some very reactive particles present within the matrix, occurrence of shale or clay near the base of the recovered core. Oil emulsion in mud tank.
33.7	35.7	1.60	1.40	Till	Till, as above, 5Y 3/1 very dark grey, bitumen odour in core getting stronger, very stiff, large clasts of igneous rocks near the base of recovered core.
			0.20	Till	Sandy clay loam, 5Y 3/2, bitumen odour still apparent in core, stiff and massive, very weak HCl reaction, pebbles and clasts <1%.
35.7	37.7	Bag sample		Sand	Driller reported hitting rocks at the top of the run and then hit 2m of Sand (medium grained, glacial).
37.7	39.8	Bag sample		Sand	Sand, as above, poorly sorted, predominantly well rounded quartz grains with a minor mafic component.
39.8	41.1	0		Silt or sand	Material hit at 40.3m most likely a Clayey Silt (driller noted hitting harder beds), otherwise sand.
41.1	45.9	0.67	0.67	Sand and till	Sand is sorted with well rounded quartz grains, tabular and angular feldspars, some igneous rock fragments and some mafic minerals, medium grained, grey in color, sandy clay loam, weak to moderate HCl reaction, medium grained light colored sand lenses or blebs, brittle and firm, bitumen smell present but fainter than in above core, sand partings present. Losing water at about 43m (75 gallons). Drill break at 45.1m (harder).
45.9	48.0	0.60	0.60	Till	Sandy clay loam, as above, large igneous clast at the base, sample taken for hydrocarbon analysis from 46.1-46.25m. Driller reported sand from 46.6m to 46.8m and from 47.2 to end of run. Base of recovered core is becoming siltier.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
48.0	51.0	1.0	1.0	Sand	Fine to medium grained sand growing finer towards the base into a firmer silt. Sand has rounde quartz grains, some angular feldspars and quartz grains with some mafic grains and rock fragments.
51.0	52.0	0		Sand	Driller thinks were back into that same grey sand.
52.0	55.0	0		Sand	Driller indicated this interval drilled like sand, but was easier drilling than the light grey sand.
55.0	58.1	0		Sand	Sand, as above.
58.1	61.3	Bag sample		Sand	Glacial sand, rich in coal, rounded quartz, igneous rock fragments.
61.3	64.2	Bag sample		Gravel	Glacial gravel, driller called it pea gravel, variety of components, rounded and angular cherts, sub rounded to angular quartz and dolomite fragments, angular igneous rock fragments, poorly sorted.
64.2	64.5	Bag sample		Gravel	Gravel, as above.
64.5	69.2	Bag sample		Sand	Sand, as above, hit a large rock (Athabasca sandstone & chlorite garnet gneiss) at 68.5m with interbeds of silt.
69.2	70.0	Bag sample		Gravel	Gravel, as above.
70.0	72.5	Bag sample		Gravel	Glacial gravel, poorly sorted, coarse grained, angular to sub rounded components, gravel components consist of cherts, dolomite, igneous and metamorphic rocks, sandstone, coal. Rock bit used to get through gravels.
72.5	75.6	Bag sample		Gravel	Gravel, as above.
75.6	78.6	Bag sample		Gravel	Gravel, as above, soft light grey material present, similar to unmixed bentonite powder, chips of white rock fragment, no HCl reaction for soft material or chips.
78.6	79.2	Bag sample		Gravel	Gravel, for upper part of interval. Bubbles noted in the mud at top of drill hole after mud tank emptied.
79.2	79.9	Bag sample		Silt (?)	Silt (?), softer interval.
79.9	80.2	Bag sample		Gravel	Back into gravel.
80.2	81.7	Bag sample		Till (#5?)	Clay loam, very dark grey (5Y 3/1), no HCl reaction, granules <1%.
81.7	82.5	0.93	0.93	Till	Clay loam, as above, (clayey sandy silt till), 1-2% pebble content, lithology of pebbles includes sandstone, siltstone, granites, large siltstone clast about 25cm from base of recovered core, large sandstone clast at the top of the interval, bitumen odour in core.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
82.5	85.5	2.85	2.85	Till	Sandy clay loam, large clasts at 1.18m from top, 1.88m from top and 2.13m from top, very brittle, very firm, very dark gre , rock fragments within the matrix react with HCl, matrix does not, faint bitumen odour in core, pebble content 1%.
85.5	88.6	1.86	1.86	Till	Silty sand loam, large sandstone clast at the base of run, very dark grey (5Y3/1), carbonate, chert, igneous, sedimentary pebbles, very weak HCl reaction, pebble content 2-3%.
88.6	91.7	2.46	2.46	Till	Silty sand loam, as above, granite cobble at the top of the interval, presence of medium to coarse sand lenses and partings, sand concentrations infrequent, pebble content increased to 3-4%, weak bitumen odour still prevalent in core.
91.7	94.8	2.18	1.13	Till	Sandy silt till, as above, large clasts of sandstone and granite, bitumen odour in core.
			0.66	Till	Sandy silt till, as above, silt content increasing, large clasts of granite, no bitumen odour in core.
			0.29	Till	Sandy silt till, as above, very dark grey (5Y 3/1), no HCl reaction, large clasts of sandstone, pebbles and granules <1% each.
			0.10	Silt	Silt, very dark grey, no HCl reaction, soft and brittle, massive.
94.8	96.7	1.38	1.38	Till	Clay silt till, very weak to no HCl reaction, pebble and granules content <1% each, siltstone pebble 20cm from base of recovered interval, breaks easily, some fine sand (?), competent, no bitumen odour in core.
96.7	98.4	1.99	1.99	Till	Clay silt till with some sand, very dark grey, no HCl reaction, large siltstone pebble 40cm from top of recovered interval, pebbles of dolomite and granite also observed, firm but easy to cut, competent and massive, some fine sand partings. Recovered additional 0.29 m core from above
98.4	101.5	3.10	3.10	Till	Sandy silt till with some clay, abundant rock clasts, including several large granite, siltstone, sandstone, chert and metamorphic rock, very dark grey (5Y 3/1), some breaks along 45° planes with sand partings common, coal fragment 73cm from top of core.
101.5	104.5	1.13	1.13	Till	Sandy silt till with some clay, as above, sand content appears to be increasing from till above, no HCl reaction, sand partings present, clasts of granite, limestone, sandstone, bitumen odour debatable in core.
104.5	107.6	2.80	2.80	Till	Sandy silt till, as above, large rock at top of cored interval, silt body at 50cm from top with rip up clasts of silt, bitumen odour present in core, rock at top encountered in previous run and is most likely the cause of the poor recovery in the last run.
107.6	110.6	1.21	1.21	Till	Sandy silt till, as above, large Athabasca sandstone clast near the base of the recovered core likely the cause of the lost core.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
110.6	113.4	0.5	0.5	Till	Driller reported hitting a large rock at 113.3m depth, slow drilling during that time, large sandstone clast at the base of cored interval likely the cause of the loss of core between 111.1m and 113.3m, large rock at the top of the cored interval (sandstone), no HCl reaction, very much like the till above, clay content appears to be increasing.
113.4	114.0	Bag sample		Boulders	Fragments of Boulders, granites.
114.0	114.3	Bag sample		Gravel	Glacial Gravel, poorly sorted, dolomite, granite, sandstone, rounded quartz grains.
114.3	115.3	Bag sample		Till	Sandy silt till, very dark grey (5Y 3/1), no HCl reaction.
115.3	116.6	1.0	0.33	Till	Sandy silt till, granule and pebble content 3-4%, no HCl reaction, hard to split.
			0.18	Sand	Silty Sand, very dark grey (5Y 3/1), no HCl reaction.
			0.49	Till	Sandy silt till, as above, large sandstone clast at the base of the recovered interval.
116.6	119.7	2.86	0.43	Sand	Silty sand, no HCl reaction, olive grey (5Y 4/2), moderately sorted, sub rounded to rounded. Driller noted one foot of sand starting at 116.6m.
			0.40	Till	Sandy silt till with some clay, pebble content 3-4%, no HCl reaction, black (5Y 2.5/1), granite and igneous pebbles dominant, hard.
			1.84	Till	Sandy silt till, very dark grey (5Y 2.5/1), no HCl reaction, large igneous and sandstone rock fragments throughout, soft and brittle, large sandstone clast 49cm from the base of the recovered core.
			0.19	Sand	Silty sand, no HCl reaction, olive grey (5Y 4/2), massive and soft.
119.7	122.7	2.74	0.19	Sand	Silty sand, as above, large sandstone clast at top of run. Driller reported hitting that rock near the top of the run. One pebble thick gravel bed marks the base, moderately sorted rounded to sub rounded.
			2.21	Till	Sandy silt till with minor clay, black, very weak HCl reaction, numerous sandstone pebbles, pebble content 3-4%, very hard.
			0.34	Sand	Silty sand, olive grey (5Y 4/2), no HCl reaction, rocks and pebbles about 1%, sandstone predominantly, medium to fine grained sand, sub rounded to rounded, moderately well sorted
122.7	125.8	2.28	2.28	Till	Sandy silt till, as above, numerous large pebbles along the outside of the core, very large granodioritic clast 62cm from the base of the recovered core, pebbles: siltstone, chert, sandstone, some granite, and sand content increasing downward.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
125.8	127.2	1.50	1.40	Till	Silty sand till, very weak HCl reaction, clasts of granite, sandstone, siltstone, and other igneous clasts, pebbles 3-4%, granules 1-2%, firm and hard to break, massive, numerous large clasts
			0.10	Sand	Silty fine grained sand, sub rounded to rounded, moderately well sorted, very dark gre , dominantly quartz with some feldspar and igneous rock fragments.
127.2	128.6	Bag sample		Till	Drilled like the silty sand till, Clayey Sand Till material recovered, abundant rocks hit. Hit rock at 127.2m and change to rock bit. Rock about 22cm thick, no HCl reaction.
128.6	129.8	Bag sample		Till	Drilled as above run, Clayey Sand Till recovered, still hitting abundant rocks, no HCl reaction.
129.8	130.5	Bag sample		Till	Clayey sand till, black, clay pieces noted in the recovered material, abundant rocks hit, no HCl reaction.
130.5	131.0	Bag sample		Till	Drilling harder for 10cm, then softer, Silty sand till, very dark grey to black clay, sample probably taken at 130.5m -130.6m, no HCl reaction.
131.0	133.5	Bag sample		Till	Drilling like the silty sand till above, hit rock at 133.2m, rock fragments, look like the rock is granite, no HCl reaction.
133.5	134.4	Bag sample		Gravel (?)	Glacial gravel, igneous, coal and quartz fragments, oxidized till fragments, olive grey (5Y 4/2), no HCl reaction.
134.4	134.5	Bag sample		Till (?)	drilling like sandy till, clayey silt till in recovered material, no HCl reaction.
134.5	136.5	Bag sample		Till	Clayey silt till, very dark grey, no HCl reaction.
136.5	138.4	Bag sample		Till	Rock at 137.5m, probably sandstone, numerous other rocks.
138.4	139.3	Bag sample		Till	Sandy silt till, very dark grey, no HCl reaction.
139.3	139.6	Bag sample		Till	Sandy silt till with minor clay, very dark grey, no HCl reaction.
139.6	139.9	Bag sample		Till	Sandy silt till with minor clay, as above.
139.9	140.2	Bag sample		Till	Sandy silt till, as above.
140.2	140.5	Bag sample		Till	Sandy silt till with minor clay.
140.5	143.6	Bag sample		Till	Sandy silt till (possibly with minor clay)
143.6	144.3	Bag sample		Till	Sandy silt till with minor clay in the matrix, granite rock fragments.
144.3	145.7	Bag sample		Till	Sandy silt till, as above, more clay, stiffer drilling at 144.8m.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
145.7	146.5	Bag sample		Till	Sandy silt till, with minor clay, very dark grey.
146.5	147.2	Bag sample		Till	Sandy silt till, with minor clay, as above.
147.2	147.7	Bag sample		Till	Silty clay till with minor sand.
147.7	149.0	Bag sample		Till (or clay)	Silty clay till, or clayey silt, very poor cuttings.
149.0	149.3	Bag sample		Till (or clay)	Silty clay till, or clayey silt, very poor cuttings.
149.3	152.2	Bag sample		Till (or clay)	Silty clay till or clayey silt.
152.2	153.2	0.75	0.75	Till	Till, hit a rock and lost most of the core.
153.2	155.2	1.50	1.50	Till	Clayey silt till with sand, black to very dark grey (5Y 2.5/1), first occurrence of shale clasts, siltstone, granite, sandstone, no HCl reaction, pebble content 3-4%, shale clasts up to 3cm long by 2cm wide, some sand lenses of fine to medium grained sand, no bitumen odour in core, 50% of the clasts appear to be local bedrock, hydrocarbon streaks and gas bubbles coming up in the mud.
155.2	157.2	1.12	1.12	Till	Clayey silt till with some sand, very dark grey to black, 2-3% pebbles, brittle, clasts of shale, siltstone, sandstone, large quartzite clast near the base of the recovered core, no HCl reaction.
157.2	159.3	2.1	2.1	Till	As described below.
159.3	162.1	0.9	0.9	Silt	Driller indicated the core recovered from this run was likely from the previous run, hit sand at 160.3m, Sandy Clayey Silt, very dark grey to black, very weak HCl reaction, abundant local bedrock clasts, very few igneous clasts, variation with depth in clay content, some sand partings and lenses, sand content increasing towards the base of the recovered interval, large shale clast 50cm from the base of the interval, easy to break.
162.1	164.3	1.58	0.68	Till	Sandy silt till with clay, black, very weak HCl reaction, siltstone and sandstone clasts, fine sand lenses and partings throughout, minor igneous rock fragments, 2-3% pebbles.
			0.90	Sand	Silty sand, light grey, poor to moderately sorted, subangular to rounded clasts, glacial origin, made up predominantly of quartz, igneous rock fragments, massive, medium to coarse grained, presence of some local bedrock clasts (namely shale and siltstone).
164.3	167.6	2.74	2.74	Till	Sandy silt till, black (5Y2.5/1), very weak to no HCl reaction, shale, siltstone, some igneous clasts, silt and fine to coarse grained sand partings and lenses, 2-3% pebbles, firm but brittl
167.6	173.5	5.6	1.8	Till	Sandy silt till, as above, large metamorphic rock at base of recovered core, stiff and brittle, absence of limestone.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			1.8	Till	Sandy silt till, as above, quartzite, granites, local bedrock clasts, coarse sand in the matrix, 4-5% pebbles and granules, hydrocarbons noted in mud tank, core in this run contains material from last run.
			2.0	Till	Sandy silt till, as above, core in this run contains some material from the previous run, abundant coarse sand, faint bitumen odour in core, few (if any) granite clasts.
		0	0.30	Till	Drilled 30cm into till TD 173.5m.

Appendix 2e: Lithology of Core Hole WEPA00-2

PROJECT: **WEPA Hydrogeology**	DATA NO: **WEPA00-2**	LOGGED BY: T. Lemay	DATE: Oct 3, 2000
DRILLER: McAuley Drilling Ltd.	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 570.83 m
LOCATION: LSD 07 SEC 31 TP 76 R 05 W4	LATITUDE: 55.6275339°	LONGITUDE: 110.7614465°	Source: Surveyed
COMMENTS ON LOCATION: Located 50 m from turn in gravel pit along Alta Gas road.			

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0.0	1.6	0	1.20	Gravel and sand	Most likely fill material
			0.40	Clay	Buff colour till or clay.
1.6	3.4	1.02	0.48	Clay	Upper 48cm likely the clay encountered in the previous run, 2.5Y 4/2 dark grey-brown mottled with grey, rusty brown mottling, no HCl reaction, soft.
			0.54	Diamicton	Sandy diamicton, sand, silt, pebbles of igneous rocks, sandstone, no HCl reaction, iron oxidation and iron staining, soft, enough clay to bind it together, 2.5Y 4/2.
3.4	4.7	0.35	0.35	Diamicton or till (?)	Clayey silty sand, 2.5Y 4/2, driller hit rocks on run from 3.4m to 4.7m, iron oxide staining forming lenses or bands along fractures (?), weak to moderate HCl reaction, 70%sand, 22% silt, 8% clay, consolidated large clasts of granite, gneiss, sandstone (most greater than 3cm by 3cm).
4.7	5.8	0.30	0.30	Till	5Y 3/2 dark olive grey, clayey silty sand till, weak to moderate HCl reaction, firm, fine san partings, remnants from the oxidation above, pebbles and granules about 1%. Driller felt that the core recovered came from the bottom of the run.
5.8	7.8	0.69	0.69	Till	5Y 3/2 very dark grey, clayey silty sand till, moderate to strong HCl reaction, several large sandstone clasts with some minor quartzite, 1% granules and pebbles, silt content increasing, coarse sand fraction decreasing, presence of some sand stringers.
7.8	8.8	0.35	0.35	Till	5Y 3/1 very dark grey, same till as above, organic matter observed, could be peat or lignite, firm and massive
8.8	10.7	0.79	0.79	Till	Till, as above, what look like roots (?) found. Mostly sand at 9.5 m.
10.7	12.1	0.22	0.22	Till	Till, as above, large gneiss clast at top of recovered interval, no organic material.
12.1	12.8	0.15	0.15	Till	Till, as above, large granite clast hit, dolomite pebble present, no organic material.
12.8	13.9	0.86	0.86	Till	Till, as above, very large boulder core of granite about 10cm from the base of recovered interval, also present large clasts of sandstone, no organic material.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
13.9	16.0	2.08	2.08	Till	Till, as above, no organic material.
16.0	16.5	0.35	0.35	Till	5Y 3/1 very dark grey, clayey silty sand till, weak to moderate HCl reaction, about 1% pebbles and granules, clasts of sandstone about 5cm from the base of the recovered interval, firm and difficult to split, no organic material
16.5	18.2	0.39	0.39	Till	Till, as above, moderate HCl reaction, pebbles 1%, large sandstone clast at the base of the recovered interval, no organic material.
18.2	20.2	2.00	2.00	Till	Till, as above, several large sandstone clasts, no organic material.
20.2	22.3	2.20	2.20	Till	Till, as above, no organic material
22.3	24.3	0.97	0.97	Till	Till, as above, no organic material; quartzite, sandstone, igneous, limestone clasts, glacial sand and gravel depth (23.6m) from drillers comments.
24.3	25.2	Bag sample	0.60	Sand and gravel	Depth from driller's comments.
25.2	27.5	1.48	1.48	Till	5Y 3/1 very dark grey, clayey sandy silt till, moderate to strong HCl reaction, large granite clast near top of recovered interval, also present are siltstone, sandstone and other igneous rock clasts, bitumen odour noted.
27.5	30.4	2.93	2.93	Till	Till, as above, sandstone clast at the top, shale or clay clast about 30cm from base of recovered interval, interesting rock about 60cm from base of run.
30.4	33.4	2.38	1.90	Till	Till, as above.
			0.14	Clay and sand	Two fining upward cycles from clay to coarse sand
			0.24	Sand	Silty sand, very dark grey, no reaction with HCl, clasts are sub angular to sub rounded, grains of quartz dominate. Driller noted that from 32.5m to 33.2m drilled like sand.
			0.10	Till	Till, as above.
33.4	36.5	1.29	1.29	Silt and clay	Alternation of dark clay bands with light silty sandy bands, bedding appears deformed and contorted, silt reacts strongly with HCl, clay has no reaction to HCl, top of interval is clay rich grading into more silty and sand rich at the bottom, clay is slickensided, presence of some large pebbles but generally pebble free.
36.5	39.6	1.56	0.14	Till	Till, as above.
			0.90	Silt, clay and sand	Fining upwards from interbedded sand, silt and clay, signs of deformation in the bedding and in the rip up clasts.
			0.32	Sand	Silty sand with some silt and clay clasts, moderate HCl reaction.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.20	Silt and clay	Silt and clay, as above.
39.6	42.6	0.60	0.10	Clay	Light grey brown, massive, silty clay, no HCl reaction.
			0.06	Gravel	Sandstone pebble horizon.
			0.09	Clay	Silt clay, light grey brown, massive, no HCl reaction.
			0.05	Sand	Fine-grained sand with minor silt.
			0.02	Clay	Light grey-brown, massive silty clay, moderate reaction of silt with HCl.
			0.14	Till	Sandy silty clay till, 2.5Y 3/1 very dark grey, weak to moderate HCl reaction.
			0.06	Clay	Clay with minor silt, light grey-brown, massive no HCl reaction.
			0.08	Till	Clayey silty sand till, 2.5Y 3/1 very dark grey, weak to moderate HCl reaction.
42.6	45.7	1.42	1.42	Clay and silt	Silty clay with some fine-grained sand, irregular bedding of light silt, sand, dark silt, and cla , only the light colour material reacts to HCl, breaks along silt and sand partings.
45.7	46.4	0.70	0.70	Clay and silt	Silty clay with regular bedding of silt and clay with some fine sand beds, bedding appears rhythmic, only the light colour material reacts with HCl.
46.4	48.7	1.42	0.10	Clay, silt and sand	Interbedded and contorted and deformed clay, silt and sand beds, weak HCl reaction, maximum bed width approx. 1cm.
			0.18	Clay and silt	Massive silty clay with blebs or rip up clasts of silt, no HCl reaction.
			0.12	Clay and silt	Interbedded and deformed, laminated silty clay, rhythmically bedded with some blebs of silt, weak HCl reaction, 2 photos taken.
			0.03	Clay and silt	Silty clay, massive, with blebs or rip up clasts of silt, no HCl reaction.
			0.55	Clay and silt	Silty clay, highly deformed and contorted, weak HCl reaction.
			0.07	Clay and silt	Silty clay, massive, with blebs or rip up clasts of silt, no HCl reaction.
			0.10	Clay and silt	Silty clay, deformed, weak HCl reaction, rhythmic bedding.
			0.27	Clay and silt	Silty clay, massive, with blebs or rip up clasts of silt, no HCl reaction.
48.7	51.7	0	0.00	Sand or clay	Clay (?), drilled very soft, cuttings didn't reveal if it was sand or clay, from the residue left in the core shoe it appears to be clay, very dark grey, no HCL reaction.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
51.7	54.8	0.25	0.25	Silt	Silt, drilling like a soft clay or sand, very dark grey, clayey silt, clay is minor, weak to moderate HCl reaction, some regular bedding of light and dark colour silt, abundant coal fragments recovered in cuttings.
54.8	56.8	0.18	0.18	Silt	Clayey silt, drilling the same as above, very soft, clay content increasing from that recovered above (about 25%), minor deformation of bedding, weak to moderate HCl reaction, very easy to cut.
56.8	58.8	0	0.00	?	Drills very easily.
58.8	60.9	0	0.00	?	Drills very easily.
60.9	64.0	Bag sample	0.00	Sand	Glacial sand, feldspar, granite, quartz, igneous rock fragments, moderately to poorly sorted, round to sub angular, grey-brown colour, last 1m of drilling was firme .
64.0	67.0	0.12	0.12	Silt	Clayey silt, drilling very easy like sand or silt, no cuttings, very dark grey, massive, weak HCl reaction. The drill hole is taking on water.
67.0	69.4	1.62	0.57	Sand	Sand, dark grey, fine to medium grained, fully saturated, well sorted, dominantly quartz with some granite and igneous rock fragments, well rounded, no HCl reaction, very soft.
			0.05	Clay	Silty clay, dark grey, massive, no HCl reaction, very soft.
			0.08	Sand	Sand, as above.
			0.04	Clay	Clay, as above, gradational contact.
			0.03	Sand	Sand, as above.
			0.03	Clay	Clay, as above, gradational contact.
			0.20	Sand	Sand, as above.
			0.10	Clay	Clay, as above, sharp contact.
			0.30	Sand	Sand, as above.
			0.22	Clay	Clay, as above.
69.4	71.5	0.40	0.40	Sand	Silty sand, dark grey, fine to medium grained, dominantly quartz with black flecks of coal o chert and some minor igneous rock fragments, well sorted, well rounded, no HCl reaction.
71.5	73.1	0.07	0.07	Sand	Clayey silty sand, dark grey, massive, weak HCl reaction.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
73.1	79.2	0.07	0.07	Sand	Clayey silty sand, no cuttings being captured, all fine grained, what little could be captured looked like glacial sand, driller noted 70cm of gravel at 78.0m, dark grey, weak to no HCl reaction, large granite clast at base of recovered interval, glacial.
79.2	80.8	0.77	0.77	Sand	Silty sand, regularly bedded, subhorizontal alternating beds of dark and light material, some appear to be deformed, no HCl reaction, predominantly quartz with some igneous rock fragments, sub rounded to rounded, very soft, glacial.
80.8	83.2	0.02	0.02	Silt	Clayey silt, dark grey, massive, some fine sand lenses, very weak to no HCl reaction, interval drilled very softly.
83.2	85.3	0.65	0.09	Sand	Silty sand, dark grey, fine-grained, massive, dominantly quartz, well rounded and well sorted, glacial.
			0.18	Till	Clayey sandy silt till, 5Y 3/1 very dark grey, weak to no HCl reaction, fine sand or silt partings and sand lenses, pebbles less than 1%, clasts of coal, sandstone, and igneous.
			0.03	Sand	Sand, as above.
			0.35	Till	Till, as above.
85.3	87.6	1.35	0.08	Sand	Silty sand, dark grey, fine-grained, massive, dominantly quartz, well rounded and well sorted, glacial.
			0.10	Silt	Clayey silt, very dark grey, massive, weak HCl reaction, some fine sand or silt lenses or partings.
			0.46	Sand	Sand, as above.
			0.20	Clay	Silty clay, very dark grey, irregular bedding of silt and clay, clay clasts in the silt beds on occasion, no HCl reaction.
			0.51	Silt	Clayey silt with some sand beds and lenses, very dark grey, no HCl reaction.
87.6	89.0	0.93	0.07	Silt	Silt, as above.
			0.86	Till	Clayey silty sand till, very dark grey, weak to moderate HCl reaction, some fine sand or silt partings, pebble content less than 1%, clasts of granite and sandstone.
89.0	92.0	3.01	3.01	Till	Till, as above, limestone clasts observed.
92.0	95.0	2.07	2.07	Till	Till, as above, some clay or shale clasts.
95.0	98.1	3.05	3.05	Till	Till, as above, some fine sand or silt partings, absence of clay or shale clasts, pebbles 1-2%

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
98.1	101.2	3.18	3.18	Till	Till, as above, moderate to strong HCl reaction, 2-3% pebbles, massive, driller indicated this interval was harder drilling.
101.2	104.2	2.98	2.98	Till	Till, as above, local bedrock clasts dominant, silt or fine sand partings
104.2	107.3	2.06	2.06	Till	Till, as above, with signs of oxidation, 56cm from top of recovered core is rusty in colour, in the same general location is a light grey lens of clayey silt 4cm by 2cm, other signs of oxidation but not as concentrated as at 56cm. Driller indicated that the last 1m drilled softer than the above.
107.3	110.3	3.00	0.28	Till	Till, as above.
			0.30	Till	Till, as above, but 5Y 4/3 olive grey, contact is gradational at the top but sharp at the bottom, mottling of olive grey and very dark grey, large shale clast.
			2.02	Till	Till, as above, unoxidized, large brown shale clast present (1.5m from the top of recovered core).
			0.40	Silt and clay	Silt and clay, rhythmically bedded dark clay beds and light grey silt and fine sand beds, irregular contact at the top with the till, clay beds between 0.5cm to 1.5cm, silt beds 0.5cm to 1cm thick, silt reacts moderately to HCl, clay no reaction, rip up clasts (?) visible at the top contact, beds near the base are deformed and contorted.
110.3	112.5	1.96	0.42	Silt and clay	Silt and clay, as above, some carbonaceous material, some fine sand, photos taken
			0.60	Clay	Clay, with thin laminates of silt, upper contact gradational with the silt and clay above, silt has a moderate HCl reaction, very soft, clay is massive, dark grey, some carbonaceous material.
			0.63	Silt and clay	Silt and clay, as above, but with silt beds becoming thicker, and clay beds becoming fewer and thinner, some fine sand
			0.25	Silt	Silt, dark grey with laminae of clay with some carbonaceous material and fine sand, silt react moderately to strongly to HCl.
			0.06	Sand	Silty sand, dark grey, fine grained, moderate to strong HCl reaction, predominantly well rounded quartz, well sorted, some pink grains either feldspar, granite, or possibly a contaminant.
112.5	115.0	2.14	2.14	Sand	Silty sand, fine grained, predominantly quartz grains, well rounded and well sorted, moderately regular bedding, and some cross bedding (?), carbonaceous (?) black material, presence of some medium grained sand beds 1-3cm thick in lower half of the recovered core, moderate to strong HCl reaction.

Appendix 2f: Lithology of Core Hole WEPA00-3

PROJECT: **WEPA Hydrogeology**	DATA NO: **WEPA00-3**	LOGGED BY: T. Lemay	DATE: Oct. 11, 2000
DRILLER: McAuley Drilling Ltd.	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 648.78 m
LOCATION: LSD 16 SEC 04 TP 75 R 05 W4	LATITUDE: 55.4730401°	LONGITUDE: 110.7072983°	Source: Surveyed
COMMENTS ON LOCATION: Approximately 20 m from the road near the tree line on the southwest side of clearing.			

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0.0	1.7	0.36	0.36	Till	Silty sand till, moderate to strong HCL reaction, some dark mottling, 4cm by 5cm pink-red sandstone clast near the top of recovered interval, dark greyish-brown (2.5Y 4/2), presence of roots, 1% pebbles.
1.7	3.1	0	0.00	Till	Silty sand till, as above from drillers' comments and cuttings.
3.1	3.7	0	0.00	Till	Silty sand till, as above from drillers' comments and cuttings, clay cutting detected in cuttings from this run.
3.7	4.4	0.20	0.20	Till	Silty sand till, as above, orange mottling, metal steak removed from hole, many oxidized grains and pebbles.
4.4	5.3	0.20	0.20	Till	Silty sand till, as above, medium sized sandstone boulder from above retrieved with this run, slight HCl reaction.
5.3	6.3	0.40	0.22	Till	Silty sand till, as above.
			0.10	Silt and clay	Interbedded silt and clay, between beds some occurrences of sand, mottled dark grey and oxidized brown, sand and silt partings or beds react strongly with HCl, some shale or clay clasts.
			0.08	Till	Silty clay till, massive, very dark grey (2.5Y 3/1), delayed moderate HCl reaction, <1% granules and <1% pebbles.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
6.3	7.9	1.1	0.41	Till	Silty clay till, as above.
			0.61	Till	Silty sand till with clay, moderate to strong HCl reaction, oxidized and grey mottling, dolostone and shale clasts, sand lenses show stronger signs of oxidation, contact with upper till sharp but with lower till more gradual, matrix is dark grey-brown.
			0.09	Till	Silty clay till, as above, with minor sand.
7.9	8.9	0.22	0.15	Till	Poor recovery due to rock in shoe (sandstone), silty sand till, as above, rocks moderate HCl reaction.
			0.07	Till	Silty sand till, oxidized, silt and sand lenses, olive brown (2.5Y 4/4), strong HCl reaction.
8.9	10.0	0.96	0.96	Sand	Silty sand, fine grained, moderately well sorted, subrounded to subangula , predominantly quartz with some feldspar and igneous rock fragments, moderate HCl reaction, sandstone, dolostone, some granite, brown with zones of rust colour sand.
10.0	12.4	0.46	0.46	Sand	Drilled like sand, a few rocks but no gravel. Clayey sand, massive, very dark grey, weak HCl reaction, granite, dolostone and sandstone clasts, a zone of oxidization is observed at the base of the recovered core.
12.4	14.4	0.43	0.22	Sand and clay	Silty sand and clay, recovered material almost appears to be vertically bedded, silty reddish brown sand in one half and very dark grey clay on the other, sand has a moderate HCl reaction, clay has no reaction, both are massive, coarse sand lenses near the base, clean, clay content increasing towards the base.
			0.21	Sand	Silty sand, vertically bedded with reddish brown fine sand in half with more clay clasts and very dark grey fine sand in the othe , both sands appear to be rounded to subrounded, predominantly quartz with some feldspar and rock fragments, reddish brown sand reacts moderate to strongly with HCl, very dark grey sand reacts weak to moderate to HCl.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
14.4	16.4	0.35	0.27	Sand	Silty sand, as above.
			0.08	Sand and till	Interbedding of sand and Sandy clay till, change is gradual, reacts moderately to HCl, clasts of sandstone and dolostone, along clasts there is a fine parting of medium sand, till expanded rapidly once removed from the core tube.
16.4	17.5	0.29	0.05	Boulders	Sandstone, igneous (gneiss) rocks.
			0.24	Till	Sandy clay till, massive, dark grey, weak to moderate HCl reaction, oxidized clasts, medium to coarse-grained sand partings, metamorphic and sandstone clasts.
17.5	18.5	0.44	0.44	Till	Sandy clay till, as above.
18.5	19.8	1.40	1.40	Till	Sandy clay till, as above, with slight bitumen odour in core.
19.8	22.0	0.76	0.40	Till	Silty clay till, massive, no HCl reaction, <1% pebbles and granules, soft, very dark grey, slight bitumen odour in core, pebble of sandstone identified
			0.36	Till	Sandy clay till, as above.
22.0	23.2	0.93	0.93	Till	Sandy clay till, as above, pebble and granule content may be increasing.
23.2	24.6	0.90	0.90	Till	Sandy clay till, as above, decreased reaction to HCl (weak reaction).
24.6	26.6	0.10	0.10	Till	Sandy clay till, as above, drilling the same based on drillers comments, schist at the base of the recovered interval was hit at 23.5m, according to the driller, and must have fallen into the hole before this run.
26.6	27.6	0.96	0.20	Till	Sandy clay till, as above, large rock hit at the start of this run.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.76	Till	Transition from sandy clay till into a sandier till, weak HCl reaction, very dark grey (5Y 3/1), bitumen odour in core noted, 1-2% pebbles and granules.
27.6	28.8	1.09	1.09	Till	Silty sand till with minor clay, massive, firm, very dark grey (5 3/1), weak to moderate HCl reaction, sandstone clasts dominate, some igneous, more clasts than in above till, 1-2% granule content, 2% pebble content, bitumen odour present in core.
28.8	30.7	1.88	1.88	Till	Silty sand till with minor clay, as above, moderate HCl reaction, bitumen odour noted in core.
30.7	32.7	1.14	1.14	Till	Silty sand till with minor clay, as above, large igneous clast 45cm from top of cored interval.
32.7	34.4	1.72	1.50	Till	Silty sand till with minor clay, as above, driller indicated he is hitting many rocks, large dolostone clast at 35cm from the top of the recovered core.
			0.05	Sand	Fine grained silty sand, very dark grey, weak HCl reaction, predominantly quartz, rounded to subrounded, well sorted.
			0.17	Till	Silty sand till, as above, moderate HCl reaction, coarse sand parting near base.
34.4	35.6	0.95	0.95	Till	Silty sand till, as above, 0.3m to 0.45m from the top of the recovered core the till becomes siltier with less clay than before, the change is abrupt at the top and bottom of this interval, bitumen odour noted in core.
35.6	36.8	1.20	1.20	Till	Sandy silt till, very dark grey (5Y 3/1), moderate to strong HCl reaction, limestone, sandstone, granite (igneous) clasts, 1-2% pebbles and granules, soft, sand lense of silty sand found at top of run.
36.8	38.8	0.82	0.82	Till	Clayey silt till, changes from a slow moderate HCl reaction at the top of run to a quick moderate to strong reaction at base, oxidized siltstone grains, percentages of sand and clay are about the same (clay increasing at base of run).

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
38.8	40.8	1.54	1.54	Till	Clayey silt till, as above, clay content has increased slightly, moderate HCl reaction, 1-2% pebbles, not as many large clasts, faint bitumen odour in core.
40.8	42.9	0.45	0.45	Till	Clayey silt till, as above, black (2.5Y 3/1), moderate HCl reaction, faint bitumen odour, clasts of limestone, sandstone, granite, gneiss, 1% pebbles, 1% granules, massive and firm
42.9	44.5	1.58	1.58	Till	Clayey silt till, as above, faint bitumen odour in core.
44.5	46.6	2.15	2.15	Till	Clayey silt till, as above.
46.6	49.0	2.40	2.40	Till	Clayey silt till, as above.
49.0	51.0	1.90	1.90	Till	Clayey silt till, as above, with some oxidized clasts and bitumen odour.
51.0	53.0	1.88	1.88	Till	Clayey silt till, as above, large sandstone clast near the base of the recovered interval (in shoe).
53.0	55.1	2.05	2.05	Till	Clayey silt till, as above.
55.1	57.1	2.00	2.00	Till	Clayey silt till, as above, till becoming richer in clay towards the base of the recovered interval.
57.1	59.1	1.6	0.80	Till	Clayey silt till, as above, but gradually becoming more clay rich.
			0.10	Till	Clayey silt till, as above, massive, very dark grey, moderate HCl reaction, gradually becoming more clay rich, (transition zone?).
			0.70	Till	Silt or clay till, percentages of silt and clay very close, very dark grey, moderate HCl reaction, 1% pebbles, 1% granules, appear to be slickensides.
59.1	61.2	2.16	1.50	Till	Clay till, very dark grey, moderate HCl reaction, 1% pebbles, 1% granules.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.15	Till	Clayey silt till, massive, very dark grey, moderate HCl reaction, 1% each pebbles and granules.
			0.10	Till	Clay till, as above.
			0.41	Till	Clayey silt till.
61.2	63.2	2.00	1.60	Till	Clay till, as above.
			0.40	Till	Clayey silt till, as above.
63.2	63.2	1.41	0.20	Till	Clayey silt till
63.2	65.2		1.21	Till	Sandy silt till, very dark grey, gradual increase in sand over clay with depth, moderate HCl reaction, 1% pebbles and granules, clasts of limestone, sandstone, and granite, large sandstone clast 10cm from the base of the recovered interval.
65.2	67.3	2.05	1.00	Till	Silty clay till, massive, 5Y 3/1, very dark grey, moderate HCl reaction, limestone, sandstone, granites, 1% pebbles, 1% granules, hard, slickensides present.
			1.05	Till	Sandy silt till, massive, moderate to strong HCl reaction, same clast lithology as above till.
67.3	69.3	1.45	1.45	Till	Sandy silt till grading into a clayey silt till, both are very dark grey, massive, 1% each pebbles and granules, weak HCl reaction (due to cold temp.?), clasts of sandstone, limestone and granite noted, large sandstone clast at the base of recovered core.
69.3	71.3	0.60	0.60	Till	Silt till, very dark grey, weak to moderate HCl reaction, massive, sand fraction increasing. (at 69.6m, driller indicated drilled like sand.)

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
71.3	73.4	0.80	0.80	Till	Driller noted that first 1.5m drilled like sand with some sti f bands, bottom portion drilled like till above, examination revealed that the till is indeed the Clay silt till, as above, sand content is high, some coarse sand partings noted.
73.4	75.8	1.55	1.55	Till	Clayey silt till, as above, sand content is increasing, possibly a sand till, coarse-grained clean sand partings, pebble and granule content decreasing.
75.8	77.8	2.00	1.50	Till	Hit sand and maybe some gravel during this run, clayey silt till, as before, sand content fluctuating
			0.10	Clay	Massive clay with silt partings and rip-up clasts.
			0.08	Till	Clay silt till, as above.
			0.32	Till and clay	Interbedded clay (as above) and clay silt till (as above).
77.8	79.5	1.57	1.57	Till	Driller reported the upper 0.1m drilled like sand, silty sand till, massive, oxidized, orange-brown colour (10YR 4/3) mottled with patches of strongly oxidized (7.5YR 4/6) and unoxidized (5Y 3/1) till, weak HCl reaction, 1-2% pebbles and granules, easily cut, soft, clay clasts noted, some coal flecks, 3 photos taken, gradual transition from oxidized to unoxidized till.
79.5	82.5	1.40	1.40	Till	Unoxidized silty sand till, as above, granule content may be increasing, several large sandstone and igneous clasts at the base of the recovered interval, coal noted.
82.5	84.8	2.38	2.38	Till	Driller reported hitting a large rock at 84.8m, silty sand till, as above.
84.8	88.3	0	0.00	Till	Till, based on drillers comments and cuttings.
88.3	89.5	0	0.00	Till and sand	Stiffer zones then easier drilling zones, one easier drilling zone at 0.1m another at 0.4m depth.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
89.5	92.0	0	0.00	Till and sand	Driller reported hitting sand in this interval 82.9m to 91.4m, lower portion appears to be silty sand till, very dark grey, no HCl reaction, no pebbles or granules noted in cuttings.
92.0	92.3	0.30	0.30	Till	Silty sand till, very dark grey, massive, no HCl reaction, bitumen odour noted in core, pebbles and granules 1% each, clasts of granite and quartzite noted, hit a rock at near the end of the last run.
92.3	94.3	2.05	2.05	Till	Silty sand till, very dark grey, no HCl reaction, igneous clasts, siltstone, sandstone, oxidized siltstone, shale, stratified sulphide bearing rock 0.2m from top of recovered interval, pebble content 2-3%, numerous large clasts, faint bitumen odour in core.
94.3	96.0	Bag sample	0.00	Till	Silty sand till, very dark grey, rock hit was 0.2m thick, frock fragments suggest the rock was a granite.
96.0	97.5	Bag sample	0.00	Till	Silty sand till, as above, some siltier and clayier cuttings present, firmer drilling at 96.0m
97.5	99.0	Bag sample	0.00	Till	Silty sand till, as above.
99.0	100.5	Bag sample	0.00	Till	Silty sand till, as above.
100.5	101.5	Bag sample	0.00	Till	Silty sand till, as above, numerous rocks hit.
101.5	103.6	Bag sample	0.00	Till	Silty sand till, as above, numerous rocks hit, rock fragments of sandstone and quartzite noted.
103.6	105.1	Bag sample	0.00	Till	Drilling stiffer like there is more clay, still appears to be silty sand till.
105.1	106.6	Bag sample	0.00	Till	Silty sand till, as above.
106.6	108.1	Bag sample	0.00	Till	Silty sand till, as above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
108.1	109.4	Bag sample	0.00	Till	Silty sand till, as above, hit a rock at 109.4m depth.
109.4	110.5	0.95	0.55	Till	Clayey sand till, massive, black, very weak HCl reaction, granules 1%, pebbles 3-4%, clasts of siltstone, granite, dolostone, bitumen odour present in core.
			0.15	Till	Silty sand till, massive, brown-black, strong bitumen odour in core, weak to no HCl reaction, sandstone, siltstone, shale, igneous clasts.
			0.25	Till	Clayey sand till, as above with coarse sand beds.
110.5	113.6	2.96	1.50	Till	Interbedded clayey sand till (as above) and silty sand till (as above), limestone clasts, sandstones, siltstones, some coarse sand partings.
			1.46	Till	Clayey sand till, as above, some silty zones with coarse sand, hit large gneiss clast 0.1m from base of run, grading into more silty sand till.
113.6	116.6	2.72	2.72	Till	Silty sand till, black, very weak HCl reaction, sandstone, shale, siltstone, granite, metamorphic clasts, many large clasts mainly sandstone, coarse sand partings and lenses near the top, granules 3-4%, pebbles 4-5%.
116.6	119.6	2.71	2.71	Till	Silty sand till, as above, large clasts throughout, large sandstone cobble 1m from top of recovered interval.
119.6	122.7	2.30	0.60	Till	Driller reported hitting sand and gravel from 121.0m to 122.0m (grab sample- glacial sand and gravel), silty sand till, as above, bitumen odour in core.
			0.33	Silt and clay	Clayey silt, irregular bedding, no HCl reaction, black, sand bed 0.65m from top, sharp contact at top and base.
			0.76	Till	Silty sand till, as above, grading into silty sand near the base, bitumen odour in core.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.07	Sand and gravel	Glacial sand and gravel, granite, quartzite, igneous rocks.
			0.56	Sand diamicton	Glacial sand, very dark grey, no HCl reaction, poorly sorted, subrounded to subangular, large granite clast 7cm from base of recovered interval.
122.7	125.7	1.75	0.95	Sand	Glacial sand, as above, ironstone clast found, dirty (silty) sand.
			0.80	Till	Silty sand till, as above, metamorphic clast 1.45m depth, driller indicated that he hit many stones, bitumen odour noted in core.
125.7	128.8	2.17	0.45	Till	Silty sand till, as above, bitumen odour still present in core.
			0.05	Sand	Glacial sand, poorly sorted silty sand, no HCl reaction, subrounded to subangular, predominantly quartz.
			0.35	Till	Silty sand till, as above.
			0.20	Sand	Glacial sand, as above, very wet, core is flowing out of core tube
			0.15	Till	Silty sand till, as above.
			0.10	Sand	Glacial sand, as above, very wet, core is flowing out of core tube
			0.87	Till	Silty sand till, as above, very large granite cobble 1.35m from top of the recovered core, several large sandstone clasts near the base of the run.
128.8	131.8	2.45	1.10	Till	Silty sand till, as above, some carbonaceous material, fine sand partings noted
			0.50	Sand	Medium grained, well sorted, rounded to subrounded glacial sand with minor silt, no HCl reaction, very wet, flowing out of core tube

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.10	Till	Silty sand till, as above.
			0.60	Sand	Sand, as above, grading into a fine-grained, moderately well sorted, subrounded to subangular glacial silty sand, no HCl reaction.
			0.15	Till	Silty sand till, as above.
131.8	134.9	2.77	2.77	Till	Silty sand till, as above, large granite clast 1m from top of core, large sandstone clast 0.7m from top of core.
134.9	137.9	2.55	0.24	Till	Sandy silt till, with clayey silt bed 7cm thick, grading into the silty sand till as above, shale clast near the top of this interval, no HCl reaction.
			1.61	Till	Silty sand till, as above, becoming sandier with depth.
			0.35	Sand	Medium grained, moderately well sorted, rounded to subrounded, glacial sand grading into a fine grained silty sand, neither show a reaction with HCl
			0.35	Till	Silty sand till, as above, silt content appears to be increasing.
137.9	141.0	2.87	2.87	Till	Silty sand till, as above, zones of medium to coarse-grained sand occur occasionally, maximum thickness 2-3cm, sand and silt partings common.
141.0	144.1	2.70	2.70	Till	Silty sand till, as above, massive, black, weak to moderate HCl reaction, clasts of siltstone, sandstone, granite, quartzite, shale, some oxidized clasts, pebble content 3-4%, granules 4-5%, some sand and silt partings.
144.1	146.8	1.80	0.95	Till	Silty sand till, as above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			0.85	Till	Silty sand till, as above, moderate to strong HCl reaction, abundant shale clasts (dominant clast type), pebbles 2-3%, granules 3-4%.
146.8	149.1	1.63	1.63	Till	Silty sand till, as above, one silt bed 5cm wide 1 m from top of recovered core, massive sulphide noted, abundant shale, abundant large sandstone clasts.
149.1	150.8	0.80	0.80	Till	Silty sand till, as above, sandstone clasts very brittle, shale clasts, medium grained sand partings, moderate HCl reaction.
150.8	153.1	1.45	1.45	Till	Silty sand till, as above, driller's comments: last 2m of run were sand.
153.1	156.2	0.33	0.33	Silt	Silt, black, no pebbles, irregular clay beds, one sandstone clast, sand partings (fine grained, silty), no HCl reaction.
156.2	157.4	0		Sand	Driller reported hitting 1m of sand, with 2 large rocks after the sand.
157.4	161.9	Bag sample	1.50	Till	No recovery, silty sand till, from cuttings.
		Bag sample	3.00	Sand	No recovery, olive grey, fine to medium grained, moderately well sorted glacial sand, sub rounded to subangular, predominantly quartz with black chert (?) and minor feldspar.
161.9	162.9	Bag sample		Sand	Olive grey glacial sand, as above.
162.9	164.4	Bag sample		Sand	Glacial sand, as above.
164.4	165.9	Bag sample		Sand	Glacial sand, as above with some very dark grey sand.
165.9	167.4	Bag sample		Sand	Glacial sand, as above, sand appears more oxidized (?).
167.4	168.4	Bag sample		Sand	Glacial sand, as above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
168.4	169.9	Bag sample		Sand	Glacial sand, as above.
169.9	172.5	Bag sample		Sand	Glacial sand, as above, some sand very light grey in colour with similar characteristics.
172.5	172.5		0.05	Sand	No recovery, glacial sand, as above.
172.5	174.0		1.45	Sand and gravel	No recovery, glacial sand and gravel.
174.0	175.8			Sand and gravel	No recovery, glacial sand and gravel, as above.
175.8	177.5			Sand and gravel	No recovery, glacial sand and gravel, as above.
177.5	182.0	Bag sample		Shale or clay	Very dark grey shale or clay, poor cuttings return. TD = 182.0m

Appendix 2g: Lithology of Core Hole WEPA00-4

PROJECT: **WEPA Hydrogeology**	DATA NO: **WEPA00-4**	LOGGED BY: T. Lemay	DATE: Oct. 17, 2000
DRILLER: McAuley Drilling Ltd.	TYPE DRILL: Wet Rotary	DRILL METHOD: Wireline Core	SURFACE ELEVATION: 569.35 m
LOCATION: LSD 08 SEC 04 TP 79 R 04 W4	LATITUDE: 55.8156450°	LONGITUDE: 110.5576402°	Source: Surveyed
COMMENTS ON LOCATION: Approximately 20 m from the road near the tree line on the southwest side of clearing.			

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
0.0	2.1	1.32	1.32	Diamicton (fill?	Silty sand diamicton, mottled strong brown and grey brown, strongly oxidized with nodules of clayey silty sand almost olive in colour on the outside but dark grey on the inside, clasts of quartzite and siltstone, roots, no reaction with HCl, some carbonaceous material. Driller reported bottom 30cm drilled like sand.
2.1	3.1	0.14	0.14	Diamicton	Till, as above, large clast of a mafic igneous rock
3.1	4.6	Bag sample	0.00	Sand	Poorly sorted sand (glacial), olive grey, oxidized.
4.6	6.3	0.29	0.29	Sand	Driller reported sand for first 1m, harder band for about 10cm, sand then lower 30cm harde .
6.3	7.8	1.1	0.08	Clay	Silty clay, highly irregular bedding, mottled grey-brown and strong brown, no HCl reaction.
			0.13	Sand	Fine grained, silty sand, oxidized brown, no HCl reaction.
			0.69	Silt and clay	Interbedded silt and clay, clay beds between 1-3cm thick, silt beds 1-10cm thick, no HCl reaction, silt predominantly oxidized, clay shows slickensides.
			0.08	Sand	Sand, as above.
			0.12	Silt and clay	Silt and clay, as above.
7.8	9.7	0.92	0.22	Silt and clay	Driller reported first 30cm drilled hard, next 1m drilled soft, next 10cm may have been gravel. Silt and clay, as above.
			0.08	Clay	Very dark grey, massive, no HCl reaction
			0.22	Sand	Very dark grey, medium grained, sub angular to angular clasts, moderately well sorted, massive, no HCl reaction.
9.7	12.4	2.58	0.13	Sand	Sand, as above.
			2.45	Till	Silty sand till, very dark grey, no HCl reaction, clasts of sandstone, siltstone, quartzite, granite and other igneous rock fragments, abundant fine sand and silt partings, pebbles about 1%, granules 2-3%.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
12.4	14.3	1.02	1.02	Till	Till, as above, large granite clast about 10cm from top of interval, rock at 14.3m.
14.3	16.0	Bag sample	0.00	Till	Till, as above, fragments of rock in cuttings suggest rock was sandstone or granite, maybe becoming more clay rich.
16.0	18.5	1.79	1.79	Till	Driller indicated last 0.5m likely sand in grab sample. Sand clay till, plastic, very dark grey, no HCL reaction, pebble content 1-2%, granules 1-2%, clasts of sandstone and some granite, medium to coarse grained sand partings, some bands of pure clay.
18.5	18.9	Bag sample		Sand	Glacial sand.
18.9	19.9	Bag sample		Gravel	Glacial gravel.
19.9	23.0	Bag sample		Sand	Glacial sand with beds of till, about 30cm thick (according to the driller).
23.0	23.6	0.22	0.22	Till	Sandy clay till, as above, large clast of sandstone at the base of the recovered interval.
23.6	24.2	Bag sample		Sand	Rock at top of run, granite, glacial sand beneath.
24.2	25.7	Bag sample		Sand and till	Glacial sand and sand clay till as above.
25.7	27.2	Bag sample		Till	Sandy clay till, as above.
27.2	29.0	Bag sample		Till	Till, as above.
29.0	30.7	0	0.00	Till	Driller indicated material drilled like till, encountered a rock.
30.7	32.1	Bag sample		Till	Till, as above.
32.1	33.9	0	0.00	Till	Till, as above.
33.9	35.5	1.10	1.10	Till	Till, as above.
35.5	36.8	0.61	0.20	Till	Till, as above, silt content may be increasing.
			0.28	Clay	Massive clay, blocky, mottled very dark grey and dark grey, some silt no HCl reaction.
			0.13	Till	Sandy silt till, as above, (driller indicated that the last 1m of this run drilled very softly).
36.8	39.8	0	0.00	Sand	Driller indicated this interval drilled like sand.
39.8	42.9	1.90	0.05	Clay and silt	Driller indicated upper 70cm sand, black clay and light grey silt, irregularly interbedded, no HCl reaction.
			1.85	Till	Till, as above, silt content may be increasing.
42.9	44.9	2.12	0.40	Till	Till, as above.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
			1.72	Till	Sandy clay till, weak HCl reaction, very dark grey, pebbles about 1%, granules about 1%, granite, sandstone, coal clasts, large granite clast at the base of the recovered interval.
44.9	46.9	1.84	0.90	Sand	Fine- medium grained sand, becoming coarser towards the bottom of the interval, clay content decreasing, silt content increasing towards bottom of run, no HCl reaction.
			0.05	Clay	Massive clay, black, no HCl reaction.
44.9	46.9		0.89	Silt and clay	Irregularly bedded, deformed silt and clay, silt beds between 1-3cm thick, clay beds between 1-2cm thick, silt beds light olive grey, clay black, silt has a moderate HCl reaction, clay has no HCl reaction.
46.9	49.0	0	0.00	Silt and clay (?)	Drilling like clay (core slipped out of core barrel on the way to the surface).
49.0	49.0	1.03	0.40	Silt and clay	Interbedded silt and clay, irregularly bedded, silt beds between 1-2cm thick, clay between 0.5-1cm thick slightly deformed, very weak HCl reaction, very dark grey clay and light grey silt.
49.0	50.0		0.63	Clay	Massive clay with minor silt beds, very dark grey, no HCl reaction.
50.0	52.6	0.73	0.73	Clay	As above clay, silt beds slightly more predominant, driller indicated that upper 1.6m drilled like clay and lower 1m drilled softer.
52.6	53.7	0.72	0.72	Till	Sandy silt till, very dark grey, very weak HCl reaction, clasts of sandstone, granite and siltstone, pebbles about 1%, granules about 1%, silt content increasing in the lower 0.25m, lighter and darker bands visible in that interval.
53.7	55.1	1.0	0.60	Till	As above till, about 15cm from top is a zone of silt or fine sand about 7cm wide
			0.10	Clay and silt	High angle contact at top and base of clay, high angle, irregular bedding of silt and clay, no HCl reaction.
			0.30	Till	Silty sand till, very dark grey, no HCl reaction, pebbles about 5%, granules 2-3%, clasts of sandstone, granite, siltstone and other igneous rocks.
55.1	57.1	1.57	1.02	Silt and sand	Silt with fine grained silty sand beds, sand beds between 1-5cm thick, fine silty sand at base o interval, light grey to grey, no HCl reaction, sharp contact with till below.
			0.55	Till	Sandy silt till, very dark grey, no HCl reaction, clasts of granite and sandstone, pebble content about 1%, granules about 1%, sand and silt partings throughout (more so near base of interval), some partings show deformation.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
57.1	59.1	1.77	1.77	Till	Sandy silt till, no HCl reaction, upper 1.5m very dark grey, lower 20 cm black, present in upper 80cm of interval: clasts of sandstone, siltstone, and calcareous siltstone as well as abundant sand and silt partings, abundant shale clasts in lower 97cm, at 80cm large sandstone clast, at base of interval a clast of gneiss, from 70-80cm are bands of fine grained sand
59.1	61.2	2.03	2.03	Till	Till, as above, shale clasts increasing, pebbles 3-4%, granules 2-3%, coal fragments observed.
61.2	63.2	2.40	2.40	Till	Till, as above.
63.2	65.2	1.54	1.29	Till	Till, as above.
			0.25	Sand	Fine grained silty sand, well sorted, light to medium grey, no HCL reaction, lower 10cm includes regularly bedded clay bands, upper 25cm less well bedded, grains are subrounded to rounded, dominantly quartz, low angle contact with till (sharp contact).
65.2	67.3	0.70	0.70	Sand	Fine to medium grained glacial sand, minor silt and clay, evidence of cross bedding and 2 (possibly 3) coarsening upwards cycles, no HCl reaction, grains are moderately well sorted, sub angular to surrounded, quartz and feldspar dominant.
67.3	69.9	0	0.00	Sand	Driller indicated 2.2m drilled like sand and 0.4m drilled like clay.
69.9	71.2	1.29	1.29	Till	Sandy silt till, as above, no shale clasts observed.
71.2	73.5	2.23	2.23	Till	Till, as above, becoming more clay rich towards the base, 5cm thick bed of silt and clay with deformed bedding about 25cm from base of run.
73.5	76.5	2.93	0.57	Clay and silt	Interbedded and deformed clay and silt, no HCl reaction, silt beds 0.5-1cm thick, clay beds 0.5-2cm thick becoming more silty towards the base, clay very dark grey to black, silt light grey to pale white yellow.
			0.35	Sand, Silt and Clay	Interbedded fine-medium grained sand, silt and cla , no HCl reaction, irregular bedding, silt and clay more prominent at top of interval and gradually decreasing, overall colour medium grey.
			2.01	Till	Silty sand till, very dark grey, no HCl reaction, clasts of shale, granite, sandstone, carbonaceous material and siltstone identified, pebbles about 1%, granules about 1%
76.5	79.5	2.51	0.81	Till	Till, as above, at 81cm from top of interval is a silt wedge about 20cm long by 8cm wide, light grey, no HCl reaction, high angled contact, inclusion of till stringers within the silt, abundant shale clasts in the till
			0.20	Silt	Deformed medium bedding, abundant shale clasts.
			1.50	Till	Abundant silt partings plus inclusions, non-horizontal, irregular form.

DRILLED DEPTH (m) from	to	CORE RECOVERY (m)	DESCRIBED INTERVAL (m)	LITHOLOGY	COMMENTS
79.5	82.6	3.09	3.09	Till	As above till, large sandstone clast about 70cm from top of interval, 75cm from base of run colour changes abruptly from dark grey to black and very dark grey (mottled), at 65cm from the base of run very hard black chert conglomerate (?) observed (or oolitic sandstone), no HCl reaction, sulphides observed.
82.6	85.6	2.35	2.35	Till	Till, as above, shale clasts increasing in number and size, presence of some fine- medium grained sand beds and some silt rich zones, clasts of sandstone, siltstone, granite and other igneous rocks.
85.6	88.7	2.48	2.48	Till	Till, as above.
88.7	90.0	1.14	0.74	Till	Till, as above.
			0.40	Silt and till	Sandy silt till, irregular bedding of light and dark coloured silt, signs of deformation, generally beds are high angled, no HCl reaction, clasts of shale, sandstone and siltstone, pebbles 1-2%, granules 1%.

Appendix 3. Geochemical Analysis of Quaternary and Upper-Bedrock Samples

Description of Geochemical Analytical Methods and Procedures

The till and bedrock samples were obtained by sub sampling cored intervals and submitting to the AGS lab for processing. 200 grams of raw sample for the Texture Analysis and 250 grams of raw sample for the Standard (Reference) Sample are placed into separate labelled bags. Each sample was dried, gently disaggregated to avoid the crushing of rock and mineral grains, and was screened using 2.00 mm, 1mm and 0.063 mm mesh stainless steel sieves. The <63mm fraction was then weighed into labelled vials. About 60 grams of the <63μm fraction were recovered from each sample. The <63mm fractions were then subdivided to provide a 30 gm subset for AGS Reserve and a 30 gm subset for Becquerel Laboratories Inc. Subsequent to drying, any dissolved metals in the water component of the sample remain within the matrix, adding to the total concentration of metals within the sample. Prior to submission of the samples to the laboratory, the sample order was randomized and both duplicate and standard samples were inserted. About five per cent of the samples which were submitted, are duplicates or standards.

Becquerel Laboratories Inc analyses package involves analyses from two different labs – Becquerel Labs conduct the Neutron Activation Analysis (NAA), a method based on nuclear reactions, and ALS Chemex conducts plasma analyses (ICPMS and ICPAES) and Cold Vapour Atomic Absorption (CVAA).

Procedure for Mercury Determination (CVAA) by ALS Chemex:

A prepared sample (0.50 grams) is digested with aqua regia for two hours in a hot water bath. After cooling, the resulting sample solution is transferred to a gas cylinder and mixed with stannous sulphate. The vapour generated is pumped through a tube that is located in the light path of an atomic absorption spectrometer. The absorbance is measured and compared to a standard series to determine the amount of mercury that is present.

Procedure for ICP Spectroscopy by ALS Chemex:

A prepared sample (usually 0.2 g) is digested using a mixture of hydrofluoric, perchloric and nitric acids. This will completely dissolve all but the most resistant minerals. Because of the use of hydrofluoric acid, silica and other more volatile elements such as arsenic and selenium, will be partially volatilized. These problems are identified by the element overlap from the various techniques.

The samples are initially analyzed using an inductively coupled atomic emission spectrometer (ICPAES). Following this analysis, the results are reviewed to ensure that base metal concentrations are less than 1%, with the exception of silver, bismuth, and tungsten which have upper analytical limits of 100, 500 and 1000 ppm, respectively. Samples that meet these criteria are then diluted and analyzed by ICPMS-MS. Samples that exceed the Upper Limits cannot be analyzed by ICPMS and they are treated as regular ICPAES analyses. The analytical results are corrected for inter-element spectral interferences.

Procedure for Neutron Activation Analysis (NAA) by Becquerel :

The method for neutron activation analysis of rocks or mineralogenic sediments such as stream sediments or till, involves the transfer of about 15 grams of sample material to tared, plastic, watertight vials. Each vial is identified with a bar code and a flux monitor affixed to the base These vials are stacked into one-foot long bundles for irradiation. The bundles contain randomly selected duplicate samples at the base of the bundle and standards inserted at random positions in the bundle. All bundles are treated in a similar manner. They are submitted for exposure to a flux of neutrons at a nuclear reacto .

These bundles are inserted into the core of a nuclear reactor for a short period of time. This irradiation causes many of the elements in the sample to become radioactive and begin to emit radiation in the form of penetrating gamma rays whose energies (or wavelengths) are characteristic of particular elements. After an appropriate decay period (usually six to seven days), the irradiated samples are loaded onto the counting system, a gamma-ray spectrometer with a high resolution, coaxial germanium detector. Gamma rays radiate continuously and the interaction of these with the detector lead to discrete voltage pulses proportional in height to the incident gamma-ray energies, producing a spectrum of gamma ray energies versus intensities. The counting time varies but it is between twenty and thirty minutes per sample. By comparing spectral peak positions and areas with library standards, the elements comprising the samples are qualitatively and quantitatively identified. If the standard values vary by more than two standard deviations from the mean, the vials are examined and recounted and the batch is reanalysed if the standard values are still unacceptable. Duplicate samples must also fall within our accepted range or recounting and/or reanalysis is done.

Table A3-1: List of elements analyzed and method of geochemical analysis.

Element	ICPMS
Al (%)	Aluminum
Ba (ppm)	Barium
Be (ppm)	Beryllium
Bi (ppm)	Bismuth
Cd (ppm)	Cadmium
Ca (%)	Calcium
Cr (ppm)	Chromium
Co (ppm)	Cobalt
Cu (ppm)	Copper
Ga (ppm)	Gallium
Ge (ppm)	Germanium
Pb (ppm)	Lead
Li (ppm)	Lithium
Mg (%)	Magnesium
Mn (ppm)	Manganese
Mo (ppm)	Molybdenum
Ni (ppm)	Nickel
Nb (ppm)	Niobium
P (ppm)	Phosphorus
K (%)	Potassium
Rb (ppm)	Rubidium
Ag (ppm)	Silver
Sr (ppm)	Strontium
Te (ppm)	Tellurium
Tl (ppm)	Thallium
Ti (%)	Titanium
W (ppm)	Tungsten
V (ppm)	Vanadium
Y (ppm)	Yttrium
Zn (ppm)	Zinc

Element	NAA
As (ppm)	Arsenic
Au (ppb)	Gold
Ba (ppm)	Barium
Br (ppm)	Bromium
Ce (ppm)	Cerium
Cs (ppm)	Cesium
Cr (ppm)	Chromium
Eu (ppm)	Europium
Hf (ppm)	Hafnium
Ir (ppm)	Iridium
Fe (%)	Iron
La (ppm)	Lanthanum
Lu (ppm)	Lutetium
Na (%)	Sodium
Sb (ppm)	Antimony
Sc (ppm)	Scandium
Se (ppm)	Selenium
Sm (ppm)	Samarium
Sn (ppm)	Tin
Ta (ppm)	Tantalum
Tb (ppm)	Terbium
Th (ppm)	Thorium
U (ppm)	Uranium
Yb (ppm)	Ytterbium
Zr (ppm)	Zirconium

Element	CVAA
Hg (ppb)	Mercury

Table A3-2: Detection limits for elements analyzed, (Becquerel Laboratory Inc).

Element	Detection limit		NAA	ICPMS	Element	Detection limit		NAA	ICPMS	Element	Detection limit		NAA	ICPMS
Aluminum	0.01	%		0.01	Hafnium	1	ppm	1		Selenium	5	ppm	5	
Antimony	0.1	ppm	0.1	0.1	Iridium	50	ppb	50		Silver	0.05	ppm	2	0.05
Arsenic	0.5	ppm	0.5	1	Iron	0.01	%	0.2	0.01	Sodium	0.01	%	0.02	0.01
Barium	10	ppm	50	10	Lanthanum	0.5	ppm	2	0.5	Strontium	0.2	ppm		0.2
Berylium	0.05	ppm		0.05	Lead	0.5	ppm		0.5	Tantalum	0.2	ppm	0.5	0.2
Bismuth	0.02	ppm		0.02	Lithium	0.2	ppm		0.2	Tellurium	0.1	ppm	10	0.1
Bromine	0.5	ppm	0.5		Lutetium	0.2	ppm	0.2		Terbium	0.5	ppm	0.5	
Cadmium	0.1	ppm	5	0.1	Magnesium	0.01	%		0.01	Thallium	0.05	ppm		0.05
Calcium	0.01	%		0.01	Manganese	5	ppm		5	Thorium	0.2	ppm	0.2	0.2
Cerium	0.01	ppm	5	0.01	Mercury	0.01	ppm		*	Tin	100	ppm	100	
Cesium	0.05	ppm	0.5	0.05	Molybdenum	1	ppm	1	1	Titanium	0.01	%		0.01
Chromium*	1	ppm	20	1	Nickel*	0.2	ppm	10	0.2	Tungsten	0.2	ppm	2	0.2
Cobalt	0.2	ppm	5	0.2	Niobium	0.2	ppm		0.2	Uranium	0.2	ppm	0.2	0.2
Copper	1	ppm		1	Phosphorus	10	ppm		10	Vanadium	1	ppm		1
Europium	1	ppm	1		Potassium	0.01	%		0.01	Ytterbium	2	ppm	2	
Gallium	0.1	ppm		0.1	Rubidium	0.2	ppm	5	0.2	Yttrium	0.1	ppm		0.1
Germanium	0.1	ppm		0.1	Samarium	0.1	ppm	0.1		Zinc	2	ppm	100	2
Gold	2	ppb	2		Scandium	0.2	ppm	0.2		Zirconium	200	ppm	200	

COMMENTS:

1. The package combines Inductivity Coupled Plasma Mass Spectrometry (ICPMS) (tri-acid) plus
   Hg Cold Vapour Atomic Adsorption (CVAA) with Nuetron Atomic Activation (NAA) on a 15 g. subsample.

2. The package is intended for unmineralized sediments. The samples are not run by ICPMS if they are
   mineralized - higher detection limits and fewer elements are available with this type of sample.

3. * denotes CVAA method of analysis.

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			NAA	NAA	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	IMS
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**	**Cr***
			grams	**ppb**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-22.4	Till	22.4	11.4	<2	1	11	590	590	2	0.29	2.4	0.56	1.04	82	5.2	84	69
W99-1-25.1	Till	25.1	13.7	<2	0.8	6.6	590	540	1.2	0.17	1.9	0.46	1.59	80	2.8	66	44
W99-1-32.6	Till	32.6	10.6	<2	0.8	12	670	610	2	0.26	2	0.32	1	72	6.3	80	70
W99-1-33.0	Till	33.0	12.7	<2	0.8	10	670	630	1.6	0.23	2.1	0.42	1	69	4.6	67	59
W99-1-39.5	Till	39.5	11.9	<2	0.8	11	660	610	1.8	0.27	1.6	0.4	1.01	77	6	67	71
W99-1-40.2	Till	40.2	11.9	<2	0.9	11	670	590	1.7	0.26	1.9	0.34	0.95	76	5.8	74	67
W99-1-41.4	Till	41.4	12.5	<2	0.8	10	600	580	1.7	0.25	1.9	0.34	1.1	72	5.6	81	65
W99-1-42.3	Till	42.3	10.8	<2	0.9	11	650	590	2.5	0.31	2.3	0.32	1	76	6.3	80	74
W99-1-43.3	Till	43.3	11.6	4	0.9	11	610	620	2	0.26	1.8	0.36	1.02	78	6.6	75	77
W99-1-44.7	Till	44.7	12.2	<2	0.9	11	560	580	1.5	0.27	1.8	0.52	0.8	76	5.9	60	68
W99-1-47.3	Till	47.3	11.4	<2	0.9	12	750	710	2.3	0.32	2.1	0.48	0.83	80	6.8	82	80
W99-1-48.3	Till	48.3	10.4	<2	0.8	10	620	550	2	0.28	2	0.48	0.77	80	6.9	82	76
W99-1-49.5	Till	49.5	12.2	<2	1	10	540	500	1.9	0.25	2.1	0.42	0.53	74	5	72	60
W99-1-50.4	Till	50.4	13.3	<2	1	10	620	550	1.6	0.27	2.1	0.44	0.67	79	5.1	80	60
W99-1-51.5	Till	51.5	13.0	<2	1	10	560	540	1.9	0.27	2	0.48	0.72	81	5.4	63	58
W99-1-52.5	Till	52.5	13.0	<2	1.1	11	690	660	1.6	0.25	2.8	0.48	0.74	78	4.6	62	60
W99-1-53.5	Till	53.5	12.3	<2	1	11	670	610	1.7	0.26	2.4	0.46	0.74	74	5	57	58
W99-1-54.4	Till	54.4	13.2	<2	1	11	590	550	1.8	0.27	2.3	0.48	0.75	75	4.9	65	59
* W99-1-54.4	Till	54.4	11.6	<2	1	11	610	550	1.8	0.24	2.4	0.44	0.76	74	4.7	62	60
W99-1-55.5	Till	55.5	11.8	<2	1	11	610	540	1.7	0.24	2.6	0.36	0.72	75	5.2	83	57
W99-1-56.4	Till	56.4	12.0	<2	1	12	620	560	1.6	0.26	2.7	0.46	0.76	75	5.1	78	58
W99-1-57.9	Till	57.9	11.8	5	1	11	610	550	1.8	0.27	2.3	1.18	0.75	82	4.3	75	59
W99-1-61.0	Till	61.0	11.8	<2	1.1	12	630	600	1.7	0.28	2.9	0.58	0.67	75	4.8	63	65
W99-1-61.7	Till	61.7	12.2	7	1.1	11	680	620	2	0.27	2.6	0.6	0.77	77	4.9	84	63
W99-1-62.1	Till	62.1	11.9	<2	0.7	16	820	780	1.8	0.26	0.8	0.1	0.62	94	4.4	70	61
W99-1-63.1	Till	63.1	11.4	<2	0.8	25	650	570	2.1	0.24	1.2	0.1	0.6	91	4.7	77	59
W99-1-63.9	Till	63.9	11.8	<2	0.8	10	570	500	1.8	0.24	0.9	0.66	0.61	88	4.7	68	59
W99-1-67.2	Till	67.2	12.7	<2	0.8	7.1	520	390	1.6	0.24	1.8	0.48	0.93	89	4.8	73	49
W99-1-68.2	Till	68.2	11.1	<2	0.8	7.9	540	470	1.6	0.24	2.1	0.32	1.31	83	4.7	61	57
W99-1-69.2	Till	69.2	11.5	<2	0.8	8.2	570	480	1.9	0.24	2.1	0.38	1.34	80	4.8	61	57
W99-1-70.0	Till	70.0	13.3	<2	0.9	8.4	590	500	1.7	0.23	2.2	0.34	1.42	80	4.8	81	57
W99-1-71.0	Till	71.0	12.7	<2	0.8	8.1	590	520	1.8	0.22	1.7	0.48	1.53	83	4.5	68	57

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

Sample #	Material	Depth	IMS Co ppm	IMS Cu ppm	NAA Eu ppm	IMS Ga ppm	IMS Ge ppm	NAA Hf ppm	NAA Ir ppb	NAA Fe %	NAA La ppm	IMS Pb ppm	IMS Li ppm	NAA Lu ppm	IMS Mg %	IMS Mn ppm	CVAA Hg ppb
W99-1-22.4	Till	22.4	14	23	<1	19.3	1.9	10	<50	3.3	39	24	58	0.3	0.89	450	40
W99-1-25.1	Till	25.1	9	14	1	11.9	1.4	17	<50	2.5	39	16	28	0.4	0.97	445	20
W99-1-32.6	Till	32.6	12	21	1	18	1.7	8	<50	3.5	40	18	55	0.3	0.91	370	30
W99-1-33.0	Till	33.0	12	16	2	16.2	1.6	10	<50	3.1	38	17	44	0.4	0.83	375	40
W99-1-39.5	Till	39.5	13	21	1	18.8	1.7	8	<50	3.4	40	20	55	0.3	0.94	370	40
W99-1-40.2	Till	40.2	13	19	<1	18.1	1.7	9	<50	3.3	40	19	51	0.4	0.87	355	60
W99-1-41.4	Till	41.4	12	18	1	16.7	1.6	9	<50	3.2	40	21	49	0.4	0.89	365	50
W99-1-42.3	Till	42.3	15	21	2	20.5	1.9	7	<50	3.5	39	21	61	0.4	0.95	380	40
W99-1-43.3	Till	43.3	14	22	<1	18.8	1.7	8	<50	3.5	40	19	55	0.4	0.99	395	30
W99-1-44.7	Till	44.7	13	22	2	18.3	1.7	8	<50	3.3	40	19	53	0.4	0.83	370	40
W99-1-47.3	Till	47.3	14	25	2	21.9	1.9	5	<50	3.9	44	20	62	0.4	0.97	420	40
W99-1-48.3	Till	48.3	15	20	3	19.6	1.7	6	<50	4.7	42	17	55	0.4	0.91	1035	30
W99-1-49.5	Till	49.5	14	19	2	16.1	1.7	11	<50	3	41	18	46	0.4	0.62	345	60
W99-1-50.4	Till	50.4	14	20	2	16.7	1.7	10	<50	3.1	42	18	46	0.5	0.71	390	40
W99-1-51.5	Till	51.5	13	19	<1	17.2	1.8	11	<50	3.2	40	18	51	0.5	0.74	385	50
W99-1-52.5	Till	52.5	13	19	1	16.4	1.8	10	<50	3.4	39	19	48	0.4	0.76	410	30
W99-1-53.5	Till	53.5	13	19	1	16.9	1.8	12	<50	3.1	40	19	50	0.4	0.74	375	40
W99-1-54.4	Till	54.4	13	19	1	16.4	1.7	10	<50	3.3	39	19	49	0.4	0.77	380	40
* W99-1-54.4	Till	54.4	11	19	<1	15.3	1.7	10	<50	3.2	39	17	44	0.4	0.78	390	40
W99-1-55.5	Till	55.5	12	18	1	15.9	1.6	11	<50	3.4	38	17	48	0.4	0.74	400	30
W99-1-56.4	Till	56.4	13	18	2	15.9	1.7	12	<50	3.5	41	18	50	0.4	0.76	385	40
W99-1-57.9	Till	57.9	12	22	<1	16	1.7	11	<50	3.3	41	20	48	0.4	0.73	360	60
W99-1-61.0	Till	61.0	13	22	2	17.6	1.9	10	<50	3.2	38	22	53	0.4	0.72	335	40
W99-1-61.7	Till	61.7	13	21	2	16.3	1.6	10	<50	3.2	38	18	42	0.4	0.74	380	40
W99-1-62.1	Till	62.1	12	17	2	17.2	1.7	12	<50	4	48	18	38	0.5	0.61	250	10
W99-1-63.1	Till	63.1	12	17	2	16.7	1.6	12	<50	3.7	48	18	37	0.5	0.61	260	10
W99-1-63.9	Till	63.9	13	19	1	17.1	1.7	13	<50	3.4	49	18	37	0.5	0.63	345	30
W99-1-67.2	Till	67.2	12	14	2	16	1.5	12	<50	3.2	46	16	36	0.5	0.77	1020	30
W99-1-68.2	Till	68.2	11	17	2	15.8	1.6	11	<50	3.1	45	16	37	0.4	0.9	610	30
W99-1-69.2	Till	69.2	12	17	2	16.3	1.6	11	<50	2.9	44	17	39	0.5	0.92	610	30
W99-1-70.0	Till	70.0	12	18	2	15.7	1.5	10	<50	3.1	42	17	38	0.4	0.92	550	30
W99-1-71.0	Till	71.0	12	17	<1	16.2	1.5	11	<50	3.1	42	17	38	0.4	0.95	545	40

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS	NAA
Sample #	**Material**	**Depth**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**	**Tb**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-22.4	Till	22.4	3.4	37	14	790	1.64	98	6.4	12	<5	0.8	0.43	141	1	0.05	1
W99-1-25.1	Till	25.1	1.6	21	10	700	1.38	62	6.5	9.4	<5	0.4	0.71	129	1.2	0.05	0.9
W99-1-32.6	Till	32.6	1.8	31	14	710	1.73	97	6.4	13	<5	0.45	0.51	133	1.3	0.05	1
W99-1-33.0	Till	33.0	2	28	14	720	1.6	88	6	11	<5	0.45	0.6	137	1.1	0.05	0.8
W99-1-39.5	Till	39.5	2	32	15	730	1.73	101	6.2	12	<5	0.45	0.53	140	1.4	0.05	0.8
W99-1-40.2	Till	40.2	1.6	31	14	690	1.65	97	6.2	13	<5	0.45	0.53	135	1.2	0.05	0.7
W99-1-41.4	Till	41.4	1.6	29	13	700	1.62	91	6.1	12	<5	0.4	0.56	134	1	0.05	0.9
W99-1-42.3	Till	42.3	2	36	15	730	1.78	111	6.1	13	<5	0.5	0.49	139	1.2	0.05	0.8
W99-1-43.3	Till	43.3	1.8	34	14	740	1.8	102	6.3	13	<5	0.45	0.5	138	1.1	0.05	0.6
W99-1-44.7	Till	44.7	2.4	32	15	700	1.7	100	6.3	13	<5	0.45	0.53	132	1	0.05	0.8
W99-1-47.3	Till	47.3	2.4	35	17	760	1.85	115	6.7	15	<5	0.45	0.45	139	1.1	0.05	0.6
W99-1-48.3	Till	48.3	1.8	32	14	720	1.73	100	6.4	14	<5	0.4	0.46	125	1.1	0.05	1.3
W99-1-49.5	Till	49.5	2.6	30	14	640	1.58	86	6.5	12	<5	0.45	0.52	124	1.4	0.05	0.9
W99-1-50.4	Till	50.4	3	30	14	650	1.52	88	6.4	12	<5	0.4	0.52	126	1.4	0.05	0.9
W99-1-51.5	Till	51.5	2.6	30	15	630	1.55	92	6.5	12	<5	0.45	0.52	129	1.2	0.05	1
W99-1-52.5	Till	52.5	2.8	29	14	680	1.56	88	6.5	12	<5	0.45	0.53	130	1	0.05	0.6
W99-1-53.5	Till	53.5	3	29	14	670	1.53	88	6.6	12	<5	0.4	0.53	130	1.2	0.05	0.9
W99-1-54.4	Till	54.4	3	29	14	660	1.54	88	6.6	12	<5	0.45	0.51	125	1.2	0.05	1
* W99-1-54.4	Till	54.4	2.8	26	12	690	1.57	83	6.4	12	<5	0.4	0.5	125	1.6	0.05	0.8
W99-1-55.5	Till	55.5	2.4	27	14	680	1.53	84	6.6	12	<5	0.4	0.5	123	1.4	0.05	0.8
W99-1-56.4	Till	56.4	2.6	28	14	680	1.53	84	6.4	12	<5	0.4	0.5	126	1.3	0.05	1.1
W99-1-57.9	Till	57.9	3.2	31	14	690	1.51	85	6.2	11	<5	1.85	0.55	127	1.2	10.05	<0.5
W99-1-61.0	Till	61.0	4.4	33	15	760	1.56	93	5.9	11	<5	0.5	0.44	130	1	0.05	0.9
W99-1-61.7	Till	61.7	3.4	30	12	680	1.54	86	6.1	11	<5	0.45	0.47	136	1.2	<0.05	0.9
W99-1-62.1	Till	62.1	2.6	29	14	1070	1.65	89	7.3	12	<5	0.45	0.59	147	1.6	<0.05	1
W99-1-63.1	Till	63.1	1.8	26	13	940	1.62	86	7.6	12	<5	0.4	0.61	139	1.5	0.05	0.9
W99-1-63.9	Till	63.9	2.4	28	13	960	1.64	89	7.7	12	<5	0.4	0.62	141	1	0.05	1.5
W99-1-67.2	Till	67.2	1.6	27	13	580	1.37	83	7.3	12	<5	0.35	0.61	121	1.3	<0.05	1.1
W99-1-68.2	Till	68.2	1.6	26	12	660	1.57	83	7	12	<5	0.35	0.57	135	1.7	0.05	0.8
W99-1-69.2	Till	69.2	1.6	26	13	650	1.58	83	7	11	<5	0.35	0.58	134	1.4	<0.05	1.1
W99-1-70.0	Till	70.0	1.8	26	12	660	1.55	81	6.6	11	<5	0.35	0.61	136	1.4	<0.05	0.9
W99-1-71.0	Till	71.0	1.8	26	12	670	1.6	84	6.6	11	<5	0.35	0.63	140	1.4	<0.05	0.8

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-22.4	Till	22.4	0.86	12	<100	0.33	2.9	4.2	143	3	23.5	88	360
W99-1-25.1	Till	25.1	0.56	11	<100	0.28	1.0	3.5	83	3	20.9	56	720
W99-1-32.6	Till	32.6	0.70	11	<100	0.33	1.3	3.7	132	2	21.2	76	<200
W99-1-33.0	Till	33.0	0.68	11	<100	0.32	1.3	3.6	108	3	22.4	70	400
W99-1-39.5	Till	39.5	0.72	11	<100	0.34	4.3	4.8	132	2	22.7	92	390
W99-1-40.2	Till	40.2	0.72	11	<100	0.32	1.8	3.9	123	2	22.4	78	380
W99-1-41.4	Till	41.4	0.66	11	<100	0.32	1.2	3.9	120	3	21.9	84	<200
W99-1-42.3	Till	42.3	0.78	11	<100	0.34	2.7	3.3	136	2	24.4	86	<200
W99-1-43.3	Till	43.3	0.76	12	<100	0.34	1.4	3.7	140	3	21.8	92	<200
W99-1-44.7	Till	44.7	0.76	11	<100	0.35	1.4	3.8	126	3	23.1	84	<200
W99-1-47.3	Till	47.3	0.80	12	<100	0.39	1.5	3.3	151	2	24.4	92	<200
W99-1-48.3	Till	48.3	0.70	11	<100	0.34	1.3	3.5	137	3	22.8	92	<200
W99-1-49.5	Till	49.5	0.74	10	<100	0.35	1.2	3.9	110	3	23.2	72	310
W99-1-50.4	Till	50.4	0.78	11	<100	0.33	1.4	4.1	115	3	22.7	72	370
W99-1-51.5	Till	51.5	0.78	10	<100	0.35	1.3	3.9	108	3	24.7	72	<200
W99-1-52.5	Till	52.5	0.78	11	<100	0.33	1.2	4.2	114	3	23.1	72	540
W99-1-53.5	Till	53.5	0.78	11	<100	0.32	1.3	3.8	112	3	23.4	70	<200
W99-1-54.4	Till	54.4	0.78	11	<100	0.33	1.4	3.8	111	3	23.2	68	420
* W99-1-54.4	Till	54.4	0.72	11	<100	0.33	1.3	3.8	115	3	21.8	70	510
W99-1-55.5	Till	55.5	0.70	11	<100	0.34	1.2	3.5	105	3	22.2	64	<200
W99-1-56.4	Till	56.4	0.74	10	<100	0.34	1.2	4.0	105	3	22.6	78	600
W99-1-57.9	Till	57.9	0.76	11	<100	0.33	7.4	3.9	108	2	22.5	72	<200
W99-1-61.0	Till	61.0	0.90	11	<100	0.34	1.7	3.7	141	2	23.8	76	<200
W99-1-61.7	Till	61.7	0.80	11	<100	0.32	1.3	3.9	127	2	22.2	76	<200
W99-1-62.1	Till	62.1	0.66	13	<100	0.36	1.5	3.2	101	3	25.1	76	600
W99-1-63.1	Till	63.1	0.64	13	<100	0.32	1.3	3.2	102	3	23.8	72	420
W99-1-63.9	Till	63.9	0.64	14	<100	0.32	1.5	3.3	104	3	24.0	76	740
W99-1-67.2	Till	67.2	0.64	13	<100	0.28	0.9	4.0	85	3	22.6	60	400
W99-1-68.2	Till	68.2	0.64	12	<100	0.32	1.4	4.3	100	3	22.3	68	310
W99-1-69.2	Till	69.2	0.60	12	<100	0.34	1.1	5.0	98	3	22.8	72	450
W99-1-70.0	Till	70.0	0.64	12	<100	0.31	1.0	5.1	102	3	21.9	76	<200
W99-1-71.0	Till	71.0	0.64	12	<100	0.32	1.3	5.7	100	3	22.2	76	440

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			NAA	NAA	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	IMS
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**	**Cr***
			grams	**ppb**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-72.0	Till	72.0	11.8	4	0.8	7.8	600	540	1.7	0.24	2	0.38	1.57	84	4.3	68	57
W99-1-73.3	Till	73.3	12.0	<2	0.6	5.7	530	470	1.9	0.21	2	0.24	2.02	89	3.9	75	56
W99-1-74.3	Till	74.3	11.4	<2	0.7	8.1	390	370	1.7	0.24	1.4	0.26	0.57	79	4.4	62	51
W99-1-75.3	Till	75.3	13.6	<2	0.7	6.4	550	500	1.7	0.2	2.4	0.34	2.61	83	4.1	68	57
W99-1-76.3	Till	76.3	13.0	<2	0.7	5.3	560	510	1.8	0.2	2.2	0.38	2.52	88	4.2	67	56
* W99-1-76.3	Till	76.3	11.3	<2	0.6	4.5	550	510	2	0.2	2.1	0.38	2.56	99	3.9	80	56
W99-1-77.3	Till	77.3	13.2	<2	0.6	5.2	590	480	1.7	0.21	1.6	0.34	2.05	84	4.4	67	57
W99-1-78.3	Till	78.3	12.1	<2	0.6	5.6	580	480	1.8	0.2	2	0.34	2.01	94	4	64	54
W99-1-79.3	Till	79.3	13.3	<2	0.7	5.3	600	510	1.7	0.2	1.7	0.4	2.69	81	4.1	53	58
W99-1-80.3	Till	80.3	13.5	<2	0.6	4.5	520	490	1.6	0.22	1.6	0.4	1.84	81	4.4	59	57
W99-1-80.7	Till	80.7	12.2	<2	0.7	6.7	610	500	1.7	0.21	2.1	0.38	2.22	88	4.4	78	60
W99-1-81.1	Till	81.1	11.3	<2	0.6	6.1	540	510	1.9	0.22	2	0.28	2.16	94	3.7	76	60
W99-1-87.1	Till	87.1	11.0	<2	0.8	10	1300	1190	1.8	0.28	2.4	0.46	1.16	83	4.4	73	60
W99-1-88.0	Till	88.0	9.5	<2	0.8	11	660	610	1.9	0.27	2.3	0.44	1.18	90	5.3	77	61
W99-1-89.7	Till	89.7	10.8	<2	0.8	10	560	490	1.8	0.24	2.2	0.4	1.07	76	4.8	68	55
W99-1-91.4	Till	91.4	12.0	<2	1	13	630	540	1.6	0.27	3	0.46	1.05	82	5.4	72	59
W99-1-92.4	Till	92.4	10.9	<2	0.9	13	630	570	2.2	0.29	3	0.56	1.03	86	5.2	79	59
W99-1-93.3	Till	93.3	12.3	<2	0.9	14	650	560	1.8	0.28	3.1	0.52	1.02	87	5.6	72	58
W99-1-95.1	Till	95.1	11.2	<2	0.9	11	620	550	2	0.28	2.6	0.46	1.2	84	5.2	76	61
W99-1-95.5	Till	95.5	11.3	7	1	11	700	590	1.7	0.24	2.6	0.62	1.14	85	5.4	76	62
W99-1-96.5	Till	96.5	10.7	5	1	8.3	640	570	2.1	0.3	2.5	0.54	1.79	83	5.7	77	77
W99-1-97.5	Till	97.5	9.6	<2	1	9	600	540	2	0.29	2.3	0.48	1.73	90	6.1	93	77
W99-1-98.1	Till	98.1	10.6	<2	1	9.1	720	650	2.4	0.3	2.9	1	1.74	89	5.3	83	76
W99-1-99.2	Till	99.2	11.1	<2	1	10	630	640	2.2	0.31	2.5	0.54	1.89	94	5.4	87	75
* W99-1-99.2	Till	99.2	11.5	5	1	9.2	650	630	2.6	0.29	2.4	0.5	1.87	89	5.6	94	75
W99-1-100.2	Till	100.2	10.6	<2	1	9.2	600	600	2.2	0.29	3.1	0.56	2.02	95	5.7	80	75
W99-1-101.3	Till	101.3	10.6	<2	1.1	72.5	750	710	2.7	0.35	3.6	0.44	1.47	88	7.5	110	91
W99-1-102.2	Till	102.2	11.5	<2	0.9	2.4	810	840	1.9	0.37	2.9	0.08	0.48	85	5	69	58
W99-1-103.4	Till	103.4	9.8	<2	1	14	620	590	1.9	0.32	2.9	0.64	0.68	74	4.5	57	53
W99-1-104.4	Till	104.4	9.9	<2	1	8.4	530	520	2	0.3	2.5	0.52	2.09	93	5.8	77	74
W99-1-105.4	Till	105.4	13.3	<2	1.1	9.4	630	570	1.7	0.25	1.6	0.48	1.47	86	5.1	82	65
W99-1-106.3	Till	106.3	12.4	<2	0.9	7	540	560	2.1	0.27	2.9	0.58	2.08	89	5.3	91	71

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS	CVAA
Sample #	**Material**	**Depth**	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**	**Hg**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppb**
W99-1-72.0	Till	72.0	12	17	1	16	1.6	11	<50	3.1	44	18	40	0.4	0.97	525	30
W99-1-73.3	Till	73.3	11	16	2	15.6	1.4	12	<50	3	45	16	38	0.4	1.11	635	30
W99-1-74.3	Till	74.3	19	16	2	15.1	1.8	13	<50	3.1	42	18	49	0.4	0.61	1000	40
W99-1-75.3	Till	75.3	11	16	2	15.7	1.4	11	<50	3	45	16	35	0.4	1.27	630	10
W99-1-76.3	Till	76.3	10	16	2	16	1.4	11	<50	3	47	16	37	0.5	1.24	595	20
* W99-1-76.3	Till	76.3	11	15	2	16.2	1.3	13	<50	2.9	45	16	36	0.3	1.25	615	20
W99-1-77.3	Till	77.3	12	14	2	16.7	1.4	11	<50	2.9	45	18	37	0.4	1.13	590	10
W99-1-78.3	Till	78.3	11	14	2	15.8	1.3	12	<50	3	47	16	35	0.4	1.07	585	10
W99-1-79.3	Till	79.3	11	16	1	15.8	1.3	11	<50	3.1	45	17	35	0.4	1.27	630	30
W99-1-80.3	Till	80.3	12	14	<1	16.9	1.4	10	<50	2.7	46	17	40	0.4	1.06	615	20
W99-1-80.7	Till	80.7	12	18	1	16.7	1.3	11	<50	3.2	48	16	39	0.4	1.21	650	20
W99-1-81.1	Till	81.1	12	16	2	17.9	1.5	11	<50	3.2	45	17	41	0.4	1.21	630	20
W99-1-87.1	Till	87.1	13	19	1	16.7	1.6	12	<50	2.9	40	18	41	0.4	0.83	460	30
W99-1-88.0	Till	88.0	13	19	2	17.2	1.6	11	<50	3.2	44	19	42	0.4	0.85	445	20
W99-1-89.7	Till	89.7	11	17	2	15.5	1.4	10	<50	3.2	42	16	38	0.4	0.76	405	20
W99-1-91.4	Till	91.4	12	20	2	15.8	1.5	11	<50	3.1	44	17	39	0.4	0.81	425	30
W99-1-92.4	Till	92.4	13	20	2	16.6	1.7	11	<50	3.2	45	21	42	0.4	0.77	415	30
W99-1-93.3	Till	93.3	13	21	2	16.6	1.6	11	<50	3.3	46	22	42	0.5	0.77	420	30
W99-1-95.1	Till	95.1	13	20	3	17.5	1.7	12	<50	3.2	46	20	43	0.5	0.86	450	20
W99-1-95.5	Till	95.5	12	19	2	15.9	1.5	11	<50	3.2	46	17	40	0.5	0.83	395	30
W99-1-96.5	Till	96.5	14	22	2	20.4	1.7	9	<50	3.4	47	20	52	0.3	1.07	630	60
W99-1-97.5	Till	97.5	14	23	1	21.1	1.7	10	<50	3.5	49	18	54	0.3	1.07	620	40
W99-1-98.1	Till	98.1	15	23	2	21.7	1.6	9	<50	3.6	49	19	57	0.4	1.05	620	40
W99-1-99.2	Till	99.2	15	25	2	22.3	1.8	10	<50	3.9	51	21	59	0.4	1.06	655	50
* W99-1-99.2	Till	99.2	14	24	2	21.4	1.8	9	<50	3.5	44	20	59	0.3	1.05	655	50
W99-1-100.2	Till	100.2	13	24	2	19.9	1.6	10	<50	3.7	49	17	53	0.4	1.11	620	40
W99-1-101.3	Till	101.3	17	28	2	24.2	1.8	7	<50	4.7	49	20	68	0.4	1.12	750	40
W99-1-102.2	Till	102.2	5	26	2	18.1	1.8	9	<50	2.5	48	20	46	0.4	0.56	105	50
W99-1-103.4	Till	103.4	14	24	1	17.3	1.9	9	<50	3.2	43	22	44	0.4	0.62	410	40
W99-1-104.4	Till	104.4	13	23	2	20.5	1.6	10	<50	3.4	50	19	56	0.4	1.09	595	30
W99-1-105.4	Till	105.4	11	20	1	16.4	1.7	12	<50	3	48	18	42	0.4	0.91	520	30
W99-1-106.3	Till	106.3	12	23	2	19	1.6	10	<50	3.3	50	20	53	0.4	1.09	635	40

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS	NAA
Sample #	**Material**	**Depth**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**	**Tb**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-72.0	Till	72.0	1.8	28	13	680	1.6	85	6.7	11	<5	0.45	0.62	141	1.6	0.05	0.7
W99-1-73.3	Till	73.3	1.2	26	12	670	1.71	84	6.9	12	<5	0.35	0.7	141	1.5	0.05	1
W99-1-74.3	Till	74.3	1.2	31	14	520	1.43	78	6.9	11	<5	0.35	0.41	90	1.7	<0.05	0.7
W99-1-75.3	Till	75.3	1.2	26	12	730	1.74	85	6.9	11	<5	0.3	0.74	153	1.3	<0.05	0.8
W99-1-76.3	Till	76.3	1.2	24	12	710	1.75	86	7	11	<5	0.35	0.7	151	1.3	0.05	0.6
* W99-1-76.3	Till	76.3	1.2	25	12	720	1.77	86	6.5	11	<5	0.4	0.66	153	1.1	<0.05	0.9
W99-1-77.3	Till	77.3	1.2	27	13	680	1.74	89	7.1	11	<5	0.35	0.7	144	1.5	<0.05	1.1
W99-1-78.3	Till	78.3	1	24	12	660	1.73	86	7.1	11	<5	0.3	0.71	145	1.1	<0.05	1.3
W99-1-79.3	Till	79.3	1.4	26	11	730	1.77	85	6.8	10	<5	0.35	0.72	156	1.2	<0.05	0.6
W99-1-80.3	Till	80.3	1.2	25	12	650	1.78	93	6.9	10	<5	0.4	0.68	146	1.2	<0.05	1.1
W99-1-80.7	Till	80.7	1.2	27	12	700	1.82	90	7.2	12	<5	0.35	0.74	153	1.1	0.05	0.7
W99-1-81.1	Till	81.1	1.2	26	14	710	1.88	99	7	11	<5	0.4	0.73	155	1	<0.05	0.9
W99-1-87.1	Till	87.1	2.2	28	13	730	1.55	86	6.2	11	<5	0.65	0.47	160	1.3	<0.05	0.9
W99-1-88.0	Till	88.0	2.4	29	14	730	1.57	88	6.7	12	<5	0.55	0.53	146	1.5	<0.05	1
W99-1-89.7	Till	89.7	2.4	26	12	680	1.43	78	6.5	12	<5	0.4	0.51	135	1.3	0.05	1
W99-1-91.4	Till	91.4	2.8	28	12	760	1.5	80	7.2	12	<5	0.4	0.51	141	1.4	0.05	1
W99-1-92.4	Till	92.4	3.2	30	13	780	1.52	86	7.1	12	<5	0.5	0.51	148	1.5	0.05	1.1
W99-1-93.3	Till	93.3	3.2	29	13	810	1.51	84	7.2	12	<5	0.4	0.53	145	1.2	0.05	0.9
W99-1-95.1	Till	95.1	2.6	30	13	730	1.59	89	6.9	12	<5	0.45	0.58	148	1.4	0.05	0.8
W99-1-95.5	Till	95.5	3	27	12	690	1.56	83	7	13	<5	0.45	0.56	148	1.3	0.05	1
W99-1-96.5	Till	96.5	2.6	34	13	690	1.72	99	6.8	14	<5	0.45	0.53	158	1.2	0.05	1.2
W99-1-97.5	Till	97.5	2.6	34	14	730	1.75	101	7.2	15	<5	0.45	0.5	153	1.2	<0.05	0.8
W99-1-98.1	Till	98.1	2.8	35	14	740	1.74	103	7.2	15	<5	0.4	0.52	155	1.2	<0.05	1
W99-1-99.2	Till	99.2	2.8	34	15	710	1.8	107	7.3	15	<5	0.45	0.5	164	1.2	0.05	0.7
* W99-1-99.2	Till	99.2	2.8	33	14	700	1.8	100	6.8	13	<5	0.4	0.47	157	1.3	0.05	1
W99-1-100.2	Till	100.2	2.4	31	13	680	1.79	97	7.1	15	<5	0.4	0.53	157	1.3	0.05	0.9
W99-1-101.3	Till	101.3	5.8	39	14	690	1.85	115	6.9	18	<5	0.4	0.46	161	1	0.05	1
W99-1-102.2	Till	102.2	1.8	14	15	500	1.55	88	6.5	12	<5	0.45	0.42	276	1.6	<0.05	0.7
W99-1-103.4	Till	103.4	4	31	14	680	1.53	88	6.5	11	<5	0.5	0.42	168	1.5	0.05	1.1
W99-1-104.4	Till	104.4	2.6	32	14	650	1.75	99	7.1	14	<5	0.35	0.54	165	1.1	0.1	0.9
W99-1-105.4	Till	105.4	2.6	27	11	600	1.63	83	6.9	13	<5	0.4	0.74	167	1.1	0.05	1
W99-1-106.3	Till	106.3	2.6	30	13	680	1.73	94	7.1	14	<5	0.4	0.61	166	1.6	<0.05	1.1

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-72.0	Till	72.0	0.68	12	<100	0.33	1.3	4.5	100	3	23.2	74	<200
W99-1-73.3	Till	73.3	0.56	13	<100	0.32	1.0	5.3	92	3	21.5	58	580
W99-1-74.3	Till	74.3	0.50	11	<100	0.38	1.3	7.7	79	3	21.9	96	690
W99-1-75.3	Till	75.3	0.58	13	<100	0.30	1.0	4.0	93	3	22.0	66	510
W99-1-76.3	Till	76.3	0.60	13	<100	0.31	0.9	3.9	93	3	22.4	66	<200
* W99-1-76.3	Till	76.3	0.60	13	<100	0.31	1.1	3.7	89	3	22.3	66	<200
W99-1-77.3	Till	77.3	0.58	13	<100	0.30	1.0	3.7	86	3	22.0	62	600
W99-1-78.3	Till	78.3	0.58	14	<100	0.30	1.0	4.0	97	3	22.0	68	440
W99-1-79.3	Till	79.3	0.60	13	<100	0.30	1.3	3.8	89	3	22.3	70	430
W99-1-80.3	Till	80.3	0.62	14	<100	0.31	1.3	3.7	98	2	21.9	68	<200
W99-1-80.7	Till	80.7	0.62	14	<100	0.32	1.2	3.7	98	3	24.1	68	630
W99-1-81.1	Till	81.1	0.66	14	<100	0.31	1.0	3.7	95	3	22.0	66	720
W99-1-87.1	Till	87.1	0.70	11	<100	0.33	1.3	3.8	108	2	23.6	72	520
W99-1-88.0	Till	88.0	0.70	12	<100	0.34	1.5	4.2	107	3	24.0	76	400
W99-1-89.7	Till	89.7	0.66	11	<100	0.31	1.2	3.8	97	3	21.6	68	440
W99-1-91.4	Till	91.4	0.74	12	<100	0.32	1.3	4.6	108	3	22.8	80	460
W99-1-92.4	Till	92.4	0.76	12	<100	0.32	1.8	4.5	107	3	24.6	78	320
W99-1-93.3	Till	93.3	0.80	12	<100	0.32	1.3	4.6	105	3	24.8	80	430
W99-1-95.1	Till	95.1	0.76	12	<100	0.33	1.4	4.4	110	3	23.5	98	<200
W99-1-95.5	Till	95.5	0.76	12	<100	0.31	1.3	4.5	122	3	21.3	78	440
W99-1-96.5	Till	96.5	0.76	12	<100	0.35	1.6	5.5	147	3	22.9	90	<200
W99-1-97.5	Till	97.5	0.74	13	<100	0.36	1.7	5.1	146	3	23.4	88	<200
W99-1-98.1	Till	98.1	0.76	13	<100	0.35	1.5	5.3	144	3	23.9	102	480
W99-1-99.2	Till	99.2	0.80	13	<100	0.36	2.0	4.7	156	3	24.5	94	<200
* W99-1-99.2	Till	99.2	0.80	13	<100	0.36	1.7	4.6	151	3	23.3	90	430
W99-1-100.2	Till	100.2	0.70	13	<100	0.36	1.4	4.4	157	3	22.3	98	610
W99-1-101.3	Till	101.3	0.84	13	<100	0.36	1.5	4.0	204	3	23.5	92	<200
W99-1-102.2	Till	102.2	0.70	12	<100	0.36	1.4	3.0	113	3	21.8	40	<200
W99-1-103.4	Till	103.4	0.96	11	<100	0.32	1.4	4.4	106	3	24.5	90	730
W99-1-104.4	Till	104.4	0.72	13	<100	0.35	1.4	4.1	146	3	23.5	86	500
W99-1-105.4	Till	105.4	0.68	13	<100	0.34	1.2	4.6	131	3	20.8	84	650
W99-1-106.3	Till	106.3	0.70	13	<100	0.35	1.8	4.7	145	3	23.5	88	<200

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			NAA	NAA	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	IMS
Sample #	Material	Depth	Wt	Au	Sb	As	Ba	Ba*	Be	Bi	Br	Cd	Ca	Ce	Cs	Cr	Cr*
			grams	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm
W99-1-109.0	Till	109.0	11.9	<2	1	12	720	690	1.8	0.3	2.8	0.46	0.87	88	5.5	72	56
W99-1-110.0	Till	110.0	12.0	<2	0.9	11	540	530	2.2	0.31	3.1	0.5	0.72	84	5.2	78	60
W99-1-111.0	Till	111.0	11.8	<2	0.8	11	560	530	1.8	0.29	3.4	0.48	0.66	96	5.7	78	61
W99-1-112.0	Till	112.0	11.9	<2	0.9	11	520	530	2.2	0.3	2.8	0.6	0.69	90	5.2	75	60
W99-1-113.0	Till	113.0	13.0	<2	0.9	11	480	490	1.9	0.31	3.2	0.52	0.7	96	5.6	90	59
W99-1-114.0	Till	114.0	11.3	10	0.9	11	860	810	1.8	0.29	2.6	0.58	0.71	88	5.1	68	57
W99-1-115.0	Till	115.0	12.0	3	1	11	590	550	1.7	0.3	2.6	0.52	0.71	86	4.8	73	57
W99-1-116.0	Till	116.0	11.7	3	0.9	11	610	560	2.1	0.33	2.5	0.54	0.66	82	4.9	60	54
W99-1-117.0	Till	117.0	11.0	<2	0.9	10	490	480	2.6	0.31	2.5	0.46	0.63	83	5.3	67	61
W99-1-118.0	Till	118.0	12.8	<2	0.9	11	570	640	1.7	0.27	2.6	0.34	0.84	85	5.6	61	72
W99-1-119.0	Till	119.0	11.3	3	0.9	11	590	540	1.7	0.3	2.9	0.54	0.66	88	5.5	69	59
* W99-1-119.0	Till	119.0	11.4	3	0.9	11	590	540	2.2	0.31	2.7	0.58	0.66	88	5.3	67	59
W99-1-120.0	Till	120.0	11.2	3	0.9	11	510	460	2.5	0.32	2.6	0.46	0.64	81	5.1	66	60
W99-1-121.0	Till	121.0	10.5	<2	0.9	11	780	740	1.9	0.29	2.6	0.58	0.63	82	5	67	59
W99-1-121.9	Till	121.9	11.7	3	1	11	480	440	1.9	0.33	2.6	0.5	0.65	86	4.6	66	56
W99-1-122.4	Till	122.4	9.1	4	1	12	620	560	2.3	0.36	3	0.58	0.6	81	6.2	71	67
W99-1-123.1	Till	123.1	12.6	3	0.9	11	500	460	2	0.29	2.5	0.62	0.62	87	5.2	66	55
W99-1-124.1	Till	124.1	11.1	<2	0.9	11	530	480	2.1	0.28	2.7	0.64	0.63	86	5.1	70	58
W99-1-125.1	Till	125.1	11.1	<2	0.9	10	480	440	1.8	0.3	2.7	0.72	0.61	89	5.5	70	62
W99-1-126.1	Till	126.1	11.3	4	0.9	10	520	470	2.5	0.3	2.4	0.4	0.61	85	5.9	80	63
W99-1-127.1	Till	127.1	10.1	<2	0.9	10	510	440	2.1	0.32	2.2	0.48	0.61	92	5.7	70	65
W99-1-128.1	Till	128.1	10.7	<2	1	10	460	450	1.9	0.32	2.8	0.8	0.61	84	5.9	80	66
W99-1-129.1	Till	129.1	12.5	<2	0.9	10	440	430	2.1	0.3	2.6	0.68	0.59	83	5.8	70	63
W99-1-130.6	Till	130.6	9.6	<2	1	10	1500	1430	1.8	0.31	2.9	0.88	0.62	92	5.6	79	63
W99-1-131.6	Till	131.6	10.6	4	0.9	12	650	600	2	0.33	2.8	0.58	0.72	92	5.1	76	60
W99-1-132.5	Till	132.5	10.9	<2	0.9	11	500	460	1.8	0.31	2.2	0.62	0.69	86	5.2	72	59
W99-1-133.5	Till	133.5	13.2	3	0.8	10	640	590	2.1	0.3	2.4	0.58	0.64	87	4.6	63	58
W99-1-134.5	Till	134.5	11.5	3	0.9	11	560	520	1.8	0.29	2.5	0.54	0.65	97	4.9	85	59
W99-1-135.5	Till	135.5	13.1	<2	1	11	580	550	1.7	0.24	2	0.54	0.57	91	3.8	78	51
W99-1-137.0	Till	137.0	11.1	<2	1.3	14	660	550	2.1	0.3	2.8	0.72	0.69	83	5.4	81	64
* W99-1-137.0	Till	137.0	11.7	<2	1.3	14	640	540	2.2	0.33	3	0.88	0.68	89	5.4	65	66
W99-1-138.0	Till	138.0	11.5	3	1.4	13	620	550	1.6	0.28	3.1	0.82	0.8	85	5	76	64

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS	CVAA
Sample #	**Material**	**Depth**	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**	**Hg**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppb**
W99-1-109.0	Till	109.0	12	20	1	16.7	1.6	12	<50	3.2	48	19	41	0.5	0.62	440	40
W99-1-110.0	Till	110.0	13	21	2	17.4	1.6	11	<50	3.2	48	18	45	0.4	0.66	400	30
W99-1-111.0	Till	111.0	13	20	3	18.4	1.6	13	<50	3.6	55	19	48	0.4	0.66	410	50
W99-1-112.0	Till	112.0	13	20	1	17.4	1.8	13	<50	3.3	47	20	46	0.5	0.65	395	40
W99-1-113.0	Till	113.0	13	20	<1	17.7	1.6	14	<50	3.4	46	21	45	0.4	0.66	395	40
W99-1-114.0	Till	114.0	12	20	2	16.7	1.7	13	<50	2.8	40	18	43	0.3	0.63	380	40
W99-1-115.0	Till	115.0	13	20	2	16.7	1.8	13	<50	2.9	42	19	44	0.3	0.64	400	40
W99-1-116.0	Till	116.0	13	20	1	17.6	1.8	12	<50	2.8	41	20	46	0.3	0.6	385	30
W99-1-117.0	Till	117.0	13	19	2	19.4	1.8	11	<50	2.9	43	19	53	0.3	0.67	370	30
W99-1-118.0	Till	118.0	10	25	1	14	1.4	11	<50	3	42	15	38	0.3	0.79	480	30
W99-1-119.0	Till	119.0	15	19	2	18.6	1.8	12	<50	3	41	19	53	0.3	0.65	385	30
* W99-1-119.0	Till	119.0	14	20	2	18.7	1.8	12	<50	3	42	21	53	0.3	0.64	380	40
W99-1-120.0	Till	120.0	16	20	1	19.2	1.8	11	<50	3	43	20	55	0.3	0.65	380	40
W99-1-121.0	Till	121.0	14	21	2	17.3	1.8	11	<50	2.8	40	18	48	0.3	0.64	385	40
W99-1-121.9	Till	121.9	15	20	2	18.6	1.8	12	<50	3	42	21	52	0.3	0.61	380	40
W99-1-122.4	Till	122.4	16	25	2	20.9	2	7	<50	3.5	41	21	62	0.3	0.77	425	30
W99-1-123.1	Till	123.1	13	19	2	16.7	1.8	13	<50	2.8	43	22	48	0.3	0.61	435	50
W99-1-124.1	Till	124.1	14	20	2	17.3	1.7	12	<50	2.9	42	18	49	0.3	0.63	390	30
W99-1-125.1	Till	125.1	13	21	1	19.1	1.8	12	<50	3.2	43	19	53	0.4	0.68	390	40
W99-1-126.1	Till	126.1	15	20	2	19.6	1.8	12	<50	3	43	19	58	0.3	0.67	380	40
W99-1-127.1	Till	127.1	14	20	2	19.7	1.7	11	<50	3.2	44	18	58	0.3	0.7	365	40
W99-1-128.1	Till	128.1	15	20	3	20.3	1.8	12	<50	3.2	43	20	59	0.3	0.72	380	40
W99-1-129.1	Till	129.1	14	19	1	19.8	1.9	11	<50	3.1	42	20	58	0.3	0.68	360	30
W99-1-130.6	Till	130.6	13	19	1	18.9	1.8	11	<50	3.1	42	19	56	0.3	0.7	365	30
W99-1-131.6	Till	131.6	14	21	1	18.3	1.7	12	<50	3.4	44	21	53	0.3	0.67	435	40
W99-1-132.5	Till	132.5	14	21	2	17.9	1.8	12	<50	3.1	42	20	51	0.2	0.65	405	40
W99-1-133.5	Till	133.5	14	19	2	17.3	1.6	14	<50	3.1	41	18	52	<0.2	0.64	415	40
W99-1-134.5	Till	134.5	13	21	3	16.4	1.7	14	<50	3.3	42	17	49	0.2	0.63	395	50
W99-1-135.5	Till	135.5	13	20	1	14.7	1.7	15	<50	3	41	18	44	0.3	0.54	370	50
W99-1-137.0	Till	137.0	14	22	2	18	1.7	11	<50	3.3	45	19	55	0.3	0.69	390	50
* W99-1-137.0	Till	137.0	14	22	2	18.8	1.8	11	<50	3.3	46	20	58	0.3	0.71	395	40
W99-1-138.0	Till	138.0	12	21	2	15.9	1.5	13	<50	3.1	45	18	47	0.3	0.66	380	50

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS	NAA
Sample #	**Material**	**Depth**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**	**Tb**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-109.0	Till	109.0	3	27	13	650	1.46	82	7.2	12	<5	0.45	0.44	151	1.4	0.05	1
W99-1-110.0	Till	110.0	3.4	29	13	660	1.48	85	7.2	12	<5	0.45	0.42	148	1.6	0.05	1.1
W99-1-111.0	Till	111.0	3	31	13	600	1.55	92	7.5	13	<5	0.45	0.47	149	1.6	<0.05	0.9
W99-1-112.0	Till	112.0	3.2	30	14	640	1.52	88	6.9	13	<5	0.45	0.46	152	1.5	<0.05	0.8
W99-1-113.0	Till	113.0	3.2	29	13	650	1.5	88	6.7	12	<5	0.45	0.44	148	1.2	<0.05	1
W99-1-114.0	Till	114.0	3.2	28	12	670	1.48	83	6.4	10	<5	0.45	0.37	160	1.6	<0.05	0.9
W99-1-115.0	Till	115.0	3.4	29	13	660	1.46	85	6.6	11	<5	0.4	0.42	153	1.6	0.05	1.1
W99-1-116.0	Till	116.0	3.4	30	15	630	1.46	87	6.7	10	<5	0.5	0.41	155	1.4	0.05	0.8
W99-1-117.0	Till	117.0	3.2	29	14	580	1.52	95	6.5	11	<5	0.45	0.4	145	1.6	0.05	0.9
W99-1-118.0	Till	118.0	2.6	23	11	820	1.79	68	6.7	12	<5	0.35	0.4	147	1.5	0.05	0.9
W99-1-119.0	Till	119.0	3.2	31	13	620	1.49	91	6.6	11	<5	0.45	0.41	153	1.5	0.05	1.1
* W99-1-119.0	Till	119.0	3.2	29	14	630	1.49	88	6.6	11	<5	0.5	0.42	154	1.4	0.05	0.8
W99-1-120.0	Till	120.0	3.2	32	14	620	1.51	94	6.7	12	<5	0.5	0.41	150	1.5	0.05	1
W99-1-121.0	Till	121.0	2.8	29	12	620	1.46	83	6.4	11	<5	0.4	0.4	154	1.3	0.05	0.9
W99-1-121.9	Till	121.9	3.4	31	14	630	1.44	92	6.6	11	<5	0.5	0.41	151	1.6	0.05	1
W99-1-122.4	Till	122.4	3	31	14	570	1.64	101	6.3	13	<5	0.5	0.43	163	1.6	0.05	0.9
W99-1-123.1	Till	123.1	3	27	13	620	1.44	80	6.8	11	<5	0.45	0.44	148	1.3	0.05	1.1
W99-1-124.1	Till	124.1	3.2	28	13	640	1.5	81	6.7	11	<5	0.45	0.43	147	1.5	<0.05	0.9
W99-1-125.1	Till	125.1	3	28	14	610	1.53	88	6.8	12	<5	0.45	0.42	147	1.6	0.05	1
W99-1-126.1	Till	126.1	3.2	31	14	620	1.53	91	6.7	12	<5	0.45	0.41	147	1.3	0.05	1.1
W99-1-127.1	Till	127.1	3	30	14	600	1.55	90	6.8	13	<5	0.45	0.42	145	1.4	0.05	0.9
W99-1-128.1	Till	128.1	3	30	14	590	1.56	94	6.8	13	<5	0.45	0.41	146	1.6	0.05	1
W99-1-129.1	Till	129.1	3	28	14	580	1.55	94	6.6	12	<5	0.45	0.41	146	1.4	0.05	1.1
W99-1-130.6	Till	130.6	3	28	13	610	1.54	90	6.7	12	<5	0.45	0.42	171	1.6	0.05	0.8
W99-1-131.6	Till	131.6	3.4	29	14	800	1.47	84	6.9	12	<5	0.45	0.45	167	1.6	0.05	0.9
W99-1-132.5	Till	132.5	3.2	30	13	690	1.49	85	6.4	11	<5	0.45	0.46	159	1.5	0.05	1
W99-1-133.5	Till	133.5	2.8	29	13	630	1.5	80	6.2	11	<5	0.45	0.42	155	1.6	0.05	0.9
W99-1-134.5	Till	134.5	3.2	26	12	640	1.49	78	6.3	12	<5	0.4	0.48	152	1.5	0.05	1
W99-1-135.5	Till	135.5	3	27	12	560	1.4	69	6.4	11	<5	0.45	0.5	154	1.2	0.1	1.1
W99-1-137.0	Till	137.0	4.6	30	13	730	1.49	85	6.8	12	<5	0.45	0.46	155	1.3	0.05	0.9
* W99-1-137.0	Till	137.0	4.8	30	13	740	1.47	88	6.7	12	<5	0.45	0.47	158	1.4	0.05	0.9
W99-1-138.0	Till	138.0	5	28	12	820	1.46	75	6.8	12	<5	0.4	0.45	154	1.3	<0.05	1.1

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-109.0	Till	109.0	0.76	12	<100	0.33	1.4	4.3	114	4	23.5	70	590
W99-1-110.0	Till	110.0	0.80	13	<100	0.34	1.4	4.7	121	3	23.7	76	590
W99-1-111.0	Till	111.0	0.76	14	<100	0.33	1.3	4.4	114	4	23.6	76	450
W99-1-112.0	Till	112.0	0.82	13	<100	0.33	1.4	4.4	122	3	23.6	84	380
W99-1-113.0	Till	113.0	0.80	12	<100	0.32	1.5	4.1	123	3	23.6	78	390
W99-1-114.0	Till	114.0	0.80	12	<100	0.32	1.4	4.3	119	3	22.7	76	330
W99-1-115.0	Till	115.0	0.84	12	<100	0.33	1.4	4.5	119	3	23.2	82	380
W99-1-116.0	Till	116.0	0.82	12	<100	0.34	1.5	4.6	111	3	24.6	72	520
W99-1-117.0	Till	117.0	0.80	12	<100	0.34	1.5	4.1	126	3	23.8	72	380
W99-1-118.0	Till	118.0	0.64	12	<100	0.41	1.3	4.5	145	3	18.9	92	380
W99-1-119.0	Till	119.0	0.82	12	<100	0.33	1.6	4.4	122	3	23.8	84	460
* W99-1-119.0	Till	119.0	0.80	12	<100	0.35	1.7	4.4	119	4	23.9	80	230
W99-1-120.0	Till	120.0	0.88	12	<100	0.34	1.7	4.3	120	3	24.7	72	360
W99-1-121.0	Till	121.0	0.80	12	<100	0.33	1.5	4.3	120	3	22.8	80	370
W99-1-121.9	Till	121.9	0.88	12	<100	0.34	1.6	4.2	113	3	25.4	70	460
W99-1-122.4	Till	122.4	0.86	12	<100	0.36	1.6	3.9	137	3	21.1	82	<200
W99-1-123.1	Till	123.1	0.76	12	<100	0.33	1.4	4.7	112	4	22.7	84	400
W99-1-124.1	Till	124.1	0.78	12	<100	0.34	1.5	4.4	116	4	22.5	86	360
W99-1-125.1	Till	125.1	0.76	12	<100	0.35	1.4	4.1	126	3	22.7	72	530
W99-1-126.1	Till	126.1	0.82	13	<100	0.35	1.5	4.3	126	3	23.6	68	580
W99-1-127.1	Till	127.1	0.80	13	<100	0.36	1.5	4.3	135	3	22.9	72	400
W99-1-128.1	Till	128.1	0.84	13	<100	0.36	1.6	4.3	139	3	23.4	84	630
W99-1-129.1	Till	129.1	0.80	12	<100	0.34	1.5	4.7	132	3	22.5	106	400
W99-1-130.6	Till	130.6	0.80	13	<100	0.35	1.6	4.5	135	4	23.0	84	390
W99-1-131.6	Till	131.6	0.84	13	<100	0.34	1.6	4.8	123	4	25.1	78	400
W99-1-132.5	Till	132.5	0.80	12	<100	0.33	1.7	4.4	117	3	23.7	76	500
W99-1-133.5	Till	133.5	0.76	12	<100	0.35	1.7	4.3	117	3	22.0	78	500
W99-1-134.5	Till	134.5	0.76	12	<100	0.34	1.3	4.4	120	3	21.4	82	420
W99-1-135.5	Till	135.5	0.76	12	<100	0.35	1.5	4.3	103	4	21.3	66	470
W99-1-137.0	Till	137.0	0.94	13	<100	0.34	1.6	5.0	139	3	22.3	90	330
* W99-1-137.0	Till	137.0	1.02	13	<100	0.34	1.7	5.1	148	3	23.0	90	520
W99-1-138.0	Till	138.0	0.92	13	<100	0.34	1.4	5.2	139	4	22.1	88	390

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			NAA	NAA	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	IMS
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**	**Cr***
			grams	**ppb**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-139.0	Till	139.0	12.1	4	1.5	14	640	550	2.1	0.31	3.1	0.94	0.87	90	5.1	78	64
W99-1-140.0	Till	140.0	11.1	4	1.5	15	580	500	2	0.33	3.5	0.88	0.87	93	5.5	75	66
W99-1-141.0	Till	141.0	13.2	<2	1.5	14	540	460	1.6	0.32	3.2	0.88	0.87	87	5	84	63
W99-1-142.0	Till	142.0	13.1	<2	1.5	15	690	610	1.9	0.31	3.8	0.86	0.93	87	5.4	77	67
W99-1-143.0	Till	143.0	10.6	3	1.5	16	990	800	2.1	0.33	3.6	0.88	0.89	88	5.2	74	64
W99-1-144.0	Till	144.0	11.4	5	1.5	15	540	480	2.1	0.31	3.4	1.04	0.87	84	5.5	71	65
W99-1-145.0	Till	145.0	11.6	5	1.5	17	1000	770	1.6	0.33	3.4	1.14	0.87	89	5.2	72	60
W99-1-146.0	Till	146.0	11.7	<2	1.5	16	690	620	1.9	0.33	3.8	1.08	0.93	93	5.5	80	69
W99-1-147.0	Till	147.0	12.2	<2	2.3	20	720	600	2.3	0.35	5	1.68	1.3	87	5.2	82	69
W99-1-148.0	Till	148.0	12.0	<2	2.2	20	700	590	2.1	0.35	4.3	1.58	1.12	92	5.4	72	69
W99-1-149.0	Till	149.0	12.1	4	2.2	19	810	700	1.8	0.36	4.7	1.52	1.14	89	5.8	82	69
W99-1-150.0	Till	150.0	13.0	36	2.2	22	660	250	1.7	0.34	4	1.46	1.03	100	4.1	76	54
W99-1-151.0	Till	151.0	11.2	5	2.6	19	740	540	1.7	0.36	4.9	1.74	1.23	87	6.4	87	75
W99-1-152.0	Till	152.0	12.1	5	2.6	20	740	610	2.1	0.37	4.9	1.74	1.19	88	5.9	90	76
W99-1-153.0	Till	153.0	11.8	4	2.8	19	740	600	2.2	0.34	5.2	1.86	1.2	90	6.4	93	76
W99-1-153.4	Till	153.4	11.1	4	3.4	21	670	570	2.1	0.37	5.6	2.66	1.42	91	6.4	85	79
W99-1-153.6	Shale	153.6	8.8	4	0.7	13	920	740	2.4	0.32	4.5	0.36	0.72	75	8.1	110	108

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS	CVAA
Sample #	**Material**	**Depth**	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**	**Hg**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppb**
W99-1-139.0	Till	139.0	13	21	2	17.1	1.6	12	<50	3.2	44	19	50	0.3	0.67	360	30
W99-1-140.0	Till	140.0	13	23	1	17.8	1.7	11	<50	3.3	46	21	52	0.3	0.7	370	40
W99-1-141.0	Till	141.0	13	21	2	17.5	1.8	12	<50	3.2	45	20	51	0.4	0.68	350	40
W99-1-142.0	Till	142.0	13	23	2	17.2	1.7	11	<50	3.4	44	19	49	0.4	0.71	360	50
W99-1-143.0	Till	143.0	14	22	1	18.2	1.9	11	<50	3.3	45	19	52	0.2	0.69	365	60
W99-1-144.0	Till	144.0	13	23	2	17.4	1.7	11	<50	3.2	44	19	48	0.4	0.69	355	60
W99-1-145.0	Till	145.0	13	23	2	16.2	1.7	12	<50	3.5	44	18	48	0.3	0.67	370	60
W99-1-146.0	Till	146.0	14	25	2	18	1.8	11	<50	3.4	45	25	50	0.3	0.73	385	70
W99-1-147.0	Till	147.0	14	28	2	18.1	1.8	10	<50	3.7	46	20	50	0.3	0.74	360	80
W99-1-148.0	Till	148.0	14	29	2	17.6	1.6	10	<50	3.6	45	19	50	0.3	0.77	375	60
W99-1-149.0	Till	149.0	14	29	2	17.9	1.6	10	<50	3.5	46	19	50	0.3	0.76	380	60
W99-1-150.0	Till	150.0	13	28	2	13.8	1.5	17	<50	3.3	49	19	40	0.5	0.58	375	70
W99-1-151.0	Till	151.0	15	32	1	17.8	1.7	10	<50	3.6	45	19	53	0.2	0.86	395	60
W99-1-152.0	Till	152.0	15	32	2	18.8	1.7	9	<50	3.5	45	20	55	0.2	0.79	390	80
W99-1-153.0	Till	153.0	15	32	2	18	2.1	10	<50	3.7	45	19	52	0.3	0.77	365	60
W99-1-153.4	Till	153.4	16	33	2	18.9	1.8	10	<50	3.9	47	20	55	<0.2	0.78	365	70
W99-1-153.6	Shale	153.6	10	25	<1	20	2.1	6	<50	3.2	39	17	78	<0.2	0.72	115	90

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS	NAA
Sample #	**Material**	**Depth**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**	**Tb**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-139.0	Till	139.0	6	30	13	850	1.46	81	7	12	<5	0.45	0.48	160	1.5	0.05	1.1
W99-1-140.0	Till	140.0	5.8	32	14	870	1.51	86	6.9	12	<5	0.5	0.48	163	1.5	0.15	0.9
W99-1-141.0	Till	141.0	6.4	30	13	850	1.46	80	6.8	12	<5	0.45	0.48	157	1.3	0.05	1.1
W99-1-142.0	Till	142.0	5.6	31	13	950	1.52	81	6.9	12	<5	0.45	0.51	171	1.2	<0.05	1.1
W99-1-143.0	Till	143.0	5.8	32	13	890	1.47	87	6.7	12	<5	0.45	0.48	181	1.2	0.05	1
W99-1-144.0	Till	144.0	5.4	31	13	870	1.46	83	6.7	12	<5	0.45	0.47	165	1.3	0.05	1.1
W99-1-145.0	Till	145.0	5.6	31	13	900	1.4	78	6.8	12	<5	0.5	0.5	177	1.4	0.15	1.1
W99-1-146.0	Till	146.0	5.8	33	13	980	1.52	85	6.9	12	<5	0.6	0.5	179	1.3	0.05	1.1
W99-1-147.0	Till	147.0	9.8	37	13	1030	1.5	85	6.9	12	<5	0.5	0.52	185	1.4	0.15	0.9
W99-1-148.0	Till	148.0	8.4	36	12	1020	1.51	81	7	12	<5	0.5	0.51	184	1.5	0.1	1
W99-1-149.0	Till	149.0	8.6	36	13	1040	1.5	82	7	12	<5	0.5	0.53	192	1.3	0.05	1.2
W99-1-150.0	Till	150.0	7.4	33	11	1110	1.35	64	8	10	<5	0.5	0.57	169	1.3	0.15	1.2
W99-1-151.0	Till	151.0	9.4	39	13	1000	1.57	83	7	13	6	0.55	0.53	195	1.4	0.15	1.2
W99-1-152.0	Till	152.0	9.8	41	12	1000	1.58	87	6.9	13	<5	0.55	0.56	196	1.5	0.15	1
W99-1-153.0	Till	153.0	9.4	40	12	1020	1.59	85	6.8	14	<5	0.55	0.54	196	1.5	0.15	1.1
W99-1-153.4	Till	153.4	12.6	46	13	950	1.59	90	6.7	13	<5	0.6	0.59	201	1.4	0.15	1
W99-1-153.6	Shale	153.6	7.2	34	15	920	1.94	112	5.3	15	<5	0.45	0.45	143	1.3	<0.05	0.9

Table A3-3: Geochemical analysis of samples from core hole WEPA99-1

			IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-1-139.0	Till	139.0	1.02	13	<100	0.33	1.5	5.3	146	4	24.4	86	420
W99-1-140.0	Till	140.0	1.10	13	<100	0.34	1.9	5.3	153	4	24.9	90	430
W99-1-141.0	Till	141.0	1.08	13	<100	0.33	1.7	5.5	145	4	24.4	86	400
W99-1-142.0	Till	142.0	1.02	13	<100	0.34	1.8	5.5	151	4	24.5	90	380
W99-1-143.0	Till	143.0	1.10	12	<100	0.33	1.5	5.5	148	3	25.1	86	260
W99-1-144.0	Till	144.0	1.02	12	<100	0.33	1.5	5.7	149	4	24.1	100	390
W99-1-145.0	Till	145.0	1.02	13	<100	0.32	1.3	6.0	138	4	24.3	88	400
W99-1-146.0	Till	146.0	1.10	13	<100	0.34	1.8	5.6	154	3	24.7	90	400
W99-1-147.0	Till	147.0	1.44	13	<100	0.31	1.6	7.0	200	3	26.6	102	500
W99-1-148.0	Till	148.0	1.36	13	<100	0.32	2.1	6.8	190	4	25.7	100	460
W99-1-149.0	Till	149.0	1.38	13	<100	0.33	1.6	6.8	194	4	26.3	98	240
W99-1-150.0	Till	150.0	1.38	14	<100	0.31	1.7	7.6	137	5	27.8	90	690
W99-1-151.0	Till	151.0	1.48	13	<100	0.33	1.6	7.3	215	3	25.4	116	450
W99-1-152.0	Till	152.0	1.58	13	<100	0.32	1.5	6.9	217	3	24.9	108	340
W99-1-153.0	Till	153.0	1.54	13	<100	0.33	1.5	7.0	228	4	24.7	122	310
W99-1-153.4	Till	153.4	1.90	13	<100	0.32	2.1	7.3	269	3	25.5	136	<200
W99-1-153.6	Shale	153.6	1.08	11	<100	0.38	1.5	5.7	192	3	20.2	122	<200

Notes: < denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* W99-1-54.4 denotes sample duplicate of W99-1-54.4

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-7.5	Till	7.5	10.6	<2	5.97	0.9	12.0	740	720	1.5	0.25	1.9	0.42	1.12	61	4.2	64
W99-2-9.5	Till	9.5	10.3	<2	6.18	0.9	13.0	700	420	1.4	0.25	2.2	0.38	1.09	67	5.1	73
W99-2-12.0	Till	12.0	12.2	5	6.21	0.9	13.0	720	710	1.5	0.27	2.3	0.36	1.09	74	4.7	80
W99-2-14.0	Till	14.0	11.3	<2	5.95	0.9	13.0	670	480	1.5	0.22	2.5	0.44	1.18	68	4.1	74
W99-2-15.0	Till	15.0	10.0	<2	5.60	0.9	14.0	670	670	1.5	0.22	2.1	0.44	1.04	67	4.1	70
W99-2-17.0	Silt	17.0	10.6	6	5.88	0.9	13.0	690	440	1.1	0.22	2.1	0.38	1.22	73	4.5	69
W99-2-21.8	Till	21.8	11.0	<2	6.10	0.9	12.0	680	660	1.5	0.23	2.3	0.36	1.32	69	4.5	76
W99-2-22.7	Till	22.7	11.6	<2	5.93	1.0	12.0	670	660	1.3	0.21	2.1	0.34	1.27	68	4.3	73
W99-2-23.4	Till	23.4	11.8	5	6.06	0.9	12.0	660	630	1.4	0.23	2.4	0.36	1.26	70	4.2	73
W99-2-29.0	Till	29.0	12.7	<2	6.21	0.9	11.0	660	560	0.9	0.22	1.8	0.34	1.38	64	4.7	74
W99-2-30.5	Till	30.5	12.1	<2	6.31	0.9	11.0	740	730	1.1	0.16	1.7	0.30	2.28	64	4.0	73
W99-2-32.5	Till	32.5	12.7	<2	5.88	0.9	10.0	640	640	0.8	0.17	1.3	0.30	2.22	69	4.0	74
W99-2-33.4	Till	33.4	12.2	<2	6.01	0.9	10.0	710	620	1.3	0.19	1.6	0.30	1.97	69	4.1	80
W99-2-35.0	Till	35.0	16.5	<2	5.01	0.7	7.9	640	660	0.9	0.13	1.5	0.20	2.73	68	2.9	78
W99-2-35.7	Till	35.7	13.2	<2	6.48	0.8	9.5	670	740	1.2	0.13	1.7	0.32	2.90	71	3.4	77
W99-2-37.5	Till	37.5	12.2	5	6.06	0.8	10.0	660	660	1.1	0.17	1.7	0.32	1.94	70	4.4	81
W99-2-38.7	Till	38.7	12.0	<2	6.26	0.8	7.8	1100	1090	1.1	0.23	1.3	0.24	1.24	68	4.8	70
W99-2-40.0	Silt & clay	40.0	14.1	<2	5.89	0.8	6.1	710	670	1.4	0.22	1.5	0.34	1.72	90	3.9	86
* W99-2-40.0	Silt & clay	40.0	14.7	<2	5.81	0.8	6.0	670	650	0.9	0.18	1.3	0.38	1.71	80	4.2	87
W99-2-41.0	Silt & clay	41.0	13.3	<2	6.48	1.0	7.7	620	620	1.2	0.25	2.2	0.24	0.66	86	4.7	83
W99-2-42.0	Till	42.0	11.6	<2	6.15	0.7	12.0	460	520	1.3	0.25	1.8	0.46	0.90	83	4.7	71
W99-2-43.0	Till	43.0	14.2	5	5.92	0.7	12.0	580	620	1.2	0.23	1.6	0.28	0.85	76	4.1	82
W99-2-44.0	Till	44.0	12.7	<2	5.81	0.8	10.0	440	460	1.0	0.22	1.5	0.24	0.82	72	3.8	64
W99-2-45.0	Till	45.0	14.6	<2	5.90	0.8	11.0	460	500	1.1	0.22	1.6	0.32	0.86	79	4.2	61
W99-2-46.0	Till	46.0	16.3	<2	5.75	0.8	10.0	460	480	1.0	0.20	1.3	0.26	0.85	75	3.9	60
W99-2-47.0	Till	47.0	15.4	<2	5.63	0.8	11.0	480	450	1.1	0.19	1.6	0.24	0.82	73	3.6	59
W99-2-48.0	Till	48.0	12.1	<2	5.91	0.8	10.0	570	580	1.0	0.24	2.0	0.30	0.81	76	4.4	65
W99-2-49.0	Till	49.0	11.2	<2	6.05	0.8	14.0	550	570	1.0	0.23	1.5	0.34	0.74	73	4.9	72
W99-2-50.0	Till	50.0	13.0	<2	5.91	0.9	12.0	540	500	1.2	0.24	2.1	0.34	0.76	72	4.6	50
W99-2-51.0	Till	51.0	12.9	<2	5.96	0.8	12.0	520	490	1.4	0.27	1.7	0.32	0.77	70	3.9	61
W99-2-52.0	Till	52.0	12.9	<2	6.09	0.9	12.0	550	510	1.3	0.26	1.4	0.36	0.80	70	4.6	69
W99-2-54.0	Till	54.0	11.2	<2	6.66	1.0	12.0	560	750	1.3	0.28	2.4	0.58	0.87	72	5.4	72

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W99-2-7.5	Till	7.5	59	14	25	2	15.6	1.5	10	<50	3.10	32	18	52	0.3	0.80	395
W99-2-9.5	Till	9.5	63	13	25	2	15.6	1.5	9	<50	3.10	34	17	55	0.4	0.85	395
W99-2-12.0	Till	12.0	67	14	25	2	16.2	1.6	8	<50	3.40	33	18	56	0.4	0.87	405
W99-2-14.0	Till	14.0	61	14	25	2	15.4	1.6	9	<50	3.00	34	19	51	0.4	0.88	425
W99-2-15.0	Till	15.0	57	14	24	1	14.6	1.5	9	<50	3.10	34	19	47	0.3	0.80	370
W99-2-17.0	Silt	17.0	61	14	25	1	14.5	1.5	9	<50	3.10	35	17	47	0.4	0.88	410
W99-2-21.8	Till	21.8	59	14	24	2	15.3	1.5	10	<50	3.00	36	18	47	0.4	0.89	425
W99-2-22.7	Till	22.7	62	13	24	2	14.6	1.4	9	<50	3.30	37	17	44	0.4	0.88	420
W99-2-23.4	Till	23.4	61	15	23	1	15.2	1.6	9	<50	3.00	37	19	49	0.4	0.88	425
W99-2-29.0	Till	29.0	70	13	26	1	15.8	1.4	9	<50	3.40	35	17	48	0.3	0.95	410
W99-2-30.5	Till	30.5	64	12	22	1	14.4	1.3	8	<50	3.10	33	14	41	0.4	1.40	505
W99-2-32.5	Till	32.5	67	12	23	2	14.4	1.3	9	<50	3.10	35	16	40	0.3	1.23	515
W99-2-33.4	Till	33.4	61	13	21	2	14.9	1.4	8	<50	3.30	33	15	42	0.4	1.20	425
W99-2-35.0	Till	35.0	56	9	15	<1	11.2	1.2	13	<50	2.30	35	13	26	0.4	1.28	410
W99-2-35.7	Till	35.7	59	11	19	1	13.1	1.2	11	<50	2.70	34	15	33	0.4	1.50	505
W99-2-37.5	Till	37.5	63	12	22	2	13.6	1.3	9	<50	3.20	34	15	39	0.3	1.20	435
W99-2-38.7	Till	38.7	61	10	22	1	14.6	1.5	10	<50	3.00	36	21	40	0.4	0.98	275
W99-2-40.0	Silt & clay	40.0	54	11	19	1	14.4	1.4	12	<50	3.10	39	17	41	0.5	0.84	485
* W99-2-40.0	Silt & clay	40.0	63	10	21	2	13.9	1.3	12	<50	3.10	39	16	37	0.4	0.83	475
W99-2-41.0	Silt & clay	41.0	60	12	24	1	15.6	1.6	11	<50	2.80	38	19	49	0.5	0.71	270
W99-2-42.0	Till	42.0	57	14	22	2	15.1	1.5	10	<50	3.90	39	18	49	0.5	0.77	540
W99-2-43.0	Till	43.0	55	12	19	2	13.7	1.4	12	<50	3.10	36	16	46	0.4	0.78	435
W99-2-44.0	Till	44.0	56	12	19	2	13.8	1.5	12	<50	2.80	34	17	46	0.4	0.74	400
W99-2-45.0	Till	45.0	58	11	21	2	14.2	1.5	12	<50	3.20	37	16	45	0.4	0.80	415
W99-2-46.0	Till	46.0	53	11	19	2	13.4	1.5	12	<50	3.10	37	16	43	0.5	0.74	410
W99-2-47.0	Till	47.0	52	11	19	2	13.2	1.1	11	<50	3.00	37	16	43	0.4	0.74	400
W99-2-48.0	Till	48.0	55	12	26	1	14.3	1.4	11	<50	3.10	37	17	48	0.5	0.78	420
W99-2-49.0	Till	49.0	58	12	24	2	15.1	1.4	9	<50	3.20	37	18	46	0.4	0.77	390
W99-2-50.0	Till	50.0	56	13	20	2	14.8	1.5	10	<50	3.30	37	17	47	0.4	0.73	365
W99-2-51.0	Till	51.0	55	13	20	1	15.3	1.7	10	<50	3.00	36	18	49	0.4	0.74	395
W99-2-52.0	Till	52.0	58	13	22	2	15.0	1.6	10	<50	3.00	36	18	48	0.5	0.77	405
W99-2-54.0	Till	54.0	65	16	23	2	17.2	1.6	8	<50	3.30	36	19	51	0.4	0.84	480

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-7.5	Till	7.5	50	2.6	27	11	740	1.64	84	5.7	10	<5	0.50	0.55	174	0.9	0.10
W99-2-9.5	Till	9.5	60	2.4	27	11	730	1.68	84	5.9	12	<5	0.50	0.58	171	1.2	<0.05
W99-2-12.0	Till	12.0	60	2.6	29	12	740	1.70	89	5.9	12	<5	0.55	0.60	176	1.3	0.05
W99-2-14.0	Till	14.0	70	2.6	28	12	720	1.72	85	6.2	11	<5	0.50	0.58	162	1.3	0.05
W99-2-15.0	Till	15.0	60	2.6	28	12	710	1.64	81	6.0	11	<5	0.50	0.62	157	1.1	0.05
W99-2-17.0	Silt	17.0	50	2.6	28	12	720	1.73	85	6.4	11	<5	0.50	0.59	158	1.1	0.05
W99-2-21.8	Till	21.8	30	2.6	28	12	690	1.74	88	6.3	11	<5	0.50	0.62	161	1.0	0.05
W99-2-22.7	Till	22.7	30	2.4	26	12	710	1.69	81	6.3	12	<5	0.50	0.60	158	1.1	0.05
W99-2-23.4	Till	23.4	40	2.4	28	11	700	1.74	86	6.1	11	<5	0.55	0.60	156	1.2	<0.05
W99-2-29.0	Till	29.0	40	2.6	27	11	800	1.74	88	6.1	12	<5	0.50	0.67	163	1.3	<0.05
W99-2-30.5	Till	30.5	30	1.4	26	10	750	1.80	79	5.5	12	<5	0.50	0.86	177	0.9	0.05
W99-2-32.5	Till	32.5	50	1.2	27	10	770	1.76	77	5.8	12	<5	0.40	0.91	169	1.0	0.05
W99-2-33.4	Till	33.4	40	1.4	27	10	670	1.66	80	5.8	12	<5	0.45	0.85	163	0.9	0.05
W99-2-35.0	Till	35.0	40	0.8	21	9	820	1.75	61	6.0	9	<5	0.40	1.10	173	1.2	<0.05
W99-2-35.7	Till	35.7	30	1.0	23	9	780	2.05	70	6.1	11	<5	0.40	1.00	206	1.0	<0.05
W99-2-37.5	Till	37.5	40	1.2	25	10	770	1.74	77	5.9	12	<5	0.45	0.80	166	1.2	0.05
W99-2-38.7	Till	38.7	30	1.2	22	10	740	1.74	83	6.2	12	<5	0.50	0.71	161	1.0	0.05
W99-2-40.0	Silt & clay	40.0	30	1.2	23	11	500	1.57	78	6.8	12	<5	0.45	0.81	166	1.5	0.05
* W99-2-40.0	Silt & clay	40.0	10	1.0	20	10	560	1.60	74	6.7	11	<5	0.46	0.78	158	1.1	0.05
W99-2-41.0	Silt & clay	41.0	40	1.4	23	12	610	1.80	89	6.9	12	<5	0.55	0.56	136	0.9	0.10
W99-2-42.0	Till	42.0	30	1.8	23	12	680	1.73	84	6.6	12	<5	0.60	0.50	126	1.3	<0.05
W99-2-43.0	Till	43.0	30	1.6	19	11	650	1.56	74	6.1	11	<5	0.50	0.49	127	1.0	0.05
W99-2-44.0	Till	44.0	30	1.8	20	11	640	1.54	75	6.2	10	<5	0.45	0.47	120	1.4	0.10
W99-2-45.0	Till	45.0	30	1.8	20	12	680	1.70	79	6.4	11	<5	0.50	0.55	127	1.3	0.10
W99-2-46.0	Till	46.0	20	2.0	19	11	650	1.65	76	6.5	10	<5	0.50	0.55	123	1.4	0.05
W99-2-47.0	Till	47.0	30	1.8	19	10	600	1.40	69	6.5	11	<5	0.46	0.55	120	1.1	0.05
W99-2-48.0	Till	48.0	40	2.0	21	12	650	1.47	74	6.4	11	<5	0.60	0.53	135	1.4	0.05
W99-2-49.0	Till	49.0	40	2.4	21	12	650	1.52	79	6.5	11	<5	0.75	0.51	132	1.2	0.05
W99-2-50.0	Till	50.0	40	2.4	22	12	640	1.48	79	6.5	11	<5	0.55	0.54	128	1.2	0.05
W99-2-51.0	Till	51.0	40	2.2	22	12	640	1.49	79	6.4	11	<5	0.60	0.50	130	1.4	<0.05
W99-2-52.0	Till	52.0	50	3.2	23	12	650	1.50	80	6.5	12	<5	0.50	0.53	133	1.3	0.05
W99-2-54.0	Till	54.0	30	2.6	28	12	660	1.54	89	6.3	12	<5	0.50	0.53	142	1.6	0.10

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-2-7.5	Till	7.5	0.8	0.70	9.1	<100	0.30	1.2	3.5	119	<2	22.8	78	<100
W99-2-9.5	Till	9.5	0.8	0.68	10.0	<100	0.30	1.1	3.7	124	3	21.8	84	140
W99-2-12.0	Till	12.0	1.0	0.72	10.0	<100	0.31	1.1	3.8	126	3	22.9	86	<100
W99-2-14.0	Till	14.0	1.0	0.76	10.0	<100	0.31	2.8	3.9	123	2	22.9	84	<100
W99-2-15.0	Till	15.0	0.9	0.78	10.0	<100	0.30	1.1	3.7	113	3	22.4	84	<100
W99-2-17.0	Silt	17.0	1.1	0.78	10.0	<100	0.31	1.1	3.7	115	3	22.6	84	<100
W99-2-21.8	Till	21.8	0.6	0.78	10.0	<100	0.31	1.2	3.8	120	2	23.4	80	<100
W99-2-22.7	Till	22.7	0.8	0.76	10.0	<100	0.32	1.2	3.7	122	3	21.9	80	110
W99-2-23.4	Till	23.4	0.9	0.76	10.0	<100	0.30	1.1	3.8	121	3	24.0	82	100
W99-2-29.0	Till	29.0	0.9	0.74	10.0	<100	0.30	1.1	3.7	126	2	22.2	88	<100
W99-2-30.5	Till	30.5	0.8	0.60	8.9	<100	0.31	0.9	3.2	123	2	19.8	76	<100
W99-2-32.5	Till	32.5	0.8	0.60	10.0	<100	0.30	1.0	3.4	116	3	20.6	80	<100
W99-2-33.4	Till	33.4	0.9	0.60	10.0	<100	0.29	1.0	3.4	120	2	20.1	70	<100
W99-2-35.0	Till	35.0	0.7	0.50	10.0	<100	0.30	0.8	3.4	82	3	20.3	62	<100
W99-2-35.7	Till	35.7	0.9	0.54	10.0	<100	0.35	1.2	3.2	118	3	20.5	66	<100
W99-2-37.5	Till	37.5	<0.5	0.60	10.0	<100	0.30	1.0	3.2	120	3	19.5	74	110
W99-2-38.7	Till	38.7	0.6	0.70	10.0	<100	0.28	2.2	3.1	121	2	20.3	66	<100
W99-2-40.0	Silt & clay	40.0	1.2	0.70	12.0	<100	0.29	1.2	3.5	115	3	22.5	60	<100
* W99-2-40.0	Silt & clay	40.0	1.0	0.62	12.0	<100	0.31	0.9	3.4	113	3	20.7	68	110
W99-2-41.0	Silt & clay	41.0	0.6	0.74	11.0	<100	0.35	1.4	3.8	124	3	22.4	70	<100
W99-2-42.0	Till	42.0	0.9	0.66	11.0	<100	0.33	1.2	3.7	111	3	23.3	76	<100
W99-2-43.0	Till	43.0	0.8	0.58	10.0	<100	0.32	1.0	3.4	104	2	20.8	60	<100
W99-2-44.0	Till	44.0	0.9	0.64	10.0	<100	0.31	1.1	3.3	101	2	19.8	62	<100
W99-2-45.0	Till	45.0	0.8	0.62	10.0	<100	0.31	1.0	3.6	106	3	21.2	66	<100
W99-2-46.0	Till	46.0	0.7	0.66	10.0	<100	0.31	1.0	3.5	97	3	20.4	62	<100
W99-2-47.0	Till	47.0	0.9	0.56	10.0	<100	0.29	1.0	3.8	98	3	20.1	60	<100
W99-2-48.0	Till	48.0	0.5	0.60	10.0	<100	0.32	1.2	3.3	106	3	21.4	62	<100
W99-2-49.0	Till	49.0	0.8	0.66	10.0	<100	0.33	1.2	3.2	115	3	22.4	64	130
W99-2-50.0	Till	50.0	0.8	0.68	10.0	<100	0.33	1.3	3.3	106	3	21.9	64	<100
W99-2-51.0	Till	51.0	0.9	0.74	10.0	<100	0.33	1.4	3.3	106	3	22.2	62	<100
W99-2-52.0	Till	52.0	0.6	0.70	10.0	<100	0.34	1.2	3.2	110	3	22.3	66	110
W99-2-54.0	Till	54.0	0.9	0.74	11.0	<100	0.32	1.7	3.3	131	3	22.5	94	<100

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-55.0	Till	55.0	12.2	<2	6.10	1.0	12.0	550	540	1.3	0.25	2.2	0.46	0.80	76	4.6	66
W99-2-56.0	Till	56.0	11.0	<2	6.19	1.0	12.0	570	2140	1.1	0.25	2.1	0.50	0.75	74	4.8	64
W99-2-57.0	Till	57.0	10.5	<2	6.85	0.9	12.0	560	540	1.5	0.29	1.9	0.36	0.70	76	4.8	79
W99-2-58.0	Silt & Clay	58.0	9.3	<2	6.67	1.0	11.0	660	590	1.1	0.27	1.8	0.34	0.73	74	5.7	66
W99-2-59.0	Silt & Clay	59.0	14.5	<2	5.12	0.8	12.0	670	620	1.0	0.16	1.8	0.26	0.92	63	3.6	65
* W99-2-59.0	Silt & Clay	59.0	10.0	<2	5.34	0.8	12.0	630	680	1.0	0.18	1.0	0.32	0.93	59	3.8	60
W99-2-60.0	Silt & Clay	60.0	12.1	6	4.98	0.9	11.0	680	650	0.9	0.16	1.7	0.28	0.96	58	3.9	62
W99-2-61.0	Silt & Clay	61.0	13.4	<2	4.09	0.7	11.0	570	620	0.6	0.13	1.1	0.26	1.03	67	2.9	59
W99-2-62.0	Silt & Clay	62.0	13.4	<2	4.50	0.7	12.0	700	580	0.9	0.15	1.4	0.22	0.87	65	3.8	73
W99-2-63.0	Till	63.0	11.6	<2	5.55	1.0	13.0	600	530	0.8	0.22	1.9	0.40	0.93	73	4.0	63
W99-2-64.0	Till	64.0	13.2	<2	5.99	0.9	14.0	610	550	1.5	0.23	2.0	0.40	1.00	78	4.3	62
W99-2-65.0	Till	65.0	12.0	<2	5.97	1.0	11.0	580	560	1.1	0.25	1.8	0.40	0.96	84	4.1	75
W99-2-66.0	Till	66.0	11.9	<2	5.89	0.9	10.0	540	560	0.7	0.25	2.0	0.38	0.98	78	3.5	88
W99-2-67.0	Till	67.0	11.4	<2	5.67	0.9	11.0	530	520	1.4	0.26	1.6	0.44	1.00	74	3.7	64
W99-2-68.0	Till	68.0	11.2	5	5.43	0.9	12.0	560	500	1.3	0.28	1.8	0.42	0.98	80	4.2	71
W99-2-69.0	Till	69.0	10.9	<2	5.89	0.9	12.0	520	500	1.8	0.22	1.7	0.38	0.93	82	3.9	65
W99-2-70.1	Till	70.1	11.1	<2	5.84	0.9	14.0	540	500	1.1	0.20	2.3	0.36	0.91	79	4.8	69
W99-2-71.0	Till	71.0	11.7	<2	5.80	1.0	12.0	560	490	1.9	0.22	1.9	0.32	0.90	78	4.1	69
W99-2-74.0	Till	74.0	12.5	<2	5.62	0.9	12.0	550	530	1.4	0.21	2.1	0.44	0.84	79	3.9	67
W99-2-75.0	Till	75.0	12.4	<2	5.71	0.9	12.0	530	480	1.4	0.22	1.7	0.42	0.85	75	4.3	71
W99-2-76.0	Till	76.0	11.1	6	5.96	0.9	12.0	540	550	1.8	0.23	2.3	0.34	0.87	75	4.2	68
W99-2-77.0	Till	77.0	10.0	<2	5.77	1.0	12.0	540	550	1.6	0.23	2.4	0.42	0.88	75	4.7	73
W99-2-78.0	Till	78.0	11.8	<2	5.84	0.9	11.0	540	550	1.3	0.23	2.0	0.40	0.86	76	3.7	63
W99-2-79.0	Till	79.0	12.2	<2	5.56	0.9	13.0	550	520	1.5	0.20	1.8	0.36	0.85	75	4.4	86
* W99-2-79.0	Till	79.0	12.1	<2	5.59	0.9	12.0	550	530	1.5	0.21	1.8	0.38	0.86	78	4.5	63
W99-2-80.0	Till	80.0	10.5	5	5.93	0.9	14.0	560	540	1.5	0.23	2.3	0.38	0.89	77	4.2	57
W99-2-81.0	Till	81.0	11.2	<2	5.71	0.9	12.0	540	530	1.4	0.22	2.2	0.40	0.87	77	4.4	49
W99-2-82.0	Till	82.0	11.2	<2	5.72	1.0	12.0	570	540	1.2	0.23	1.5	0.38	0.83	76	4.3	67
W99-2-83.0	Till	83.0	11.5	<2	5.73	0.9	13.0	560	580	1.3	0.22	2.0	0.38	0.81	77	4.1	65
W99-2-84.0	Till	84.0	11.7	<2	5.50	1.0	13.0	550	540	1.5	0.22	2.5	0.42	0.77	70	4.1	67
W99-2-85.0	Till	85.0	13.7	<2	5.77	1.0	12.0	570	580	1.4	0.22	2.3	0.40	0.81	79	5.0	71
W99-2-86.0	Till	86.0	9.8	6	5.47	1.1	13.0	590	600	1.1	0.22	2.3	0.56	0.91	79	4.3	64

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W99-2-55.0	Till	55.0	59	13	22	2	14.8	1.4	9	<50	3.10	36	18	45	0.5	0.77	420
W99-2-56.0	Till	56.0	63	14	24	2	15.3	1.6	9	<50	3.40	37	19	47	0.4	0.77	430
W99-2-57.0	Till	57.0	64	13	23	1	16.3	1.5	8	<50	3.50	38	116	50	0.4	0.82	345
W99-2-58.0	Silt & Clay	58.0	65	14	27	2	15.6	1.6	6	<50	3.60	35	18	46	0.4	0.83	645
W99-2-59.0	Silt & Clay	59.0	50	10	19	2	11.3	1.3	9	<50	2.70	31	15	32	0.4	0.76	515
* W99-2-59.0	Silt & Clay	59.0	53	11	20	2	11.5	1.3	9	<50	2.70	28	16	33	0.4	0.79	540
W99-2-60.0	Silt & Clay	60.0	50	11	17	2	11.6	1.4	10	<50	2.60	29	16	32	0.4	0.79	465
W99-2-61.0	Silt & Clay	61.0	41	9	13	1	8.5	1.2	15	<50	2.20	31	15	25	0.5	0.71	375
W99-2-62.0	Silt & Clay	62.0	45	9	15	2	10.2	1.3	11	<50	2.50	31	14	31	0.4	0.68	375
W99-2-63.0	Till	63.0	51	11	20	2	11.5	1.2	11	<50	2.80	35	16	34	0.5	0.74	430
W99-2-64.0	Till	64.0	56	13	22	2	13.7	1.4	11	<50	3.70	37	19	42	0.5	0.83	505
W99-2-65.0	Till	65.0	56	12	21	2	13.0	1.3	13	<50	3.10	38	19	40	0.5	0.80	440
W99-2-66.0	Till	66.0	56	12	23	1	13.6	1.4	12	<50	3.10	36	19	39	0.5	0.82	450
W99-2-67.0	Till	67.0	55	13	20	1	13.9	1.4	12	<50	2.90	34	21	42	0.4	0.76	420
W99-2-68.0	Till	68.0	54	13	19	2	14.7	1.4	11	<50	3.10	36	19	44	0.5	0.72	400
W99-2-69.0	Till	69.0	55	14	22	1	15.7	1.4	12	<50	3.30	38	16	45	0.4	0.72	395
W99-2-70.1	Till	70.1	55	14	21	2	15.1	1.5	11	<50	3.10	37	16	45	0.4	0.74	400
W99-2-71.0	Till	71.0	55	14	21	2	15.8	1.5	11	<50	3.00	37	17	45	0.5	0.73	395
W99-2-74.0	Till	74.0	57	14	21	2	15.4	1.7	12	<50	3.00	37	16	43	0.4	0.75	420
W99-2-75.0	Till	75.0	51	13	19	2	15.1	1.5	12	<50	3.10	38	17	43	0.5	0.68	370
W99-2-76.0	Till	76.0	56	14	21	2	16.0	1.6	11	<50	2.90	36	16	45	0.5	0.77	420
W99-2-77.0	Till	77.0	56	14	20	2	15.2	1.5	11	<50	3.00	37	19	43	0.4	0.78	410
W99-2-78.0	Till	78.0	57	14	22	2	15.6	1.5	11	<50	3.00	36	17	43	0.4	0.75	425
W99-2-79.0	Till	79.0	56	14	22	2	15.5	1.5	11	<50	3.20	38	16	43	0.4	0.76	425
* W99-2-79.0	Till	79.0	55	13	20	2	15.6	1.6	11	<50	3.30	37	17	44	0.3	0.74	415
W99-2-80.0	Till	80.0	57	14	21	2	16.0	1.6	11	<50	3.00	36	18	46	0.5	0.75	410
W99-2-81.0	Till	81.0	55	13	21	1	14.9	1.6	11	<50	3.20	37	17	43	0.5	0.75	390
W99-2-82.0	Till	82.0	56	13	22	1	14.7	1.6	11	<50	3.10	37	17	40	0.4	0.72	395
W99-2-83.0	Till	83.0	58	13	23	2	14.0	1.5	11	<50	3.20	38	17	40	0.4	0.78	440
W99-2-84.0	Till	84.0	54	12	23	2	14.4	1.5	11	<50	3.10	37	17	41	0.5	0.71	385
W99-2-85.0	Till	85.0	61	13	24	2	14.9	1.4	12	<50	3.20	37	17	40	0.5	0.78	395
W99-2-86.0	Till	86.0	64	13	27	1	14.1	1.6	10	<50	3.00	35	16	39	0.4	0.84	375

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

Sample #	Material	Depth	CVAA Hg ppb	IMS Mo ppm	IMS Ni ppm	IMS Nb ppm	IMS P ppm	IMS K %	IMS Rb ppm	NAA Sm ppm	NAA Sc ppm	NAA Se ppm	IMS Ag ppm	NAA Na %	IMS Sr ppm	NAA Ta ppm	IMS Te ppm
W99-2-55.0	Till	55.0	50	2.6	23	11	670	1.45	78	6.3	12	<5	0.55	0.53	135	1.5	<0.05
W99-2-56.0	Till	56.0	50	2.6	25	11	680	1.50	80	6.5	12	<5	0.55	0.52	158	1.2	0.05
W99-2-57.0	Till	57.0	40	2.6	24	12	660	1.73	91	6.7	13	<5	0.55	0.46	135	1.3	0.10
W99-2-58.0	Silt & Clay	58.0	40	1.8	25	11	680	1.59	83	6.4	13	<5	0.65	0.51	127	1.3	0.05
W99-2-59.0	Silt & Clay	59.0	40	1.2	20	9	690	1.47	63	5.6	10	<5	0.45	0.73	135	1.2	0.05
* W99-2-59.0	Silt & Clay	59.0	50	1.2	21	10	700	1.55	61	5.3	10	<5	0.50	0.68	143	1.2	<0.05
W99-2-60.0	Silt & Clay	60.0	60	1.2	21	10	730	1.33	63	5.6	10	<5	0.45	0.66	132	1.0	0.05
W99-2-61.0	Silt & Clay	61.0	50	1.0	17	9	730	1.21	52	5.7	8.3	<5	0.40	0.71	121	1.1	<0.05
W99-2-62.0	Silt & Clay	62.0	50	0.8	16	9	700	1.23	57	5.7	9.3	<5	0.45	0.69	165	1.3	0.05
W99-2-63.0	Till	63.0	30	1.8	19	10	640	1.40	63	6.5	11	<5	0.45	0.58	124	1.0	0.05
W99-2-64.0	Till	64.0	30	2.2	23	11	670	1.75	84	6.6	12	<5	0.55	0.61	144	1.0	0.05
W99-2-65.0	Till	65.0	40	2.2	22	10	670	1.72	77	6.6	11	<5	0.55	0.57	141	1.1	0.15
W99-2-66.0	Till	66.0	30	2.4	22	11	680	1.48	73	6.1	10	<5	0.60	0.51	141	1.2	0.05
W99-2-67.0	Till	67.0	30	2.4	24	12	660	1.55	78	6.2	10	<5	0.60	0.53	138	1.2	0.05
W99-2-68.0	Till	68.0	20	2.6	24	12	650	1.51	77	6.5	11	<5	0.55	0.55	135	1.1	0.05
W99-2-69.0	Till	69.0	30	2.4	25	12	690	1.59	76	6.7	11	<5	0.60	0.56	136	1.2	0.10
W99-2-70.1	Till	70.1	40	2.6	26	11	690	1.56	77	6.9	11	<5	0.55	0.55	139	1.3	0.05
W99-2-71.0	Till	71.0	30	2.4	26	11	670	1.46	76	6.9	11	<5	0.60	0.61	142	1.1	0.10
W99-2-74.0	Till	74.0	30	2.4	25	11	730	1.35	74	6.8	11	<5	0.50	0.56	146	1.3	0.05
W99-2-75.0	Till	75.0	30	2.6	25	11	610	1.42	73	6.8	11	<5	0.55	0.58	135	1.2	0.05
W99-2-76.0	Till	76.0	30	2.6	26	11	700	1.42	76	6.8	11	<5	0.60	0.58	149	1.2	0.15
W99-2-77.0	Till	77.0	40	2.6	26	12	690	1.65	81	6.6	11	<5	0.55	0.55	144	1.1	0.05
W99-2-78.0	Till	78.0	30	2.6	26	12	700	1.53	76	6.6	11	<5	0.65	0.56	146	0.9	0.05
W99-2-79.0	Till	79.0	40	2.6	25	11	680	1.41	73	6.7	11	<5	0.50	0.57	142	1.2	0.05
* W99-2-79.0	Till	79.0	40	2.6	24	12	670	1.55	77	6.5	11	<5	0.50	0.54	141	1.0	0.05
W99-2-80.0	Till	80.0	30	3.0	25	12	710	1.55	77	6.7	11	<5	0.55	0.57	145	1.2	0.15
W99-2-81.0	Till	81.0	40	3.0	25	11	700	1.45	73	6.6	11	<5	0.55	0.57	143	1.3	0.10
W99-2-82.0	Till	82.0	40	2.8	24	10	700	1.44	73	6.6	11	<5	0.55	0.57	143	1.2	0.05
W99-2-83.0	Till	83.0	40	2.6	24	11	750	1.51	71	6.7	11	<5	0.45	0.54	145	1.4	0.05
W99-2-84.0	Till	84.0	40	2.8	24	10	700	1.37	72	6.7	11	<5	0.65	0.57	141	1.3	0.05
W99-2-85.0	Till	85.0	50	2.8	24	10	780	1.47	74	6.7	12	<5	0.50	0.53	148	1.2	0.05
W99-2-86.0	Till	86.0	50	2.8	28	11	800	1.38	75	6.3	11	<5	0.25	0.54	131	1.2	0.05

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-2-55.0	Till	55.0	0.8	0.76	10.0	<100	0.30	1.2	3.4	122	3	21.4	72	<100
W99-2-56.0	Till	56.0	0.8	0.80	11.0	<100	0.31	1.2	3.0	122	3	21.6	72	<100
W99-2-57.0	Till	57.0	0.9	0.74	11.0	<100	0.33	1.2	3.8	132	3	21.4	68	120
W99-2-58.0	Silt & Clay	58.0	1.1	0.70	10.0	<100	0.33	1.2	3.2	127	<2	20.1	72	<100
W99-2-59.0	Silt & Clay	59.0	0.8	0.58	8.5	<100	0.30	0.9	2.9	100	2	18.2	66	<100
* W99-2-59.0	Silt & Clay	59.0	0.8	0.60	7.9	<100	0.33	1.0	2.8	105	2	18.7	68	<100
W99-2-60.0	Silt & Clay	60.0	0.8	0.64	8.5	<100	0.29	1.0	3.1	108	3	19.7	78	100
W99-2-61.0	Silt & Clay	61.0	0.8	0.50	9.0	<100	0.27	0.8	4.0	87	4	18.9	64	<100
W99-2-62.0	Silt & Clay	62.0	0.6	0.54	8.9	<100	0.28	1.0	3.5	94	3	17.9	60	<100
W99-2-63.0	Till	63.0	1.0	0.68	10.0	<100	0.30	1.0	3.9	99	3	19.5	74	<100
W99-2-64.0	Till	64.0	0.8	0.82	10.0	<100	0.29	1.5	4.2	110	3	22.3	74	<100
W99-2-65.0	Till	65.0	0.8	0.74	11.0	<100	0.30	1.2	3.9	113	3	21.9	74	<100
W99-2-66.0	Till	66.0	0.9	0.74	10.0	<100	0.32	1.5	3.7	112	2	21.7	70	120
W99-2-67.0	Till	67.0	0.7	0.80	10.0	<100	0.33	1.4	3.5	103	3	23.3	70	<100
W99-2-68.0	Till	68.0	0.9	0.76	10.0	<100	0.33	1.2	3.8	100	3	23.0	68	<100
W99-2-69.0	Till	69.0	0.9	0.62	10.0	<100	0.33	1.1	4.1	101	3	23.9	70	<100
W99-2-70.1	Till	70.1	1.0	0.64	11.0	<100	0.32	1.2	3.6	103	3	23.1	78	<100
W99-2-71.0	Till	71.0	0.7	0.64	11.0	<100	0.30	1.5	3.9	101	3	23.9	68	<100
W99-2-74.0	Till	74.0	1.0	0.60	11.0	<100	0.30	1.1	3.8	106	3	24.2	72	<100
W99-2-75.0	Till	75.0	0.8	0.62	11.0	<100	0.30	1.0	4.4	100	3	23.7	62	<100
W99-2-76.0	Till	76.0	0.9	0.62	11.0	<100	0.31	1.1	3.8	112	3	24.3	72	<100
W99-2-77.0	Till	77.0	1.0	0.66	11.0	<100	0.31	1.1	4.0	114	3	24.1	70	<100
W99-2-78.0	Till	78.0	0.9	0.64	11.0	<100	0.33	1.2	4.1	112	3	24.9	70	<100
W99-2-79.0	Till	79.0	0.8	0.62	11.0	<100	0.30	1.2	4.5	108	3	23.7	70	<100
* W99-2-79.0	Till	79.0	0.9	0.66	11.0	<100	0.32	1.3	4.4	105	3	21.4	68	<100
W99-2-80.0	Till	80.0	0.8	0.66	11.0	<100	0.32	1.1	3.8	107	3	21.3	74	<100
W99-2-81.0	Till	81.0	0.9	0.68	10.0	<100	0.31	1.1	3.7	109	3	20.6	70	<100
W99-2-82.0	Till	82.0	0.9	0.68	11.0	<100	0.29	1.1	4.1	106	3	20.7	70	<100
W99-2-83.0	Till	83.0	0.9	0.66	11.0	<100	0.30	1.0	3.8	119	3	19.8	76	<100
W99-2-84.0	Till	84.0	1.0	0.66	10.0	<100	0.28	1.1	4.0	111	3	19.8	70	<100
W99-2-85.0	Till	85.0	0.8	0.70	11.0	<100	0.29	1.0	3.9	123	3	19.2	74	<100
W99-2-86.0	Till	86.0	0.7	0.78	10.0	<100	0.30	1.1	3.9	135	3	20.6	88	100

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-87.0	Till	87.0	12.1	<2	6.43	1.4	14.0	670	650	1.7	0.28	2.9	0.80	1.17	80	5.5	69
W99-2-88.0	Till	88.0	11.5	<2	6.24	1.4	13.0	680	630	2.0	0.27	2.6	0.72	1.09	80	5.0	67
W99-2-92.7	Till	92.7	11.2	<2	5.76	1.4	15.0	620	640	1.5	0.23	2.7	0.68	1.13	77	4.5	85
W99-2-93.1	Till	93.1	12.2	<2	5.79	1.5	15.0	650	650	1.3	0.24	2.4	0.64	1.02	78	4.4	65
W99-2-94.0	Till	94.0	12.3	11	6.15	1.4	13.0	660	660	1.3	0.25	3.3	0.74	1.07	85	5.1	71
W99-2-95.0	Till	95.0	10.8	<2	6.19	1.4	14.0	700	680	1.8	0.24	2.3	0.66	1.14	82	5.0	88
W99-2-96.0	Till	96.0	12.1	3	5.63	1.5	17.0	760	690	1.9	0.24	2.4	0.78	1.05	78	5.1	94
W99-2-97.0	Till	97.0	11.3	<2	6.45	1.2	12.0	700	660	1.5	0.25	2.4	0.56	1.14	83	5.2	86
W99-2-98.0	Till	98.0	12.1	<2	6.04	1.2	12.0	700	620	1.4	0.25	2.7	0.62	1.14	78	5.0	84
W99-2-99.0	Till	99.0	12.1	<2	6.37	1.2	12.0	680	650	1.6	0.23	2.8	0.62	1.16	73	5.4	71
W99-2-100.0	Till	100.0	10.6	<2	6.08	1.1	13.0	680	580	1.3	0.24	2.8	0.52	0.90	77	5.4	71
* W99-2-100.0	Till	100.0	10.4	<2	6.33	1.1	13.0	650	620	1.7	0.25	2.7	0.56	0.94	72	5.6	76
W99-2-101.0	Till	101.0	10.7	4	6.41	1.2	13.0	660	490	1.5	0.26	3.0	0.58	1.02	71	5.6	73
W99-2-102.0	Till	102.0	10.9	<2	6.50	1.3	13.0	710	680	1.8	0.28	2.9	0.74	1.12	77	5.9	76
W99-2-103.0	Till	103.0	11.3	3	6.54	1.3	14.0	740	680	1.6	0.29	2.6	0.68	1.14	72	5.6	70
W99-2-104.0	Till	104.0	10.0	<2	6.32	1.3	14.0	740	680	2.1	0.26	3.1	0.64	1.08	75	5.3	94
W99-2-105.0	Till	105.0	10.8	<2	6.44	1.3	13.0	720	700	1.3	0.26	3.0	0.74	1.14	74	5.4	84
W99-2-106.0	Till	106.0	10.9	<2	6.39	1.3	14.0	710	680	1.6	0.26	3.4	0.80	0.95	78	6.1	72
W99-2-107.1	Till	107.1	8.8	<2	6.50	1.3	17.0	770	640	1.8	0.30	3.2	0.70	1.01	79	6.1	80
W99-2-108.0	Till	108.0	11.4	<2	6.65	1.4	15.0	740	730	2.0	0.28	3.1	0.74	0.97	77	6.1	70
W99-2-109.0	Till	109.0	11.8	<2	6.55	1.5	16.0	760	680	1.9	0.27	3.5	0.80	0.96	79	6.5	69
W99-2-110.1	Till	110.1	9.3	<2	6.28	1.2	14.0	750	710	1.9	0.29	3.3	0.66	0.89	77	5.4	79
W99-2-111.0	Till	111.0	11.2	3	6.25	1.1	13.0	910	870	1.8	0.25	2.6	0.64	1.02	78	5.7	69
W99-2-112.0	Till	112.0	12.4	4	5.96	1.2	15.0	760	690	1.5	0.22	2.2	0.44	1.30	76	4.8	76
W99-2-113.5	Till	113.5	9.9	<2	6.09	1.1	11.0	720	670	1.5	0.23	2.3	0.54	1.33	76	4.8	84
W99-2-114.3	Till	114.3	11.6	<2	6.13	1.0	11.0	620	650	1.6	0.23	2.1	0.50	1.27	75	4.6	67
W99-2-115.0	Till	115.0	10.5	3	5.81	1.0	12.0	660	620	1.3	0.22	1.7	0.46	1.23	62	4.2	80
W99-2-116.0	Till	116.0	10.4	<2	6.08	1.1	13.0	710	650	1.5	0.24	2.2	0.52	1.36	67	5.2	64
W99-2-117.0	Till	117.0	9.3	3	5.93	1.1	11.0	710	630	1.5	0.24	2.3	0.54	1.27	65	5.3	62
W99-2-118.0	Till	118.0	12.9	<2	6.25	1.1	12.0	720	650	1.6	0.21	2.3	0.56	1.41	67	5.4	68
* W99-2-118.0	Till	118.0	11.2	<2	6.24	1.1	12.0	720	650	1.7	0.24	2.4	0.48	1.40	79	5.3	74
W99-2-119.0	Till	119.0	11.0	3	6.29	1.1	10.0	730	670	1.6	0.22	1.7	0.44	1.48	70	5.1	73

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

Sample #	Material	Depth	IMS Cr* ppm	IMS Co ppm	IMS Cu ppm	NAA Eu ppm	IMS Ga ppm	IMS Ge ppm	NAA Hf ppm	NAA Ir ppb	NAA Fe %	NAA La ppm	IMS Pb ppm	IMS Li ppm	NAA Lu ppm	IMS Mg %	IMS Mn ppm
W99-2-87.0	Till	87.0	73	15	27	2	18.0	1.6	9	<50	3.20	37	19	47	0.4	0.84	375
W99-2-88.0	Till	88.0	65	15	26	2	18.0	1.6	9	<50	3.10	36	18	46	0.4	0.81	360
W99-2-92.7	Till	92.7	63	13	26	<1	15.2	1.4	10	<50	3.10	36	17	39	0.4	0.74	350
W99-2-93.1	Till	93.1	61	13	26	2	14.7	1.5	11	<50	3.30	35	16	39	0.4	0.77	355
W99-2-94.0	Till	94.0	66	14	25	1	15.9	1.6	10	<50	3.60	36	17	41	0.3	0.79	355
W99-2-95.0	Till	95.0	68	14	26	2	17.1	1.6	11	<50	3.40	35	18	45	0.3	0.82	360
W99-2-96.0	Till	96.0	62	14	25	2	15.2	1.6	11	<50	3.30	38	17	40	0.4	0.75	340
W99-2-97.0	Till	97.0	66	14	25	2	16.1	1.6	11	<50	3.40	38	17	44	0.4	0.85	380
W99-2-98.0	Till	98.0	63	14	24	1	16.8	1.7	10	<50	3.40	38	17	43	0.4	0.80	355
W99-2-99.0	Till	99.0	68	13	26	2	16.5	1.6	9	<50	3.40	37	17	42	0.4	0.84	380
W99-2-100.0	Till	100.0	63	13	24	<1	15.1	1.4	9	<50	3.40	39	16	42	0.4	0.77	360
* W99-2-100.0	Till	100.0	65	14	25	2	16.4	1.6	9	<50	3.40	39	18	48	0.4	0.81	380
W99-2-101.0	Till	101.0	67	14	25	2	17.2	1.6	9	<50	3.40	37	18	44	0.4	0.81	370
W99-2-102.0	Till	102.0	69	15	27	1	17.5	1.7	9	<50	3.40	38	19	44	0.3	0.79	335
W99-2-103.0	Till	103.0	70	14	28	2	17.5	1.7	9	<50	3.30	37	19	45	0.4	0.82	395
W99-2-104.0	Till	104.0	69	14	27	<1	16.9	1.7	9	<50	3.30	39	18	44	0.3	0.80	345
W99-2-105.0	Till	105.0	69	14	26	1	17.8	1.8	9	<50	3.30	38	18	46	0.3	0.82	355
W99-2-106.0	Till	106.0	69	14	27	2	16.5	1.7	10	<50	3.40	39	19	44	0.4	0.77	335
W99-2-107.1	Till	107.1	71	14	27	2	17.1	1.7	9	<50	3.40	39	18	45	0.4	0.78	330
W99-2-108.0	Till	108.0	73	14	26	2	17.4	1.7	10	<50	3.40	40	19	48	0.4	0.80	340
W99-2-109.0	Till	109.0	73	14	28	2	17.1	1.7	9	<50	3.50	40	19	45	0.4	0.75	330
W99-2-110.1	Till	110.1	68	14	26	1	17.3	1.6	10	<50	3.30	38	19	44	0.4	0.76	340
W99-2-111.0	Till	111.0	66	14	26	1	16.6	1.6	9	<50	3.20	38	18	41	0.4	0.79	325
W99-2-112.0	Till	112.0	61	14	24	1	15.3	1.6	10	<50	3.50	37	18	38	0.4	0.83	370
W99-2-113.5	Till	113.5	62	13	25	2	15.5	1.4	10	<50	3.50	36	16	38	0.3	0.85	385
W99-2-114.3	Till	114.3	63	12	25	1	15.0	1.5	11	<50	3.30	34	16	36	0.4	0.84	380
W99-2-115.0	Till	115.0	59	13	24	1	15.2	1.5	9	<50	2.90	30	17	38	<0.2	0.79	355
W99-2-116.0	Till	116.0	63	13	24	2	15.8	1.5	10	<50	3.00	32	17	39	0.3	0.85	380
W99-2-117.0	Till	117.0	63	13	24	2	15.3	1.5	9	<50	3.10	34	16	39	0.3	0.81	360
W99-2-118.0	Till	118.0	65	13	25	2	16.2	1.5	8	<50	3.10	34	17	38	0.3	0.87	375
* W99-2-118.0	Till	118.0	65	13	25	2	15.0	1.5	10	<50	3.50	36	17	36	0.4	0.86	365
W99-2-119.0	Till	119.0	67	13	25	<1	15.6	1.5	9	<50	3.10	34	17	35	0.3	0.88	380

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-87.0	Till	87.0	60	4.6	32	12	810	1.64	89	6.6	13	6	0.65	0.54	170	1.2	0.05
W99-2-88.0	Till	88.0	50	4.6	31	12	720	1.48	85	6.5	12	<5	0.65	0.57	162	1.2	0.05
W99-2-92.7	Till	92.7	50	4.6	30	11	760	1.59	79	6.5	11	<5	0.55	0.60	154	1.1	0.05
W99-2-93.1	Till	93.1	50	4.4	28	11	750	1.47	73	6.4	12	6	0.55	0.57	158	1.1	0.05
W99-2-94.0	Till	94.0	40	4.8	30	11	770	1.48	80	6.2	12	<5	0.55	0.58	159	1.0	0.10
W99-2-95.0	Till	95.0	70	4.4	33	11	780	1.55	83	5.5	12	<5	0.60	0.51	166	0.9	0.10
W99-2-96.0	Till	96.0	40	5.2	31	11	720	1.59	83	6.1	12	5	0.55	0.56	154	1.2	0.10
W99-2-97.0	Till	97.0	40	3.6	28	12	740	1.58	82	6.1	12	<5	0.60	0.54	163	1.1	0.05
W99-2-98.0	Till	98.0	50	3.8	30	12	700	1.58	83	6.2	12	<5	0.55	0.52	160	1.3	0.10
W99-2-99.0	Till	99.0	40	3.8	29	11	740	1.59	81	6.1	12	<5	0.55	0.53	161	1.1	0.05
W99-2-100.0	Till	100.0	40	3.4	26	11	720	1.54	77	6.4	12	<5	0.55	0.49	147	1.3	0.05
* W99-2-100.0	Till	100.0	40	4.0	28	13	760	1.63	84	6.4	12	<5	0.65	0.49	153	1.3	0.10
W99-2-101.0	Till	101.0	40	4.4	30	11	760	1.74	86	6.2	12	<5	0.55	0.49	158	1.0	0.05
W99-2-102.0	Till	102.0	50	5.2	33	13	800	1.66	91	6.2	12	<5	0.65	0.51	169	0.9	0.15
W99-2-103.0	Till	103.0	40	5.0	33	13	800	1.69	92	6.2	12	<5	0.65	0.54	170	1.0	0.10
W99-2-104.0	Till	104.0	50	5.2	30	12	770	1.61	84	6.3	12	<5	0.70	0.52	168	1.4	0.10
W99-2-105.0	Till	105.0	20	5.0	32	12	750	1.66	90	6.2	12	<5	0.65	0.55	174	1.2	0.15
W99-2-106.0	Till	106.0	40	5.6	31	12	840	1.63	87	6.4	13	<5	0.65	0.48	167	1.2	0.10
W99-2-107.1	Till	107.1	50	5.6	32	13	810	1.69	88	6.5	13	<5	0.65	0.49	169	1.4	0.15
W99-2-108.0	Till	108.0	50	6.0	32	13	820	1.73	92	6.4	13	<5	0.70	0.49	175	1.3	0.15
W99-2-109.0	Till	109.0	50	6.0	32	13	860	1.67	84	6.5	13	<5	0.65	0.49	167	1.4	0.10
W99-2-110.1	Till	110.1	40	4.8	30	13	820	1.74	92	6.5	12	<5	0.70	0.49	161	1.4	0.10
W99-2-111.0	Till	111.0	30	4.2	29	13	770	1.67	84	6.3	11	<5	0.65	0.54	167	1.3	0.10
W99-2-112.0	Till	112.0	40	3.0	29	12	690	1.64	78	5.9	12	<5	0.60	0.63	162	0.9	0.10
W99-2-113.5	Till	113.5	60	3.0	28	12	730	1.64	75	5.7	12	<5	0.55	0.61	162	1.5	0.05
W99-2-114.3	Till	114.3	60	2.8	27	11	740	1.63	77	5.5	11	6	0.50	0.56	155	1.2	0.10
W99-2-115.0	Till	115.0	50	2.8	28	12	710	1.60	75	5.6	9.1	<5	0.55	0.49	153	1.1	0.10
W99-2-116.0	Till	116.0	50	3.2	29	11	720	1.65	78	5.8	11	<5	0.60	0.53	158	1.2	0.10
W99-2-117.0	Till	117.0	40	3.2	28	12	720	1.62	76	6.1	11	<5	0.60	0.53	154	1.2	0.10
W99-2-118.0	Till	118.0	50	3.2	29	11	750	1.65	77	6.0	11	<5	0.50	0.53	159	1.2	0.10
* W99-2-118.0	Till	118.0	50	3.2	29	12	750	1.66	75	6.0	13	<5	0.60	0.61	158	1.2	0.10
W99-2-119.0	Till	119.0	30	3.0	28	11	760	1.66	76	6.0	11	<5	0.55	0.58	162	1.4	0.05

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-2-87.0	Till	87.0	0.6	0.98	11.0	<100	0.33	1.2	4.5	159	3	21.9	86	<100
W99-2-88.0	Till	88.0	1.0	0.88	11.0	<100	0.30	1.2	4.7	152	2	22.0	86	<100
W99-2-92.7	Till	92.7	0.8	0.84	10.0	<100	0.29	1.1	4.4	139	3	20.5	88	<100
W99-2-93.1	Till	93.1	0.8	0.82	11.0	<100	0.29	1.0	4.5	146	3	19.6	84	<100
W99-2-94.0	Till	94.0	0.9	0.84	11.0	<100	0.30	1.2	4.8	153	2	20.9	84	<100
W99-2-95.0	Till	95.0	0.6	0.86	10.0	<100	0.30	2.9	4.0	156	3	21.3	114	140
W99-2-96.0	Till	96.0	0.9	0.88	11.0	<100	0.29	1.2	4.5	143	3	21.4	82	110
W99-2-97.0	Till	97.0	0.9	0.80	11.0	<100	0.33	1.2	4.2	145	3	19.8	84	120
W99-2-98.0	Till	98.0	0.8	0.82	11.0	<100	0.32	1.6	4.3	141	3	20.6	86	100
W99-2-99.0	Till	99.0	0.7	0.78	11.0	<100	0.32	1.4	3.9	149	3	19.8	86	130
W99-2-100.0	Till	100.0	0.9	0.74	11.0	<100	0.32	1.0	4.2	138	3	19.1	80	<100
* W99-2-100.0	Till	100.0	1.0	0.82	11.0	<100	0.34	1.2	4.4	147	3	22.1	84	130
W99-2-101.0	Till	101.0	0.7	0.86	11.0	<100	0.29	1.3	4.2	150	3	21.1	86	100
W99-2-102.0	Till	102.0	0.7	1.00	11.0	<100	0.32	1.3	4.4	154	3	22.4	88	130
W99-2-103.0	Till	103.0	0.9	0.96	11.0	<100	0.32	2.3	4.6	158	3	23.1	90	160
W99-2-104.0	Till	104.0	0.7	0.92	11.0	<100	0.33	1.4	4.7	156	3	21.4	92	<100
W99-2-105.0	Till	105.0	0.9	0.94	11.0	170	0.32	1.3	5.0	159	3	22.5	90	110
W99-2-106.0	Till	106.0	1.1	0.96	11.0	<100	0.31	2.3	4.6	166	3	22.0	94	130
W99-2-107.1	Till	107.1	1.0	0.98	11.0	<100	0.34	1.4	5.0	162	3	22.6	94	130
W99-2-108.0	Till	108.0	0.8	1.00	11.0	<100	0.34	1.3	4.7	176	3	22.4	98	100
W99-2-109.0	Till	109.0	0.9	1.04	11.0	<100	0.34	1.4	5.0	171	3	22.9	96	130
W99-2-110.1	Till	110.1	0.8	1.00	11.0	<100	0.32	1.5	4.8	152	4	23.5	94	180
W99-2-111.0	Till	111.0	0.9	0.86	11.0	<100	0.33	1.4	4.3	141	3	22.9	90	160
W99-2-112.0	Till	112.0	0.7	0.78	11.0	<100	0.33	1.4	4.1	126	3	20.9	84	140
W99-2-113.5	Till	113.5	0.8	0.74	10.0	<100	0.33	1.2	4.0	127	3	20.2	82	120
W99-2-114.3	Till	114.3	0.6	0.74	10.0	<100	0.32	1.1	3.5	128	3	20.4	80	140
W99-2-115.0	Till	115.0	0.6	0.74	10.0	<100	0.32	1.2	3.7	120	2	19.7	74	<100
W99-2-116.0	Till	116.0	0.8	0.78	10.0	<100	0.32	1.1	3.9	125	3	20.4	80	<100
W99-2-117.0	Till	117.0	0.9	0.78	10.0	<100	0.32	1.3	3.9	130	3	20.3	78	<100
W99-2-118.0	Till	118.0	0.7	0.76	10.0	<100	0.32	1.2	4.0	136	3	20.0	80	<100
* W99-2-118.0	Till	118.0	0.9	0.76	11.0	<100	0.33	1.2	3.7	134	3	20.4	82	<100
W99-2-119.0	Till	119.0	0.9	0.76	11.0	<100	0.34	1.2	3.7	134	2	20.0	84	110

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-120.0	Till	120.0	12.3	3	6.12	1.1	13.0	730	680	1.6	0.23	2.0	0.56	1.42	63	5.0	70
W99-2-121.0	Till	121.0	9.7	4	6.17	1.1	12.0	720	770	1.2	0.24	2.1	0.44	1.32	68	4.7	70
W99-2-122.0	Till	122.0	9.8	3	6.18	1.1	11.0	680	670	1.6	0.25	2.4	0.54	1.11	72	5.1	69
W99-2-123.0	Till	123.0	10.1	<2	6.12	1.1	12.0	720	670	1.4	0.21	2.1	0.44	1.43	70	5.0	82
W99-2-124.0	Till	124.0	10.3	<2	6.24	1.1	10.0	750	690	1.5	0.20	1.7	0.38	1.75	70	5.1	81
W99-2-125.0	Till	125.0	12.2	3	6.23	1.0	12.0	780	730	1.3	0.20	1.5	0.48	1.64	71	5.1	80
W99-2-127.0	Till	127.0	11.1	3	6.49	0.9	12.0	770	740	1.7	0.23	1.5	0.42	1.87	70	4.9	83
W99-2-128.0	Till	128.0	11.4	3	6.20	1.0	11.0	740	690	1.4	0.21	1.7	0.40	1.57	70	4.8	80
W99-2-129.0	Till	129.0	11.3	<2	6.24	1.0	10.0	790	730	1.3	0.24	1.6	0.40	1.61	68	4.5	81
W99-2-130.0	Till	130.0	9.9	4	6.28	1.0	7.9	790	720	1.5	0.22	1.1	0.38	1.87	73	5.2	75
W99-2-131.0	Till	131.0	9.6	5	6.15	1.1	10.0	730	650	1.4	0.21	1.7	0.42	1.75	74	4.9	84
W99-2-132.0	Till	132.0	10.9	3	6.25	1.0	34.0	810	720	1.1	0.21	1.6	0.46	1.88	70	5.0	95
W99-2-133.0	Till	133.0	9.6	5	6.16	1.0	15.0	790	710	1.3	0.22	1.8	0.36	1.72	72	5.1	83
W99-2-134.2	Till	134.2	12.2	<2	6.62	1.0	11.0	860	790	1.4	0.24	1.7	0.38	1.83	73	5.3	83
W99-2-135.0	Till	135.0	9.8	5	6.49	1.1	40.0	860	750	1.1	0.22	2.1	0.40	1.96	78	4.8	100
W99-2-136.0	Till	136.0	11.6	<2	6.50	1.0	7.6	810	750	1.2	0.22	1.3	0.28	2.18	77	4.6	95
W99-2-137.0	Till	137.0	13.7	4	6.85	1.0	9.1	810	780	1.7	0.22	1.1	0.26	2.27	81	4.9	100
* W99-2-137.0	Till	137.0	11.1	7	6.42	1.0	8.4	870	770	1.7	0.23	1.2	0.24	2.32	73	5.0	98
W99-2-138.0	Silt & Clay	138.0	10.2	3	5.69	0.9	10.0	790	700	1.1	0.19	1.4	0.24	2.07	57	3.9	71
W99-2-139.0	Silt & Clay	139.0	11.9	<2	5.62	0.9	9.1	810	730	1.1	0.15	1.4	0.24	2.14	58	3.8	77
W99-2-140.0	Silt	140.0	10.6	4	5.93	0.9	11.0	830	770	1.3	0.17	1.3	0.24	2.24	57	4.0	73
W99-2-141.0	Silt	141.0	10.6	<2	5.71	1.0	10.0	940	840	1.3	0.20	1.2	0.26	2.03	63	4.3	92
W99-2-142.0	Silt	142.0	12.7	<2	6.27	1.1	11.0	890	800	1.4	0.21	1.4	0.26	1.99	70	5.1	97
W99-2-143.0	Silt	143.0	11.5	8	6.12	1.0	11.0	930	830	1.4	0.22	1.0	0.22	2.01	78	4.7	120
W99-2-144.0	Silt	144.0	14.2	<2	5.74	0.9	8.4	830	780	1.0	0.18	1.0	0.24	2.08	61	3.6	84
W99-2-145.0	Silt	145.0	12.5	4	6.95	1.0	22.0	780	730	1.8	0.29	1.3	0.28	2.05	61	5.5	92
W99-2-146.0	Silt	146.0	12.9	3	5.81	1.0	8.4	910	830	1.5	0.19	1.3	0.28	2.18	77	3.9	110
W99-2-148.1	Silt & Clay	148.1	12.3	3	5.79	1.0	8.0	790	750	1.2	0.15	1.2	0.32	2.12	69	3.6	79
W99-2-149.0	Till & Clay	149.0	12.7	<2	5.55	1.1	9.0	870	790	1.4	0.21	1.5	0.42	1.78	68	4.3	83
W99-2-149.9	Till & Clay	149.9	12.9	<2	5.43	0.9	9.5	840	800	1.1	0.19	1.4	0.32	2.06	74	4.1	88
W99-2-151.0	Till & Clay	151.0	12.5	7	6.59	1.0	12.0	760	680	1.2	0.27	1.6	0.42	1.91	71	5.4	79
W99-2-152.0	Till & Clay	152.0	12.5	<2	6.65	0.9	6.0	830	810	0.9	0.18	1.2	0.32	3.01	63	4.0	83

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

Sample #	Material	Depth	IMS Cr* ppm	IMS Co ppm	IMS Cu ppm	NAA Eu ppm	IMS Ga ppm	IMS Ge ppm	NAA Hf ppm	NAA Ir ppb	NAA Fe %	NAA La ppm	IMS Pb ppm	IMS Li ppm	NAA Lu ppm	IMS Mg %	IMS Mn ppm
W99-2-120.0	Till	120.0	66	13	25	1	15.7	1.5	10	<50	3.20	33	20	38	0.3	0.86	380
W99-2-121.0	Till	121.0	64	13	25	2	14.8	1.4	8	<50	3.20	32	16	36	0.4	0.85	370
W99-2-122.0	Till	122.0	66	13	25	2	15.6	1.6	10	<50	3.20	37	17	38	0.4	0.80	350
W99-2-123.0	Till	123.0	64	13	24	<1	15.1	1.5	9	<50	3.50	35	15	34	0.4	0.88	365
W99-2-124.0	Till	124.0	64	12	24	2	16.0	1.3	8	<50	3.30	33	15	35	0.3	0.95	390
W99-2-125.0	Till	125.0	65	13	24	1	15.5	1.2	9	<50	3.30	35	16	36	0.4	0.92	380
W99-2-127.0	Till	127.0	67	13	24	2	17.0	1.4	8	<50	3.10	35	16	36	0.4	1.00	400
W99-2-128.0	Till	128.0	63	13	23	2	15.9	1.4	9	<50	3.40	35	16	37	0.5	0.92	375
W99-2-129.0	Till	129.0	66	13	24	2	16.1	1.6	9	<50	3.30	34	17	38	0.4	0.93	375
W99-2-130.0	Till	130.0	68	13	26	1	16.1	1.4	8	<50	3.50	35	16	34	0.3	0.99	400
W99-2-131.0	Till	131.0	70	12	25	2	16.3	1.5	8	<50	3.80	36	17	33	0.3	0.95	395
W99-2-132.0	Till	132.0	68	14	25	2	16.0	1.3	8	<50	3.40	35	16	35	0.4	0.98	390
W99-2-133.0	Till	133.0	68	13	25	2	15.0	1.3	8	<50	3.30	35	16	33	0.3	0.94	375
W99-2-134.2	Till	134.2	69	14	26	2	16.6	1.4	9	<50	3.40	36	17	37	0.4	1.01	415
W99-2-135.0	Till	135.0	66	15	25	<1	15.4	1.3	9	<50	3.20	35	16	34	0.4	1.02	420
W99-2-136.0	Till	136.0	69	14	28	2	15.8	1.4	11	<50	5.00	34	18	32	0.4	1.08	555
W99-2-137.0	Till	137.0	73	14	28	2	16.1	1.4	11	<50	6.40	36	19	32	0.4	1.11	675
* W99-2-137.0	Till	137.0	76	15	29	1	16.3	1.4	11	<50	6.20	36	20	31	0.4	1.08	675
W99-2-138.0	Silt & Clay	138.0	59	12	21	1	13.7	1.2	9	<50	3.10	27	14	28	0.2	1.04	520
W99-2-139.0	Silt & Clay	139.0	58	11	21	1	13.3	1.2	9	<50	2.60	28	14	27	0.4	1.07	440
W99-2-140.0	Silt	140.0	63	12	22	1	13.8	1.3	7	<50	2.70	27	15	28	0.3	1.13	465
W99-2-141.0	Silt	141.0	64	12	22	1	12.9	1.3	11	<50	2.70	30	15	26	0.4	1.02	400
W99-2-142.0	Silt	142.0	72	13	27	2	15.1	1.3	11	<50	3.80	34	17	29	0.4	1.04	475
W99-2-143.0	Silt	143.0	71	13	25	2	15.2	1.3	17	<50	3.70	39	18	30	0.5	1.05	495
W99-2-144.0	Silt	144.0	59	11	20	2	13.1	1.3	10	<50	2.60	30	15	26	0.4	1.03	370
W99-2-145.0	Silt	145.0	76	15	32	1	17.1	1.4	6	<50	5.60	32	19	34	0.3	1.11	585
W99-2-146.0	Silt	146.0	62	12	21	2	13.8	1.3	14	<50	2.80	36	16	27	0.5	1.04	380
W99-2-148.1	Silt & Clay	148.1	58	11	21	1	13.1	1.3	11	<50	2.40	32	15	26	0.4	1.06	380
W99-2-149.0	Till & Clay	149.0	60	11	20	<1	13.1	1.2	10	<50	2.80	34	16	26	0.4	0.97	380
W99-2-149.9	Till & Clay	149.9	60	12	21	2	13.5	1.3	10	<50	3.10	34	16	27	0.5	1.04	395
W99-2-151.0	Till & Clay	151.0	69	14	26	2	15.7	1.4	8	<50	4.00	36	18	33	0.4	1.06	440
W99-2-152.0	Till & Clay	152.0	64	12	23	2	14.6	1.3	8	<50	2.80	31	16	26	0.4	1.28	425

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-120.0	Till	120.0	30	3.2	30	12	730	1.67	77	5.9	11	<5	0.60	0.58	163	0.9	0.15
W99-2-121.0	Till	121.0	40	2.8	27	11	740	1.65	75	5.9	11	<5	0.60	0.56	156	1.2	0.05
W99-2-122.0	Till	122.0	40	3.2	27	12	760	1.67	79	6.1	12	<5	0.60	0.53	155	1.2	0.10
W99-2-123.0	Till	123.0	40	2.6	29	11	720	1.66	72	5.7	12	<5	0.55	0.61	156	1.1	0.05
W99-2-124.0	Till	124.0	30	2.2	28	11	700	1.66	76	5.6	13	<5	0.50	0.65	163	1.2	0.05
W99-2-125.0	Till	125.0	30	2.0	28	11	710	1.69	75	5.6	12	<5	0.50	0.67	164	1.0	0.05
W99-2-127.0	Till	127.0	30	2.2	29	12	680	1.70	81	5.5	12	<5	0.55	0.71	174	1.0	0.05
W99-2-128.0	Till	128.0	30	2.2	29	11	710	1.57	77	5.7	13	<5	0.50	0.67	161	1.1	0.05
W99-2-129.0	Till	129.0	60	2.6	30	12	690	1.71	78	5.7	12	<5	0.55	0.69	163	0.9	0.05
W99-2-130.0	Till	130.0	60	2.0	29	11	710	1.73	69	5.5	13	<5	0.55	0.65	162	1.2	0.05
W99-2-131.0	Till	131.0	70	1.8	28	11	690	1.69	65	5.6	14	<5	0.55	0.63	156	1.0	0.05
W99-2-132.0	Till	132.0	40	4.2	31	11	660	1.68	67	5.6	14	<5	0.55	0.72	167	1.0	0.05
W99-2-133.0	Till	133.0	50	2.4	30	11	690	1.67	67	5.7	13	<5	0.50	0.67	164	1.1	0.05
W99-2-134.2	Till	134.2	40	2.4	31	11	700	1.77	81	5.8	13	<5	0.55	0.70	179	1.2	0.10
W99-2-135.0	Till	135.0	40	3.6	33	11	660	1.68	78	5.7	13	<5	0.55	0.75	175	0.7	0.10
W99-2-136.0	Till	136.0	40	1.0	31	9	770	1.69	77	5.6	14	<5	0.45	0.77	177	1.0	0.10
W99-2-137.0	Till	137.0	50	1.0	30	10	820	1.65	73	5.8	15	<5	0.50	0.71	179	0.7	0.10
* W99-2-137.0	Till	137.0	60	1.2	33	11	860	1.69	62	6.0	15	<5	0.55	0.71	179	1.0	0.05
W99-2-138.0	Silt & Clay	138.0	40	1.0	27	10	720	1.57	65	5.2	10	<5	0.40	0.64	164	0.9	0.10
W99-2-139.0	Silt & Clay	139.0	50	1.2	27	9	710	1.59	59	5.2	10	<5	0.50	0.77	175	0.9	0.05
W99-2-140.0	Silt	140.0	50	1.4	27	10	770	1.72	61	5.1	10	<5	0.45	0.81	184	0.9	0.05
W99-2-141.0	Silt	141.0	40	1.2	28	10	710	1.58	56	5.7	10	<5	0.50	0.78	186	1.1	0.15
W99-2-142.0	Silt	142.0	50	1.2	30	10	770	1.63	65	6.0	13	<5	0.50	0.70	175	1.2	0.10
W99-2-143.0	Silt	143.0	50	1.2	30	11	770	1.58	62	6.7	12	<5	0.55	0.74	183	1.0	0.15
W99-2-144.0	Silt	144.0	30	1.4	26	9	700	1.56	64	5.1	11	<5	0.40	0.84	181	0.9	0.05
W99-2-145.0	Silt	145.0	60	1.8	35	11	900	1.65	78	5.4	15	<5	0.50	0.57	165	0.8	0.05
W99-2-146.0	Silt	146.0	50	1.4	27	10	720	1.56	63	6.0	12	<5	0.50	0.86	183	1.1	0.05
W99-2-148.1	Silt & Clay	148.1	50	1.4	26	10	690	1.57	66	5.4	11	<5	0.45	0.88	180	0.9	0.10
W99-2-149.0	Till & Clay	149.0	40	1.2	27	10	670	1.62	61	5.6	11	<5	0.55	0.83	166	1.3	0.10
W99-2-149.9	Till & Clay	149.9	30	1.0	26	10	710	1.63	59	5.5	11	<5	0.55	0.87	173	0.9	0.05
W99-2-151.0	Till & Clay	151.0	40	1.6	32	11	750	1.75	83	5.7	14	<5	0.55	0.67	164	1.0	0.10
W99-2-152.0	Till & Clay	152.0	40	1.6	28	10	650	1.72	69	5.0	12	<5	0.50	1.00	206	0.7	0.05

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-2-120.0	Till	120.0	0.8	0.80	10.0	<100	0.34	2.0	4.1	131	3	21.2	88	<100
W99-2-121.0	Till	121.0	0.9	0.80	10.0	<100	0.33	1.1	4.0	135	3	19.7	80	110
W99-2-122.0	Till	122.0	1.0	0.76	11.0	<100	0.33	1.2	4.1	135	3	20.4	84	<100
W99-2-123.0	Till	123.0	0.9	0.68	10.0	<100	0.32	1.2	3.7	130	3	19.0	80	150
W99-2-124.0	Till	124.0	0.8	0.68	10.0	<100	0.32	1.0	3.4	124	3	19.1	78	120
W99-2-125.0	Till	125.0	0.9	0.66	10.0	<100	0.32	1.3	3.5	129	3	20.1	80	110
W99-2-127.0	Till	127.0	0.8	0.70	10.0	<100	0.33	1.2	3.6	130	3	19.4	78	110
W99-2-128.0	Till	128.0	0.7	0.70	10.0	<100	0.30	1.1	3.9	129	3	19.9	76	<100
W99-2-129.0	Till	129.0	0.9	0.76	10.0	<100	0.33	1.2	3.6	128	3	19.7	78	110
W99-2-130.0	Till	130.0	<0.5	0.72	10.0	<100	0.33	1.3	4.0	132	3	18.7	84	130
W99-2-131.0	Till	131.0	0.9	0.68	10.0	<100	0.32	1.1	4.0	132	3	17.6	86	140
W99-2-132.0	Till	132.0	0.7	0.64	11.0	<100	0.31	1.1	3.8	131	3	17.4	80	100
W99-2-133.0	Till	133.0	0.7	0.68	10.0	<100	0.31	1.2	3.7	134	3	17.5	80	<100
W99-2-134.2	Till	134.2	0.9	0.76	11.0	<100	0.33	1.2	3.9	138	3	19.7	82	130
W99-2-135.0	Till	135.0	0.6	0.74	10.0	<100	0.32	1.1	4.0	132	3	19.3	78	<100
W99-2-136.0	Till	136.0	0.6	0.62	10.0	<100	0.31	1.0	3.1	135	3	20.0	86	<100
W99-2-137.0	Till	137.0	0.8	0.58	11.0	<100	0.34	1.1	3.3	144	3	21.7	92	130
* W99-2-137.0	Till	137.0	0.9	0.62	10.0	<100	0.36	1.1	3.4	144	3	23.3	90	120
W99-2-138.0	Silt & Clay	138.0	0.9	0.54	8.9	<100	0.30	1.0	3.4	113	2	20.0	72	<100
W99-2-139.0	Silt & Clay	139.0	0.6	0.54	8.7	<100	0.30	0.9	3.0	108	2	18.7	66	<100
W99-2-140.0	Silt	140.0	0.8	0.62	8.6	<100	0.32	1.0	3.2	116	2	18.4	72	<100
W99-2-141.0	Silt	141.0	0.8	0.54	10.0	<100	0.32	0.9	3.7	112	3	18.9	72	<100
W99-2-142.0	Silt	142.0	1.0	0.60	11.0	<100	0.35	1.1	3.5	134	3	21.4	86	<100
W99-2-143.0	Silt	143.0	0.9	0.56	12.0	<100	0.38	1.1	4.2	131	3	23.7	80	110
W99-2-144.0	Silt	144.0	0.8	0.54	9.0	<100	0.30	0.9	3.2	109	3	18.5	66	<100
W99-2-145.0	Silt	145.0	0.7	0.64	9.4	<100	0.34	1.3	3.0	152	3	22.6	92	<100
W99-2-146.0	Silt	146.0	0.7	0.56	11.0	<100	0.34	1.0	3.8	114	3	20.9	68	<100
W99-2-148.1	Silt & Clay	148.1	0.9	0.56	9.3	<100	0.31	1.0	3.6	106	3	20.4	76	<100
W99-2-149.0	Till & Clay	149.0	0.8	0.64	10.0	<100	0.31	1.1	3.1	112	3	20.0	70	<100
W99-2-149.9	Till & Clay	149.9	0.8	0.62	9.3	<100	0.32	1.1	2.9	109	3	20.3	74	<100
W99-2-151.0	Till & Clay	151.0	0.7	0.78	10.0	<100	0.32	1.1	3.3	137	3	21.7	78	<100
W99-2-152.0	Till & Clay	152.0	0.6	0.58	9.2	<100	0.31	1.0	3.6	112	3	18.2	74	<100

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-153.0	Till & Clay	153.0	10.8	<2	6.47	1.1	11.0	720	660	1.5	0.24	1.8	0.42	1.77	70	5.0	82
W99-2-154.0	Till & Clay	154.0	11.3	<2	6.00	1.1	8.0	880	810	1.3	0.21	1.4	0.42	2.05	70	4.5	94
W99-2-155.0	Till & Clay	155.0	11.7	<2	6.54	1.0	11.0	890	810	1.4	0.21	1.3	0.38	2.62	66	4.6	84
W99-2-156.0	Till	156.0	12.5	<2	6.36	1.0	11.0	740	700	1.1	0.25	1.7	0.46	1.46	75	5.2	83
W99-2-157.0	Till	157.0	10.3	<2	6.22	1.1	12.0	740	690	1.5	0.25	2.3	0.52	1.36	66	5.1	76
W99-2-158.0	Till	158.0	11.5	<2	6.14	1.1	11.0	780	720	1.5	0.26	1.9	0.42	1.74	76	4.9	79
W99-2-159.0	Mudstone	159.0	11.1	<2	8.70	1.3	11.0	830	800	1.9	0.31	1.2	0.36	1.72	60	6.9	110
W99-2-160.0	Mudstone	160.0	10.4	<2	7.68	1.1	9.2	900	860	1.9	0.31	1.2	0.38	2.14	73	5.7	96

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W99-2-153.0	Till & Clay	153.0	68	14	25	2	15.8	1.5	7	<50	4.00	35	18	33	0.3	1.03	445
W99-2-154.0	Till & Clay	154.0	61	11	23	2	13.5	1.3	12	<50	2.70	33	17	28	0.4	1.00	385
W99-2-155.0	Till & Clay	155.0	66	13	25	1	14.5	1.3	8	<50	3.00	33	17	29	0.4	1.18	430
W99-2-156.0	Till	156.0	66	13	24	2	14.9	1.4	10	<50	3.40	38	19	33	0.5	0.94	425
W99-2-157.0	Till	157.0	64	14	24	1	15.6	1.5	10	<50	3.40	37	19	34	0.4	0.90	400
W99-2-158.0	Till	158.0	66	13	25	1	15.4	1.4	9	<50	3.50	36	18	32	0.4	0.98	420
W99-2-159.0	Mudstone	159.0	93	14	34	2	20.8	1.5	4	<50	4.70	29	20	32	0.3	1.26	295
W99-2-160.0	Mudstone	160.0	84	15	30	2	18.0	1.5	6	<50	3.80	32	19	36	0.4	1.25	365

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W99-2-153.0	Till & Clay	153.0	70	2.0	31	10	750	1.77	84	5.7	13	<5	0.55	0.67	158	0.9	0.05
W99-2-154.0	Till & Clay	154.0	50	2.0	27	10	690	1.73	72	5.6	12	<5	0.50	0.80	174	1.1	0.05
W99-2-155.0	Till & Clay	155.0	50	2.0	31	10	670	1.72	74	5.3	12	<5	0.50	0.88	193	0.9	0.10
W99-2-156.0	Till	156.0	50	2.6	28	11	770	1.67	78	6.1	12	<5	0.60	0.69	161	1.2	0.05
W99-2-157.0	Till	157.0	50	3.0	31	12	750	1.62	81	6.1	12	<5	0.60	0.68	155	1.0	0.20
W99-2-158.0	Till	158.0	50	2.4	29	11	700	1.74	69	5.9	13	<5	0.60	0.72	158	1.1	0.05
W99-2-159.0	Mudstone	159.0	110	1.4	36	11	630	1.79	81	4.9	19	<5	0.60	0.53	149	0.9	0.10
W99-2-160.0	Mudstone	160.0	60	1.4	35	12	650	1.88	88	5.0	16	<5	0.65	0.62	163	1.1	0.15

Table A3-4: Geochemical analysis of samples from core hole WEPA99-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W99-2-153.0	Till & Clay	153.0	0.8	0.76	10.0	<100	0.29	1.1	3.4	136	3	20.7	80	<100
W99-2-154.0	Till & Clay	154.0	0.7	0.66	10.0	<100	0.31	1.1	4.3	114	3	19.4	86	<100
W99-2-155.0	Till & Clay	155.0	0.9	0.68	10.0	<100	0.32	1.1	4.1	121	3	19.7	80	<100
W99-2-156.0	Till	156.0	0.8	0.84	11.0	<100	0.32	1.3	3.7	135	3	22.2	78	<100
W99-2-157.0	Till	157.0	0.8	0.80	10.0	<100	0.32	1.2	4.6	135	3	23.2	78	<100
W99-2-158.0	Till	158.0	0.8	0.78	10.0	<100	0.34	1.3	3.5	133	3	20.5	80	120
W99-2-159.0	Mudstone	159.0	0.6	0.78	10.0	<100	0.36	1.4	2.8	172	3	19.0	110	110
W99-2-160.0	Mudstone	160.0	0.7	0.82	10.0	<100	0.35	1.4	3.2	166	2	20.6	104	<100

Notes: < denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* W99-2-40.0 denotes sample duplicate of W99-2-40.0

Table A3-5: Geochemical analysis of samples from core hole WR99-1

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
WR99-1-26.0	Till	26.0	10.8	<2	5.96	1.0	12.0	570	580	1.5	0.31	2.1	0.52	0.97	83	4.5	62
WR99-1-28.9	Till	28.9	11.3	<2	5.86	1.0	12.0	560	590	1.6	0.30	2.2	0.58	0.89	84	4.6	70
WR99-1-30.6	Till	30.6	10.1	<2	5.42	0.7	10.0	560	490	1.3	0.43	1.9	0.42	1.01	73	4.1	68
WR99-1-31.6	Till	31.6	10.5	<2	5.78	1.0	13.0	560	550	1.6	0.27	2.1	0.54	0.86	73	4.5	77
WR99-1-34.8	Till	34.8	12.0	<2	6.37	1.0	13.0	580	580	1.5	0.28	2.6	0.48	0.87	75	5.1	86
WR99-1-35.0	Till	35.0	9.9	<2	5.67	1.2	13.0	610	530	1.4	0.27	2.6	0.58	0.83	78	4.8	78
WR99-1-35.9	Till	35.9	11.4	<2	6.16	1.0	13.0	660	580	1.6	0.29	2.2	0.48	0.79	81	5.3	83
WR99-1-36.6	Till	36.6	10.3	<2	6.10	1.0	13.0	570	570	1.7	0.27	2.3	0.50	0.83	75	4.8	71
WR99-1-37.7	Till	37.7	10.5	<2	6.10	1.1	12.0	600	590	1.5	0.27	2.6	0.54	0.90	72	4.9	76
WR99-1-38.6	Till	38.6	10.2	4.0	6.38	1.1	13.0	560	680	1.5	0.29	2.1	0.52	0.91	77	4.9	89
WR99-1-39.9	Till	39.9	9.8	3.0	6.18	1.0	12.0	590	560	1.7	0.28	2.6	0.52	0.83	85	4.6	68
WR99-1-40.9	Till	40.9	12.3	<2	6.40	1.0	11.0	600	600	1.8	0.27	1.9	0.44	0.87	77	5.0	89
WR99-1-43.0	Silt & Clay	43.0	10.5	<2	6.42	0.7	9.1	630	670	1.3	0.21	1.8	0.36	1.75	69	4.1	68
WR99-1-46.5	Silt & Clay	46.5	8.9	6.0	6.91	1.0	12.0	600	660	1.9	0.30	2.0	0.46	0.89	76	4.9	74
* WR99-1-46.5	Silt & Clay	46.5	8.1	6.0	6.73	1.0	11.0	630	610	1.9	0.29	2.2	0.42	0.87	77	5.4	94
WR99-1-47.5	Till	47.5	11.4	6.0	6.28	1.3	13.0	600	660	1.8	0.30	2.7	0.64	0.82	76	4.9	75
WR99-1-48.6	Till	48.6	10.9	<2	6.22	1.3	14.0	640	590	1.6	0.28	2.9	0.64	0.82	79	5.1	94
WR99-1-49.8	Till	49.8	10.0	<2	6.19	1.3	13.0	620	610	1.6	0.29	2.5	0.62	0.79	75	5.3	89
WR99-1-51.0	Till	51.0	10.9	<2	6.13	1.3	14.0	590	620	1.7	0.30	2.8	0.62	0.80	78	4.9	77
WR99-1-52.3	Till	52.3	9.5	<2	6.04	1.2	14.0	590	550	2.0	0.29	2.4	0.64	0.78	81	5.3	85
WR99-1-53.2	Till	53.2	10.8	<2	5.96	1.2	13.0	600	550	2.1	0.27	2.4	0.64	0.82	73	4.5	69
WR99-1-54.3	Till	54.3	9.5	<2	6.06	1.2	14.0	580	570	1.6	0.29	3.1	0.62	0.79	81	5.4	72
WR99-1-58.2	Till	58.2	9.8	<2	5.94	1.1	11.0	580	580	1.5	0.26	2.2	0.58	0.80	84	4.5	81
WR99-1-59.0	Till	59.0	10.4	<2	5.52	1.1	12.0	560	520	1.5	0.25	2.2	0.58	0.78	88	4.7	87
WR99-1-60.0	Till	60.0	10.9	<2	5.49	1.1	13.0	590	580	1.4	0.25	2.4	0.54	0.80	82	4.4	83
WR99-1-61.0	Till	61.0	10.9	<2	5.31	1.0	12.0	560	510	1.6	0.24	2.3	0.50	0.76	79	4.3	84
WR99-1-62.0	Till	62.0	11.0	<2	5.73	1.0	12.0	560	530	1.3	0.26	2.3	0.54	0.82	75	4.1	68
WR99-1-63.0	Till	63.0	11.6	<2	5.54	1.0	12.0	550	480	1.3	0.26	2.1	0.54	0.76	78	4.3	68
WR99-1-65.4	Till	65.4	11.1	<2	5.63	0.9	11.0	610	560	1.4	0.26	2.1	0.42	0.92	77	4.6	62
WR99-1-66.4	Till	66.4	11.5	<2	5.77	0.9	12.0	580	570	1.7	0.26	2.2	0.48	0.90	73	4.3	79
WR99-1-68.0	Till	68.0	12.1	<2	5.42	0.9	11.0	560	560	1.4	0.25	2.0	0.48	0.88	69	3.8	78
WR99-1-69.5	Till	69.5	11.7	<2	5.74	0.8	11.0	630	560	1.6	0.24	1.4	0.26	0.97	68	4.5	70

Table A3-5: Geochemical analysis of samples from core hole WR99-1

Sample #	Material	Depth	IMS Cr* ppm	IMS Co ppm	IMS Cu ppm	NAA Eu ppm	IMS Ga ppm	IMS Ge ppm	NAA Hf ppm	NAA Ir ppb	NAA Fe %	NAA La ppm	IMS Pb ppm	IMS Li ppm	NAA Lu ppm	IMS Mg %	IMS Mn ppm
WR99-1-26.0	Till	26.0	57	14.0	22	2	15.3	1.5	13	<50	2.8	42	17.5	40	0.3	0.72	480
WR99-1-28.9	Till	28.9	55	13.8	24	2	14.9	1.5	12	<50	3.0	46	21.0	38	0.4	0.68	465
WR99-1-30.6	Till	30.6	52	13.6	20	2	15.5	1.5	10	<50	2.9	44	16.5	41	0.3	0.75	420
WR99-1-31.6	Till	31.6	55	14.2	24	2	14.5	1.6	11	<50	2.9	44	16.0	39	0.4	0.69	495
WR99-1-34.8	Till	34.8	63	13.8	26	2	15.5	1.6	10	<50	3.3	45	15.5	41	0.4	0.79	425
WR99-1-35.0	Till	35.0	55	14.0	25	1	14.2	1.5	11	<50	3.0	46	15.0	38	0.4	0.67	500
WR99-1-35.9	Till	35.9	59	14.2	25	1	15.6	1.6	10	<50	3.2	46	15.0	42	0.3	0.73	410
WR99-1-36.6	Till	36.6	59	13.4	25	2	15.0	1.6	10	<50	3.1	44	15.0	40	0.3	0.73	425
WR99-1-37.7	Till	37.7	59	13.8	25	1	14.8	1.5	11	<50	2.9	44	15.5	40	0.4	0.71	470
WR99-1-38.6	Till	38.6	61	14.6	26	1	15.3	1.6	10	<50	3.2	45	15.5	41	0.3	0.81	455
WR99-1-39.9	Till	39.9	62	14.4	26	<1	15.4	1.6	10	<50	3.2	43	15.0	42	0.3	0.73	440
WR99-1-40.9	Till	40.9	64	14.0	27	2	15.6	1.5	9	<50	3.3	46	15.0	40	0.3	0.78	435
WR99-1-43.0	Silt & Clay	43.0	59	12.6	23	1	14.2	1.3	6	<50	2.9	38	13.5	36	0.3	1.28	540
WR99-1-46.5	Silt & Clay	46.5	69	15.2	27	2	17.8	1.6	8	<50	3.2	44	16.5	49	0.3	0.91	460
* WR99-1-46.5	Silt & Clay	46.5	67	14.4	28	1	17.2	1.6	8	<50	3.3	43	15.5	48	0.3	0.90	440
WR99-1-47.5	Till	47.5	62	15.4	28	<1	15.2	1.6	10	<50	2.9	45	15.5	42	0.4	0.70	465
WR99-1-48.6	Till	48.6	63	14.2	27	2	14.8	1.6	10	<50	3.1	44	15.0	42	0.4	0.70	465
WR99-1-49.8	Till	49.8	61	14.6	27	2	14.9	1.5	10	<50	3.0	44	17.0	42	0.4	0.68	455
WR99-1-51.0	Till	51.0	62	15.0	26	2	15.8	1.6	10	<50	2.9	44	16.5	44	0.3	0.68	450
WR99-1-52.3	Till	52.3	61	14.8	26	2	15.6	1.6	10	<50	3.1	45	17.0	43	0.4	0.66	450
WR99-1-53.2	Till	53.2	58	14.0	26	2	14.6	1.5	10	<50	2.9	46	15.5	40	0.4	0.66	450
WR99-1-54.3	Till	54.3	58	14.8	26	<1	15.2	1.6	10	<50	3.1	45	15.5	41	0.4	0.65	450
WR99-1-58.2	Till	58.2	57	14.2	26	<1	14.7	1.6	11	<50	3.0	44	15.0	42	0.3	0.66	450
WR99-1-59.0	Till	59.0	53	13.6	24	2	13.8	1.5	14	<50	2.9	43	15.0	38	0.3	0.63	445
WR99-1-60.0	Till	60.0	53	13.0	24	2	13.5	1.5	12	<50	3.0	46	14.0	37	0.4	0.64	465
WR99-1-61.0	Till	61.0	54	12.8	26	2	13.2	1.5	12	<50	2.8	44	14.0	37	0.4	0.60	460
WR99-1-62.0	Till	62.0	51	13.4	23	1	13.6	1.5	11	<50	2.8	43	14.5	38	0.4	0.68	465
WR99-1-63.0	Till	63.0	51	14.0	24	2	14.2	1.6	11	<50	2.8	43	15.0	40	0.4	0.62	480
WR99-1-65.4	Till	65.4	53	13.6	22	1	15.1	1.6	11	<50	3.0	43	15.0	42	0.4	0.72	435
WR99-1-66.4	Till	66.4	57	13.6	24	2	14.9	1.5	10	<50	2.9	42	15.5	41	0.4	0.72	445
WR99-1-68.0	Till	68.0	53	12.8	23	2	13.6	1.5	11	<50	2.8	40	14.5	38	0.4	0.70	445
WR99-1-69.5	Till	69.5	57	12.2	22	2	14.2	1.5	10	<50	3.0	41	14.0	42	0.3	0.77	370

Table A3-5: Geochemical analysis of samples from core hole WR99-1

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
WR99-1-26.0	Till	26.0	50	3.4	33.2	13.6	760	1.65	93.6	6.3	11.0	<5	0.15	0.49	160	1.2	0.05
WR99-1-28.9	Till	28.9	70	3.8	31.2	13.2	740	1.60	93.2	6.7	12.0	<5	0.10	0.53	159	1.2	0.05
WR99-1-30.6	Till	30.6	70	2.8	31.4	13.4	610	1.53	93.8	6.2	11.0	<5	0.10	0.58	157	0.9	0.05
WR99-1-31.6	Till	31.6	70	3.6	31.8	10.4	730	1.41	85.6	6.6	11.0	<5	0.05	0.53	156	1.2	0.05
WR99-1-34.8	Till	34.8	100	3.6	32.6	10.8	760	1.47	88.6	6.5	13.0	<5	0.05	0.55	163	1.1	0.05
WR99-1-35.0	Till	35.0	50	3.8	33.0	10.8	720	1.31	78.4	6.7	12.0	<5	0.05	0.55	153	1.1	0.05
WR99-1-35.9	Till	35.9	40	3.8	33.6	11.2	720	1.44	90.4	6.6	13.0	<5	0.10	0.55	157	1.1	0.05
WR99-1-36.6	Till	36.6	30	3.6	31.6	11.4	740	1.41	85.0	6.5	12.0	<5	0.10	0.54	156	1.2	0.05
WR99-1-37.7	Till	37.7	40	4.0	32.4	11.6	740	1.58	90.0	6.4	12.0	<5	0.15	0.54	155	1.2	0.05
WR99-1-38.6	Till	38.6	50	4.0	37.2	11.8	790	1.48	94.8	6.7	13.0	<5	0.05	0.57	159	1.1	0.05
WR99-1-39.9	Till	39.9	40	4.0	34.2	11.8	750	1.39	88.4	6.5	13.0	<5	0.15	0.55	152	1.2	0.05
WR99-1-40.9	Till	40.9	40	3.4	32.4	11.6	750	1.47	87.0	6.5	13.0	<5	0.05	0.56	150	0.9	0.05
WR99-1-43.0	Silt & Clay	43.0	40	1.4	31.0	10.0	710	1.91	93.0	5.5	11.0	<5	<0.05	0.89	179	1.1	0.05
WR99-1-46.5	Silt & Clay	46.5	60	2.6	37.8	13.4	720	1.88	114.0	6.3	13.0	<5	0.10	0.63	166	1.3	0.05
* WR99-1-46.5	Silt & Clay	46.5	50	2.4	35.6	12.2	720	1.63	100.0	6.1	14.0	<5	0.10	0.65	159	1.1	0.05
WR99-1-47.5	Till	47.5	50	4.2	36.8	11.8	790	1.48	92.4	6.5	12.0	<5	0.05	0.50	151	1.2	0.10
WR99-1-48.6	Till	48.6	60	4.2	34.6	11.2	810	1.46	88.2	6.4	13.0	<5	0.10	0.48	154	1.3	0.05
WR99-1-49.8	Till	49.8	50	4.2	35.4	11.2	770	1.39	86.6	6.5	12.0	<5	0.15	0.47	152	1.4	0.05
WR99-1-51.0	Till	51.0	50	4.4	36.6	12.4	790	1.53	97.0	6.5	12.0	<5	0.20	0.50	159	1.3	0.05
WR99-1-52.3	Till	52.3	50	4.4	35.0	11.8	800	1.36	88.4	6.7	12.0	<5	0.10	0.50	165	1.2	0.10
WR99-1-53.2	Till	53.2	40	4.4	33.8	11.0	780	1.37	85.2	6.6	12.0	<5	0.10	0.49	159	1.2	0.05
WR99-1-54.3	Till	54.3	60	4.6	45.4	11.4	770	1.43	91.0	6.6	13.0	<5	0.05	0.52	156	1.2	0.05
WR99-1-58.2	Till	58.2	50	4.2	33.8	11.6	780	1.40	88.8	6.3	12.0	<5	0.05	0.48	157	1.1	0.05
WR99-1-59.0	Till	59.0	40	4.0	32.0	11.2	740	1.33	80.4	6.5	10.0	<5	<0.05	0.48	157	1.0	0.05
WR99-1-60.0	Till	60.0	50	4.0	30.2	11.2	750	1.36	79.8	6.7	12.0	<5	0.05	0.53	157	1.2	0.05
WR99-1-61.0	Till	61.0	40	3.6	32.0	10.2	680	1.30	77.2	6.5	11.0	<5	<0.05	0.55	143	1.3	0.05
WR99-1-62.0	Till	62.0	40	3.4	30.0	10.8	790	1.42	88.4	6.5	11.0	<5	0.10	0.51	153	1.1	0.05
WR99-1-63.0	Till	63.0	40	3.8	32.2	11.2	690	1.40	83.8	6.5	11.0	<5	0.15	0.52	147	1.2	0.05
WR99-1-65.4	Till	65.4	50	3.0	30.6	11.2	730	1.45	87.8	6.4	11.0	<5	0.05	0.57	154	1.2	0.05
WR99-1-66.4	Till	66.4	40	3.0	32.4	12.0	750	1.42	88.2	6.3	11.0	<5	0.15	0.56	157	1.2	0.05
WR99-1-68.0	Till	68.0	40	3.0	29.8	10.6	740	1.40	81.4	6.1	11.0	<5	0.80	0.60	150	1.4	0.05
WR99-1-69.5	Till	69.5	50	2.0	29.2	9.8	680	1.43	85.0	6.0	12.0	<5	<0.05	0.61	141	1.1	0.05

Table A3-5: Geochemical analysis of samples from core hole WR99-1

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
WR99-1-26.0	Till	26.0	0.7	0.74	11.0	<100	0.34	1.3	3.6	114	2	23.7	82	380
WR99-1-28.9	Till	28.9	0.8	0.74	11.0	<100	0.34	1.3	3.8	114	3	23.4	82	<200
WR99-1-30.6	Till	30.6	1.0	0.64	11.0	<100	0.29	1.3	3.5	96	2	21.9	70	290
WR99-1-31.6	Till	31.6	0.7	0.70	11.0	<100	0.27	1.3	3.7	117	3	21.5	80	<200
WR99-1-34.8	Till	34.8	0.7	0.66	11.0	<100	0.29	1.0	3.7	130	3	20.6	90	280
WR99-1-35.0	Till	35.0	0.8	0.68	11.0	<100	0.27	1.1	3.9	123	3	21.2	86	350
WR99-1-35.9	Till	35.9	1.0	0.66	11.0	<100	0.28	1.0	3.6	128	3	21.3	92	450
WR99-1-36.6	Till	36.6	0.9	0.66	11.0	<100	0.29	1.0	3.5	128	3	20.9	90	260
WR99-1-37.7	Till	37.7	0.8	0.72	10.0	<100	0.30	1.0	3.8	129	2	22.1	88	290
WR99-1-38.6	Till	38.6	0.9	0.68	11.0	<100	0.30	1.1	3.4	130	2	21.8	94	<200
WR99-1-39.9	Till	39.9	0.9	0.70	11.0	<100	0.30	1.0	3.7	129	3	21.9	90	310
WR99-1-40.9	Till	40.9	1.0	0.64	11.0	<100	0.30	1.2	3.5	132	3	20.5	92	490
WR99-1-43.0	Silt & Clay	43.0	0.9	0.58	8.8	<100	0.28	0.8	2.7	107	2	18.4	76	260
WR99-1-46.5	Silt & Clay	46.5	0.8	0.72	11.0	<100	0.33	1.2	3.3	141	2	21.8	94	<200
* WR99-1-46.5	Silt & Clay	46.5	0.9	0.64	10.0	<100	0.32	1.0	3.3	137	3	20.4	94	420
WR99-1-47.5	Till	47.5	1.0	0.80	11.0	<100	0.31	1.2	4.7	149	3	22.1	104	<200
WR99-1-48.6	Till	48.6	0.7	0.74	11.0	<100	0.30	1.0	4.3	152	3	21.2	100	360
WR99-1-49.8	Till	49.8	1.0	0.74	11.0	<100	0.30	1.1	4.0	147	3	21.4	98	360
WR99-1-51.0	Till	51.0	0.9	0.80	11.0	<100	0.30	1.2	4.3	145	3	23.3	98	360
WR99-1-52.3	Till	52.3	0.9	0.76	11.0	<100	0.29	1.1	4.1	138	2	23.0	94	460
WR99-1-53.2	Till	53.2	1.0	0.70	11.0	<100	0.28	1.1	4.3	131	3	22.0	94	260
WR99-1-54.3	Till	54.3	0.9	0.72	11.0	<100	0.28	1.1	4.2	130	3	22.2	94	<200
WR99-1-58.2	Till	58.2	0.9	0.72	11.0	<100	0.29	1.1	3.9	132	2	22.3	92	530
WR99-1-59.0	Till	59.0	0.9	0.68	11.0	<100	0.28	1.0	4.2	118	2	21.6	86	430
WR99-1-60.0	Till	60.0	0.7	0.68	11.0	<100	0.29	1.0	4.1	119	2	21.8	88	<200
WR99-1-61.0	Till	61.0	0.7	0.62	11.0	<100	0.26	0.9	3.8	102	3	20.5	82	530
WR99-1-62.0	Till	62.0	0.7	0.66	11.0	<100	0.27	0.9	3.7	104	3	21.8	80	420
WR99-1-63.0	Till	63.0	1.0	0.68	10.0	<100	0.28	1.2	3.8	107	3	21.7	84	410
WR99-1-65.4	Till	65.4	0.7	0.62	11.0	<100	0.27	1.1	3.5	111	3	21.7	80	300
WR99-1-66.4	Till	66.4	1.0	0.64	11.0	<100	0.28	1.0	3.5	113	3	22.1	86	360
WR99-1-68.0	Till	68.0	0.8	0.62	10.0	<100	0.26	1.0	3.4	108	2	20.7	82	370
WR99-1-69.5	Till	69.5	0.9	0.54	10.0	<100	0.26	1.0	3.1	107	2	19.1	72	440

Table A3-5: Geochemical analysis of samples from core hole WR99-1

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
WR99-1-71.2	Till	71.2	13.0	<2	5.94	0.8	10.0	520	530	1.6	0.25	1.4	0.28	0.98	71	4.7	75
* WR99-1-71.2	Till	71.2	11.7	<2	5.96	0.8	10.0	540	510	1.6	0.23	1.6	0.30	0.99	74	4.9	68
WR99-1-72.5	Till	72.5	11.8	<2	5.84	0.7	10.0	550	510	1.5	0.23	1.3	0.28	0.95	77	4.8	76
WR99-1-73.6	Till	73.6	10.6	<2	5.85	0.8	10.0	590	550	1.7	0.26	1.6	0.28	0.81	74	5.1	78
WR99-1-74.5	Till	74.5	11.0	5.0	6.03	0.8	11.0	590	540	1.6	0.26	2.2	0.34	0.95	74	5.2	74
WR99-1-80.6	Till & Clay	80.6	10.8	<2	6.09	0.7	8.1	610	600	1.5	0.25	1.3	0.34	1.11	75	4.4	69
WR99-1-86.0	Clay	86.0	8.7	<2	5.11	0.6	12.0	520	90	1.3	0.20	7.5	0.26	4.25	53	4.1	61
WR99-1-89.5	Sand	89.5	10.5	4.0	4.76	0.4	3.5	450	400	1.4	0.19	1.1	0.12	0.85	63	2.9	58
WR99-1-93.0	Till	93.0	11.6	<2	6.06	0.7	7.8	480	460	1.4	0.23	1.5	0.22	1.01	80	4.8	85
WR99-1-94.0	Till	94.0	11.1	7.0	6.58	0.8	9.4	500	560	1.8	0.27	1.6	0.26	0.93	71	5.4	76
WR99-1-95.0	Till	95.0	14.0	<2	6.43	0.8	10.0	500	460	1.8	0.26	1.4	0.24	0.98	74	5.1	68
WR99-1-96.0	Silt	96.0	12.1	<2	6.94	0.8	11.0	590	650	1.7	0.30	1.7	0.26	0.85	82	5.7	82
WR99-1-98.0	Silt	98.0	15.4	<2	5.19	0.8	10.0	650	560	1.3	0.22	1.0	0.32	0.94	64	3.7	63
WR99-1-101.8	Clay	101.8	8.4	3.0	6.94	0.9	13.0	670	740	2.1	0.29	2.0	0.42	0.81	72	6.1	85
WR99-1-110.0	Clay	110.0	11.0	<2	7.72	0.8	10.0	510	500	1.9	0.34	1.3	0.36	0.82	78	6.6	92
WR99-1-118.0	Silt	118.0	12.4	<2	6.03	1.0	5.7	710	630	1.6	0.24	1.6	0.40	1.17	70	4.9	82
WR99-1-122.0	Silt	122.0	12.9	<2	4.92	0.8	8.6	600	520	1.2	0.18	1.2	0.30	1.19	64	3.0	65
WR99-1-139.0	Sand	139.0	14.3	<2	4.28	0.6	5.3	580	530	1.0	0.14	0.7	0.16	1.13	72	2.3	64
WR99-1-146.0	Clay	146.0	11.8	<2	6.25	0.8	7.1	710	670	1.4	0.23	0.8	0.24	1.06	69	4.0	79
WR99-1-238.7	Shale	238.7	10.0	5.0	6.43	0.5	12.0	490	470	1.7	0.30	0.8	0.12	0.54	75	6.8	68
WR99-1-242.5	Shale	242.5	12.5	4.0	6.64	0.5	25.0	510	310	2.1	0.33	1.1	0.16	0.55	90	6.6	78
WR99-1-245.8	Shale	245.8	12.3	<2	7.43	0.5	15.0	610	580	2.0	0.42	1.5	0.14	0.50	76	10.0	82
WR99-1-249.5	Shale	249.5	10.9	5.0	7.94	0.5	12.0	710	660	2.0	0.33	1.5	0.16	0.54	72	10.0	83

Table A3-5: Geochemical analysis of samples from core hole WR99-1

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
WR99-1-71.2	Till	71.2	57	13.4	22	1	15.1	1.6	10	<50	3.1	43	15.0	45	0.3	0.77	405
* WR99-1-71.2	Till	71.2	58	12.8	22	2	14.7	1.5	10	<50	3.0	40	13.5	42	0.4	0.75	390
WR99-1-72.5	Till	72.5	56	12.0	22	1	14.1	1.5	10	<50	2.9	42	13.5	39	0.3	0.74	375
WR99-1-73.6	Till	73.6	56	12.4	22	1	14.8	1.6	9	<50	2.9	42	14.5	40	0.3	0.69	340
WR99-1-74.5	Till	74.5	57	13.4	22	2	14.8	1.5	11	<50	3.0	45	15.0	40	0.4	0.74	380
WR99-1-80.6	Till & Clay	80.6	59	12.6	23	2	15.4	1.5	8	<50	3.3	42	14.5	43	0.3	0.93	520
WR99-1-86.0	Clay	86.0	50	11.0	20	1	12.4	1.1	6	<50	4.3	30	12.5	35	0.2	0.67	1510
WR99-1-89.5	Sand	89.5	44	8.8	16	1	12.1	1.3	10	<50	2.1	35	13.5	39	0.3	0.65	290
WR99-1-93.0	Till	93.0	59	12.4	22	1	15.5	1.5	9	<50	2.9	43	14.5	45	0.3	0.80	395
WR99-1-94.0	Till	94.0	65	13.4	24	2	16.4	1.6	8	<50	3.1	42	15.5	48	0.3	0.84	405
WR99-1-95.0	Till	95.0	63	13.8	23	<1	16.6	1.6	8	<50	3.1	42	15.5	46	0.3	0.83	400
WR99-1-96.0	Silt	96.0	69	14.0	24	<1	17.7	1.7	7	<50	3.3	42	15.0	51	0.3	0.85	380
WR99-1-98.0	Silt	98.0	49	11.6	20	1	13.2	1.5	10	<50	2.7	35	13.5	35	0.3	0.73	360
WR99-1-101.8	Clay	101.8	75	15.2	27	<1	17.8	1.8	6	<50	3.9	38	15.5	52	0.2	0.88	420
WR99-1-110.0	Clay	110.0	74	15.6	27	3	19.5	1.7	6	<50	4.3	42	17.0	51	0.3	0.93	1215
WR99-1-118.0	Silt	118.0	57	10.4	26	2	14.5	1.4	8	<50	2.9	41	14.0	38	0.3	0.83	380
WR99-1-122.0	Silt	122.0	45	9.4	17	1	11.4	1.4	12	<50	2.5	39	11.5	29	0.3	0.72	475
WR99-1-139.0	Sand	139.0	35	8.2	13	1	9.6	1.2	17	<50	2.0	41	11.5	21	0.4	0.55	560
WR99-1-146.0	Clay	146.0	56	12.0	22	1	15.2	1.5	8	<50	2.9	41	14.0	35	0.3	0.74	475
WR99-1-238.7	Shale	238.7	60	12.2	19	2	16.3	1.7	9	<50	2.7	46	16.5	39	0.4	0.77	445
WR99-1-242.5	Shale	242.5	60	14.2	23	2	17.1	1.7	13	<50	3.4	50	19.0	50	0.5	0.78	280
WR99-1-245.8	Shale	245.8	73	16.0	28	2	19.5	1.8	5	<50	4.0	46	20.5	50	0.4	0.87	350
WR99-1-249.5	Shale	249.5	72	14.4	25	1	18.7	1.6	5	<50	3.9	46	17.0	47	0.3	0.93	230

Table A3-5: Geochemical analysis of samples from core hole WR99-1

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
WR99-1-71.2	Till	71.2	40	2.0	31.6	11.2	630	1.46	88.4	6.1	12.0	<5	0.05	0.57	143	1.1	0.05
* WR99-1-71.2	Till	71.2	40	2.0	29.8	10.6	650	1.46	86.2	6.1	12.0	<5	0.05	0.57	139	0.9	0.05
WR99-1-72.5	Till	72.5	40	2.0	27.6	10.4	660	1.49	83.8	6.1	12.0	<5	<0.05	0.57	137	1.2	0.05
WR99-1-73.6	Till	73.6	40	2.4	29.6	11.2	660	1.42	87.8	6.3	12.0	<5	0.05	0.54	145	1.1	0.05
WR99-1-74.5	Till	74.5	40	2.2	29.6	11.4	700	1.47	86.2	6.5	12.0	<5	<0.05	0.57	147	1.0	<0.05
WR99-1-80.6	Till & Clay	80.6	40	1.6	31.2	11.0	700	1.56	90.4	6.1	12.0	<5	<0.05	0.69	150	1.2	<0.05
WR99-1-86.0	Clay	86.0	40	1.6	27.4	7.8	770	1.32	73.6	4.6	10.0	<5	<0.05	0.57	202	1.0	0.05
WR99-1-89.5	Sand	89.5	40	1.0	21.6	8.6	520	1.29	69.4	4.9	9.2	<5	0.20	0.62	140	0.9	<0.05
WR99-1-93.0	Till	93.0	30	1.6	29.4	10.6	620	1.47	88.2	6.1	12.0	<5	0.05	0.63	140	1.1	0.05
WR99-1-94.0	Till	94.0	40	1.6	31.2	11.6	700	1.61	97.2	6.1	13.0	<5	0.05	0.60	146	0.9	0.05
WR99-1-95.0	Till	95.0	30	1.8	31.6	11.8	710	1.69	96.8	6.0	12.0	<5	<0.05	0.58	144	1.3	0.05
WR99-1-96.0	Silt	96.0	40	2.0	34.2	11.6	730	1.63	102.0	5.9	13.0	<5	0.05	0.55	146	1.1	0.05
WR99-1-98.0	Silt	98.0	50	1.6	28.2	10.0	710	1.46	80.4	5.3	11.0	<5	0.05	0.78	146	1.1	0.05
WR99-1-101.8	Clay	101.8	80	1.8	37.2	11.4	740	1.69	106.0	5.6	14.0	<5	0.05	0.59	137	1.4	0.05
WR99-1-110.0	Clay	110.0	50	1.8	34.2	11.6	660	1.64	109.0	6.2	14.0	<5	0.05	0.45	142	1.2	0.05
WR99-1-118.0	Silt	118.0	40	3.2	28.0	9.6	560	1.48	84.0	6.0	12.0	<5	<0.05	0.70	147	1.0	0.05
WR99-1-122.0	Silt	122.0	40	3.4	22.6	8.8	580	1.33	67.8	5.9	10.0	<5	<0.05	0.84	146	1.1	<0.05
WR99-1-139.0	Sand	139.0	10	0.8	17.0	8.0	480	1.27	57.0	6.2	8.3	<5	0.10	0.86	146	1.0	<0.05
WR99-1-146.0	Clay	146.0	30	1.6	28.6	10.6	490	1.45	83.0	6.0	12.0	<5	0.05	0.75	151	0.9	0.05
WR99-1-238.7	Shale	238.7	30	3.2	26.6	14.4	670	1.42	96.0	6.8	12.0	<5	0.10	0.42	154	1.2	0.05
WR99-1-242.5	Shale	242.5	50	2.0	27.4	14.8	770	0.80	52.0	7.6	13.0	<5	0.15	0.46	185	1.4	0.15
WR99-1-245.8	Shale	245.8	50	2.0	32.8	14.0	470	1.60	119.0	6.4	15.0	<5	0.15	0.53	249	1.1	0.05
WR99-1-249.5	Shale	249.5	30	1.6	30.8	12.4	530	1.55	104.5	6.3	16.0	<5	0.05	0.64	306	1.1	0.05

Table A3-5: Geochemical analysis of samples from core hole WR99-1

Sample #	Material	Depth	NAA Tb ppm	IMS Tl ppm	NAA Th ppm	NAA Sn ppm	IMS Ti %	IMS W ppm	NAA U ppm	IMS V ppm	NAA Yb ppm	IMS Y ppm	IMS Zn ppm	NAA Zr ppm
WR99-1-71.2	Till	71.2	0.8	0.56	11.0	<100	0.28	1.4	3.4	110	3	20.3	78	250
* WR99-1-71.2	Till	71.2	0.9	0.50	10.0	<100	0.27	1.1	3.3	109	3	19.3	80	240
WR99-1-72.5	Till	72.5	0.8	0.48	10.0	100	0.28	1.1	3.2	106	2	19.1	74	280
WR99-1-73.6	Till	73.6	0.8	0.56	11.0	<100	0.28	1.5	3.2	111	3	20.1	72	250
WR99-1-74.5	Till	74.5	0.8	0.56	11.0	<100	0.29	1.1	3.6	108	3	20.9	82	370
WR99-1-80.6	Till & Clay	80.6	0.9	0.54	11.0	<100	0.29	1.1	2.6	108	2	19.2	74	340
WR99-1-86.0	Clay	86.0	0.6	0.44	7.8	<100	0.21	0.8	2.6	91	<2	15.0	76	<200
WR99-1-89.5	Sand	89.5	0.6	0.36	9.2	<100	0.22	0.8	2.1	73	<2	15.6	56	270
WR99-1-93.0	Till	93.0	0.9	0.50	11.0	<100	0.27	0.9	2.9	110	2	19.2	74	<200
WR99-1-94.0	Till	94.0	0.7	0.56	11.0	<100	0.30	1.2	3.9	124	2	19.8	86	400
WR99-1-95.0	Till	95.0	0.8	0.56	11.0	<100	0.30	1.2	3.2	119	2	20.2	80	320
WR99-1-96.0	Silt	96.0	0.8	0.58	11.0	<100	0.30	1.1	3.0	132	2	20.3	84	<200
WR99-1-98.0	Silt	98.0	0.6	0.56	8.9	<100	0.25	0.9	3.0	102	2	19.2	74	350
WR99-1-101.8	Clay	101.8	1.0	0.64	11.0	<100	0.29	1.1	3.1	148	2	19.4	102	<200
WR99-1-110.0	Clay	110.0	0.8	0.64	12.0	<100	0.31	1.1	3.5	152	<2	21.8	96	260
WR99-1-118.0	Silt	118.0	0.8	0.64	10.0	<100	0.26	0.9	3.1	121	2	19.4	78	240
WR99-1-122.0	Silt	122.0	0.7	0.50	10.0	<100	0.25	0.8	3.6	86	2	18.2	58	220
WR99-1-139.0	Sand	139.0	0.9	0.36	11.0	<100	0.25	0.7	3.1	63	3	17.3	38	560
WR99-1-146.0	Clay	146.0	0.6	0.56	11.0	<100	0.29	1.1	3.0	109	2	19.2	70	450
WR99-1-238.7	Shale	238.7	0.8	0.52	12.0	<100	0.28	1.5	3.2	117	3	25.1	88	410
WR99-1-242.5	Shale	242.5	0.9	0.52	12.0	<100	0.31	1.4	3.8	115	3	30.3	116	420
WR99-1-245.8	Shale	245.8	0.8	0.54	13.0	<100	0.28	1.5	3.3	137	2	23.7	120	<200
WR99-1-249.5	Shale	249.5	1.0	0.50	13.0	<100	0.28	1.2	3.3	139	2	20.5	106	<200

Notes:
< denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* WR99-1-46.5 denotes sample duplicate of WR99-1-46.5

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-1-2.9	Till	2.90	5.0	<2	5.59	0.9	9.5	820.0	434.0	1.20	0.50	2.8	0.22	3.46	120.0	4.9	79.0
W00-1-4.25	Till	4.25	5.0	<4	5.34	0.6	5.4	500.0	442.0	1.05	0.45	2.2	0.24	3.65	66.0	2.7	51.0
W00-1-6.0	Till	6.00	7.7	<2	5.22	0.5	5.9	460.0	443.5	1.00	0.46	1.8	0.30	3.78	53.0	2.9	55.0
W00-1-7.0	Till	7.00	7.8	<2	5.21	0.6	5.1	520.0	438.5	1.20	0.47	1.6	0.48	3.45	66.0	2.8	60.0
W00-1-9.3	Till	9.30	7.9	<2	5.23	0.5	4.5	500.0	428.5	1.10	0.43	1.7	0.30	3.52	57.0	2.6	46.0
* W00-1-9.3	Till	9.30	6.8	<2	5.48	0.5	4.9	460.0	421.5	1.05	0.43	1.7	0.24	3.50	65.0	2.7	53.0
W00-1-10.35	Till	10.35	8.7	<2	5.32	0.5	5.9	500.0	432.5	1.10	0.46	1.9	0.36	3.19	69.0	2.8	64.0
W00-1-12.0	Till	12.00	8.3	<2	5.59	0.5	4.8	500.0	445.0	1.10	0.45	1.8	0.32	3.58	70.0	2.7	60.0
W00-1-13.4	Till	13.40	9.7	<2	4.91	0.5	4.7	510.0	418.0	1.05	0.43	2.0	0.32	3.65	65.0	2.9	56.0
W00-1-14.65	Till	14.65	5.7	<2	5.49	0.5	5.4	540.0	431.5	1.00	0.53	1.8	0.40	3.34	67.0	3.2	63.0
W00-1-22.95	Till	22.95	8.3	5.0	5.54	0.6	13.0	600.0	440.5	1.30	0.45	1.3	0.24	1.27	84.0	3.2	68.0
W00-1-24.45	Till	24.45	8.4	<2	6.02	0.5	7.4	550.0	453.0	1.35	0.47	1.3	0.20	1.35	84.0	3.8	65.0
W00-1-25.5	Till	25.50	8.9	<2	6.01	0.6	8.4	600.0	464.5	1.25	0.47	1.5	0.26	1.38	77.0	4.0	63.0
W00-1-27.3	Till	27.30	10.5	<2	5.90	0.6	7.6	610.0	462.5	1.30	0.47	1.5	0.30	1.34	86.0	3.9	70.0
W00-1-28.5	Till	28.50	5.8	<2	5.89	0.5	6.9	570.0	446.0	1.25	0.46	1.4	0.26	1.34	81.0	3.8	77.0
W00-1-29.5	Till	29.50	10.8	<2	5.53	0.6	7.4	530.0	426.0	1.30	0.44	1.3	0.22	1.39	76.0	3.7	71.0
W00-1-32.2	Till	32.20	5.2	<2	6.08	0.5	8.0	610.0	428.5	1.30	0.44	2.2	0.22	1.58	86.0	4.2	77.0
W00-1-34.0	Till	34.00	5.7	<2	5.62	0.5	7.4	530.0	432.0	1.30	0.45	1.2	0.22	1.64	87.0	3.3	73.0
W00-1-34.9	Till	34.90	5.2	<2	6.40	0.5	5.9	580.0	475.0	1.50	0.48	1.5	0.30	1.45	94.0	3.7	68.0
W00-1-45.4	Till	45.40	6.3	<2	5.48	0.5	8.8	550.0	418.0	1.25	0.48	1.4	0.20	1.41	79.0	4.2	62.0
W00-1-46.4	Till	46.40	5.1	<2	5.73	0.5	6.7	580.0	435.0	1.25	0.45	1.5	0.20	1.33	73.0	3.1	65.0
W00-1-82.05	Till	82.05	7.2	<2	6.05	0.7	7.3	520.0	488.5	1.30	0.49	1.6	0.20	1.23	90.0	4.0	74.0
W00-1-83.1	Till	83.10	6.4	7.0	6.00	0.6	6.8	560.0	475.0	1.15	0.46	1.4	0.18	1.17	78.0	4.0	79.0
W00-1-84.1	Till	84.10	8.3	<2	5.83	0.6	7.9	590.0	481.0	1.20	0.47	1.5	0.24	1.30	79.0	3.7	63.0
* W00-1-84.1	Till	84.10	5.9	<2	5.93	0.6	7.8	560.0	480.5	1.45	0.50	1.3	0.24	1.28	72.0	3.8	61.0
W00-1-85.2	Till	85.20	7.3	3.0	6.01	0.6	7.9	600.0	465.0	1.30	0.51	1.2	0.22	1.20	73.0	4.5	83.0
W00-1-86.2	Till	86.20	6.4	5.0	5.96	0.6	8.2	640.0	484.0	1.35	0.47	1.5	0.22	1.20	76.0	3.7	67.0
W00-1-87.2	Till	87.20	6.8	5.0	5.83	0.6	7.2	590.0	470.5	1.15	0.44	1.2	0.26	1.24	73.0	4.1	77.0
W00-1-89.4	Till	89.40	7.3	<2	6.14	0.6	7.9	580.0	485.0	1.35	0.50	1.3	0.24	1.20	75.0	4.1	69.0
W00-1-90.4	Till	90.40	7.4	<2	5.83	0.6	7.0	600.0	479.0	1.20	0.45	1.2	0.38	1.27	76.0	3.7	77.0
W00-1-91.4	Till	91.40	6.1	20.0	5.81	0.6	7.6	590.0	481.0	1.35	0.45	1.3	0.28	1.29	74.0	3.3	54.0
W00-1-92.35	Till	92.35	5.4	<2	5.79	0.6	7.7	580.0	471.0	1.30	0.45	1.5	0.22	1.25	74.0	4.3	76.0

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-1-2.9	Till	2.90	56.0	Co	26.8	<1	11.85	1.20	13.0	<50	4.2	48.0	15.0	30.6	0.3	1.73	500
W00-1-4.25	Till	4.25	51.0	19.0	25.8	2.0	11.95	1.45	9.0	<50	2.4	30.0	14.5	31.2	0.3	1.73	365
W00-1-6.0	Till	6.00	48.0	14.0	25.0	2.0	11.65	1.20	8.0	<50	2.2	30.0	15.5	30.4	0.3	1.83	415
W00-1-7.0	Till	7.00	52.0	10.0	25.6	<1	12.50	1.20	8.0	<50	2.5	31.0	14.0	33.6	0.3	1.64	355
W00-1-9.3	Till	9.30	50.0	10.0	24.0	2.0	11.85	1.05	8.0	<50	2.4	31.0	15.0	32.0	0.2	1.70	420
* W00-1-9.3	Till	9.30	50.0	13.0	24.6	1.0	11.90	1.15	8.0	<50	2.5	31.0	14.0	32.4	0.3	1.76	440
W00-1-10.35	Till	10.35	49.0	9.0	24.4	<1	11.90	1.15	8.0	<50	2.6	32.0	15.5	33.6	0.3	1.50	405
W00-1-12.0	Till	12.00	53.0	12.0	24.8	2.0	12.20	1.15	9.0	<50	2.4	32.0	14.0	35.2	0.3	1.81	450
W00-1-13.4	Till	13.40	48.0	12.0	25.2	1.0	11.15	1.05	9.0	<50	2.2	32.0	20.0	30.0	0.3	1.69	405
W00-1-14.65	Till	14.65	53.0	8.0	24.4	2.0	12.05	1.10	7.0	<50	2.5	33.0	13.5	32.4	0.3	1.68	440
W00-1-22.95	Till	22.95	51.0	12.0	27.8	<1	12.70	1.40	11.0	<50	3.5	37.0	18.0	32.2	0.4	0.92	280
W00-1-24.45	Till	24.45	60.0	13.0	27.4	3.0	14.00	1.35	10.0	<50	2.9	39.0	15.0	37.8	0.3	0.96	485
W00-1-25.5	Till	25.50	58.0	14.0	28.0	2.0	14.05	1.35	10.0	<50	3.1	40.0	16.0	38.2	0.3	1.02	495
W00-1-27.3	Till	27.30	58.0	17.0	27.8	2.0	13.40	1.30	9.0	<50	2.8	38.0	19.0	36.8	0.3	1.02	485
W00-1-28.5	Till	28.50	55.0	13.0	26.2	2.0	13.25	1.35	10.0	<50	3.0	38.0	16.5	35.8	0.4	0.97	440
W00-1-29.5	Till	29.50	52.0	15.0	24.8	1.0	12.30	1.30	11.0	<50	2.7	39.0	15.0	33.4	0.4	0.92	415
W00-1-32.2	Till	32.20	62.0	13.0	28.2	<1	13.95	1.15	7.0	<50	3.0	42.0	15.5	41.6	0.3	1.12	410
W00-1-34.0	Till	34.00	55.0	13.0	27.0	1.0	13.45	1.15	8.0	<50	2.8	39.0	14.5	40.2	0.3	1.09	375
W00-1-34.9	Till	34.90	64.0	14.0	30.4	<1	15.60	1.40	8.0	<50	3.0	40.0	15.5	44.2	0.3	1.09	395
W00-1-45.4	Till	45.40	51.0	14.0	24.6	2.0	12.55	1.35	10.0	<50	2.7	38.0	15.5	35.0	0.3	0.85	370
W00-1-46.4	Till	46.40	51.0	12.0	26.4	2.0	12.65	1.30	11.0	<50	2.9	39.0	20.5	33.6	0.4	0.84	470
W00-1-82.05	Till	82.05	58.0	13.0	27.2	1.0	14.00	1.40	11.0	<50	3.0	39.0	18.0	38.8	0.4	0.90	385
W00-1-83.1	Till	83.10	55.0	15.0	26.2	<1	13.30	1.35	11.0	<50	3.2	34.0	16.0	37.0	0.3	0.90	380
W00-1-84.1	Till	84.10	53.0	12.0	25.2	<1	12.85	1.30	11.0	<50	2.7	34.0	15.0	36.2	0.3	0.93	395
* W00-1-84.1	Till	84.10	54.0	12.0	25.8	2.0	13.30	1.40	9.0	<50	2.8	36.0	14.5	36.4	0.3	0.92	395
W00-1-85.2	Till	85.20	56.0	11.0	26.4	<1	13.30	1.25	11.0	<50	2.9	36.0	19.5	36.4	0.3	0.92	385
W00-1-86.2	Till	86.20	55.0	11.0	25.8	2.0	13.80	1.40	10.0	<50	2.9	37.0	15.5	37.2	0.3	0.90	380
W00-1-87.2	Till	87.20	53.0	13.0	26.2	1.0	13.10	1.35	10.0	<50	2.8	36.0	19.5	35.4	0.3	0.92	395
W00-1-89.4	Till	89.40	56.0	12.0	26.8	1.0	13.95	1.35	9.0	<50	2.7	36.0	17.0	38.8	0.3	0.88	365
W00-1-90.4	Till	90.40	51.0	12.0	25.0	2.0	12.75	1.35	10.0	<50	2.7	36.0	14.5	34.4	0.4	0.88	375
W00-1-91.4	Till	91.40	52.0	11.0	24.6	<1	13.20	1.35	10.0	<50	2.6	37.0	15.0	34.6	0.3	0.85	360
W00-1-92.35	Till	92.35	53.0	11.0	25.0	1.0	13.05	1.30	10.0	<50	2.7	36.0	14.5	35.0	0.3	0.88	375

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-1-2.9	Till	2.90	30.0	1.10	28.6	8.7	600	1.61	65.6	7.9	14.0	<5	0.25	1.10	136.5	1.1	<0.05
W00-1-4.25	Till	4.25	40.0	1.05	23.0	9.3	580	1.61	65.7	4.8	8.8	<5	0.30	0.67	140.0	0.8	0.05
W00-1-6.0	Till	6.00	30.0	1.05	23.0	8.8	570	1.59	64.4	4.7	8.7	<5	0.30	0.73	143.5	0.9	<0.05
W00-1-7.0	Till	7.00	30.0	1.10	25.0	9.1	560	1.61	67.8	5.1	9.0	<5	0.30	0.68	138.0	0.8	<0.05
W00-1-9.3	Till	9.30	20.0	0.95	22.8	8.7	540	1.55	64.0	4.9	8.7	<5	0.30	0.71	140.0	0.9	<0.05
* W00-1-9.3	Till	9.30	20.0	0.95	22.4	9.0	570	1.54	62.6	5.1	10.0	<5	0.30	0.75	141.0	0.7	0.05
W00-1-10.35	Till	10.35	30.0	1.00	23.0	9.1	540	1.56	64.9	5.1	9.2	<5	0.30	0.70	133.5	0.9	<0.05
W00-1-12.0	Till	12.00	30.0	0.90	25.2	9.0	570	1.61	67.5	5.1	10.0	<5	0.30	0.71	146.0	0.8	<0.05
W00-1-13.4	Till	13.40	20.0	0.85	21.4	8.2	540	1.56	60.4	4.9	9.2	<5	0.25	0.76	135.5	0.8	<0.05
W00-1-14.65	Till	14.65	20.0	1.00	24.2	9.2	580	1.60	64.8	5.1	9.4	<5	0.25	0.72	134.0	0.8	<0.05
W00-1-22.95	Till	22.95	20.0	1.50	23.8	10.0	710	1.45	65.3	5.8	11.0	<5	0.35	0.61	111.0	1.1	<0.05
W00-1-24.45	Till	24.45	20.0	1.15	25.4	10.8	590	1.54	70.6	6.0	11.0	<5	0.35	0.56	114.5	1.4	<0.05
W00-1-25.5	Till	25.50	30.0	1.10	25.2	11.1	590	1.58	71.8	6.0	12.0	<5	0.40	0.62	124.0	1.3	0.05
W00-1-27.3	Till	27.30	30.0	1.10	24.4	10.9	610	1.53	69.3	6.0	11.0	<5	0.35	0.61	124.0	0.8	<0.05
W00-1-28.5	Till	28.50	30.0	1.00	23.4	10.8	610	1.55	68.3	6.0	11.0	<5	0.35	0.62	124.0	1.1	<0.05
W00-1-29.5	Till	29.50	30.0	1.00	22.6	9.6	590	1.41	62.8	6.0	11.0	<5	0.30	0.64	121.5	1.0	<0.05
W00-1-32.2	Till	32.20	20.0	1.60	26.8	10.3	550	1.51	67.7	6.1	12.0	<5	0.35	0.67	143.0	0.7	0.05
W00-1-34.0	Till	34.00	20.0	1.15	25.4	10.7	550	1.55	68.0	5.8	10.0	<5	0.35	0.66	147.5	0.7	<0.05
W00-1-34.9	Till	34.90	20.0	1.00	28.8	12.0	580	1.75	78.9	6.2	11.0	<5	0.35	0.61	145.0	1.1	<0.05
W00-1-45.4	Till	45.40	30.0	1.10	22.4	10.6	570	1.45	66.5	6.0	10.0	<5	0.35	0.55	118.0	1.0	0.05
W00-1-46.4	Till	46.40	20.0	1.10	22.2	10.7	600	1.48	65.9	6.2	12.0	<5	0.35	0.54	115.5	1.0	<0.05
W00-1-82.05	Till	82.05	30.0	1.10	24.0	10.8	650	1.63	74.8	5.9	12.0	<5	0.35	0.68	131.5	1.1	<0.05
W00-1-83.1	Till	83.10	40.0	1.05	23.8	10.4	600	1.59	71.4	5.5	12.0	<5	0.35	0.61	125.0	1.1	0.05
W00-1-84.1	Till	84.10	30.0	1.05	23.0	10.1	610	1.58	69.7	5.6	10.0	<5	0.45	0.58	131.5	1.3	<0.05
* W00-1-84.1	Till	84.10	30.0	1.15	23.0	10.5	610	1.59	69.6	5.7	10.0	<5	0.35	0.63	132.0	1.0	<0.05
W00-1-85.2	Till	85.20	30.0	1.10	23.0	10.3	630	1.55	67.0	5.8	11.0	<5	0.35	0.62	128.5	1.0	<0.05
W00-1-86.2	Till	86.20	30.0	1.10	23.2	10.1	620	1.51	70.6	6.0	11.0	<5	0.30	0.67	132.0	0.9	<0.05
W00-1-87.2	Till	87.20	20.0	1.15	22.4	9.8	620	1.55	69.1	6.0	10.0	<5	0.35	0.68	135.0	1.1	0.05
W00-1-89.4	Till	89.40	30.0	1.20	23.6	10.6	610	1.62	73.0	5.8	11.0	<5	0.35	0.63	133.5	1.1	<0.05
W00-1-90.4	Till	90.40	30.0	1.15	21.8	10.2	600	1.62	67.9	6.1	11.0	<5	0.30	0.70	132.5	1.1	0.05
W00-1-91.4	Till	91.40	40.0	1.15	22.2	10.4	620	1.61	68.3	5.9	10.0	<5	0.35	0.71	133.5	1.3	<0.05
W00-1-92.35	Till	92.35	30.0	1.10	22.0	10.4	620	1.58	68.0	5.9	11.0	<5	0.30	0.67	134.0	1.1	<0.05

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

Sample #	Material	Depth	NAA Tb ppm	IMS Tl ppm	NAA Th ppm	NAA Sn ppm	IMS Ti %	IMS W ppm	NAA U ppm	IMS V ppm	NAA Yb ppm	IMS Y ppm	IMS Zn ppm	NAA Zr ppm
W00-1-2.9	Till	2.90	1.10	0.48	15.0	<100	0.26	0.8	3.4	92.0	3.0	17.9	<100	620
W00-1-4.25	Till	4.25	0.80	0.44	8.4	<100	0.25	0.8	2.1	89.0	2.0	18.2	<100	<200
W00-1-6.0	Till	6.00	0.70	0.46	8.4	<100	0.24	0.7	2.3	85.0	<2	18.0	<100	550
W00-1-7.0	Till	7.00	0.70	0.48	8.8	<100	0.23	0.8	2.5	88.0	<2	18.8	<100	440
W00-1-9.3	Till	9.30	<0.5	0.44	8.2	<100	0.24	0.7	2.8	83.0	<2	17.6	<100	<200
* W00-1-9.3	Till	9.30	0.60	0.44	8.5	<100	0.25	0.7	2.7	87.0	2.0	17.2	<100	<200
W00-1-10.35	Till	10.35	0.60	0.44	8.8	<100	0.25	0.8	2.5	82.0	<2	17.9	<100	<200
W00-1-12.0	Till	12.00	0.70	0.46	8.7	<100	0.25	0.6	2.9	90.0	<2	18.7	<100	590
W00-1-13.4	Till	13.40	0.60	0.42	8.4	<100	0.22	0.8	2.9	79.0	2.0	17.1	<100	570
W00-1-14.65	Till	14.65	0.70	0.44	8.5	<100	0.26	0.7	2.4	92.0	<2	17.4	<100	<200
W00-1-22.95	Till	22.95	0.70	0.44	10.0	<100	0.27	0.8	2.4	91.0	3.0	19.9	<100	580
W00-1-24.45	Till	24.45	0.70	0.48	10.0	<100	0.29	0.9	3.2	97.0	2.0	19.8	<100	<200
W00-1-25.5	Till	25.50	0.90	0.48	10.0	<100	0.30	1.1	3.5	96.0	3.0	20.3	<100	590
W00-1-27.3	Till	27.30	0.90	0.46	11.0	<100	0.29	1.1	3.1	99.0	3.0	19.8	<100	<200
W00-1-28.5	Till	28.50	0.80	0.46	10.0	<100	0.29	0.9	2.7	94.0	3.0	19.5	<100	<200
W00-1-29.5	Till	29.50	0.90	0.44	10.0	<100	0.27	0.8	2.9	84.0	3.0	18.8	110	300
W00-1-32.2	Till	32.20	0.70	0.44	11.0	<100	0.29	1.4	2.7	92.0	<2	18.2	130	<200
W00-1-34.0	Till	34.00	<0.5	0.44	10.0	<100	0.28	0.9	2.9	85.0	<2	18.9	<100	<200
W00-1-34.9	Till	34.90	0.80	0.50	11.0	<100	0.31	1.0	2.8	101.0	<2	20.0	<100	<200
W00-1-45.4	Till	45.40	0.60	0.44	11.0	<100	0.27	0.9	3.1	86.0	2.0	19.5	<100	<200
W00-1-46.4	Till	46.40	0.70	0.44	10.0	<100	0.29	0.9	3.3	87.0	3.0	20.5	140	800
W00-1-82.05	Till	82.05	1.00	0.50	10.0	<100	0.28	1.0	3.1	102.0	3.0	20.3	<100	<200
W00-1-83.1	Till	83.10	0.70	0.48	10.0	<100	0.29	0.9	3.1	98.0	2.0	19.3	<100	650
W00-1-84.1	Till	84.10	0.60	0.48	10.0	<100	0.28	0.9	2.9	94.0	<2	19.4	<100	<200
* W00-1-84.1	Till	84.10	0.70	0.48	9.3	<100	0.29	0.9	2.9	96.0	2.0	19.5	<100	<200
W00-1-85.2	Till	85.20	0.80	0.48	10.0	<100	0.28	2.7	3.1	103.0	2.0	19.3	<100	430
W00-1-86.2	Till	86.20	0.60	0.46	10.0	<100	0.28	0.9	3.1	98.0	2.0	19.6	110	<200
W00-1-87.2	Till	87.20	0.70	0.46	10.0	<100	0.27	0.9	3.1	94.0	3.0	19.6	<100	<200
W00-1-89.4	Till	89.40	0.80	0.50	10.0	<100	0.29	0.9	2.9	100.0	2.0	19.5	110	280
W00-1-90.4	Till	90.40	0.70	0.46	10.0	<100	0.29	0.9	3.1	90.0	2.0	19.3	100	480
W00-1-91.4	Till	91.40	0.80	0.46	10.0	<100	0.28	0.9	2.9	91.0	<2	20.0	<100	340
W00-1-92.35	Till	92.35	0.90	0.46	10.0	<100	0.29	1.0	3.3	93.0	<2	19.3	<100	<200

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-1-93.4	Till	93.40	10.6	<2	5.87	0.6	7.2	590.0	487.5	1.40	0.47	1.1	0.28	1.28	80.0	3.8	72.0
W00-1-95.1	Till	95.10	6.9	<2	5.47	0.6	6.4	600.0	513.8	1.15	0.45	1.0	0.30	1.46	72.0	2.8	55.0
W00-1-96.0	Till	96.00	4.5	<2	5.79	0.6	11.0	650.0	390.5	0.95	0.37	1.8	0.28	1.31	78.0	3.0	60.0
W00-1-96.9	Till	96.90	6.4	<2	5.90	0.6	7.3	560.0	472.5	1.30	0.46	1.9	0.46	1.21	75.0	4.0	69.0
W00-1-98.05	Till	98.05	4.5	<2	5.97	0.6	7.5	600.0	452.0	1.35	0.45	1.4	0.44	1.27	74.0	3.9	62.0
W00-1-99.0	Till	99.00	7.0	<2	6.12	0.6	8.5	570.0	480.0	1.35	0.48	1.2	0.24	1.29	77.0	4.1	73.0
W00-1-100.0	Till	100.00	5.1	<2	6.08	0.6	8.2	560.0	455.0	1.15	0.46	1.4	0.20	1.28	70.0	3.7	64.0
W00-1-101.0	Till	101.00	3.8	<5	5.95	0.7	9.2	570.0	490.5	1.25	0.48	1.4	0.24	1.29	74.0	3.4	71.0
W00-1-102.0	Till	102.00	4.4	<2	5.96	0.6	7.7	600.0	481.5	1.20	0.47	1.4	0.24	1.21	66.0	3.4	69.0
W00-1-104.6	Till	104.60	6.2	<2	6.07	0.7	8.1	590.0	457.0	1.30	0.45	1.5	0.22	1.28	81.0	4.1	62.0
W00-1-105.7	Till	105.70	8.3	<2	5.95	0.6	8.1	610.0	480.5	1.30	0.45	1.3	0.20	1.21	79.0	3.9	73.0
* W00-1-105.7	Till	105.70	8.9	7.0	5.77	0.6	8.0	640.0	509.8	1.35	0.52	1.1	0.22	1.22	78.0	4.4	74.0
W00-1-106.7	Till	106.70	10.1	<2	6.05	0.6	7.7	590.0	477.0	1.30	0.50	1.2	0.28	1.25	84.0	3.7	68.0
W00-1-107.7	Till	107.70	8.5	4.0	5.96	0.7	7.8	570.0	487.0	1.35	0.58	1.2	0.24	1.20	80.0	3.6	86.0
W00-1-108.7	Till	108.70	8.0	<2	5.99	0.6	8.7	530.0	481.5	1.25	0.48	1.4	2.50	1.16	82.0	3.7	70.0
W00-1-110.9	Till	110.90	10.1	<2	6.15	0.6	7.7	580.0	481.0	1.35	0.47	1.2	0.22	1.30	79.0	4.0	67.0
W00-1-115.4	Till	115.40	6.6	<2	6.04	1.0	11.0	580.0	482.5	1.35	0.54	2.6	0.60	0.73	83.0	4.5	73.0
W00-1-117.3	Till	117.30	7.4	<2	6.22	1.3	13.0	600.0	513.8	1.65	0.57	2.9	0.80	0.74	89.0	4.5	64.0
W00-1-120.05	Till	120.05	7.8	<2	6.03	1.4	13.0	550.0	473.5	1.50	0.58	3.0	0.84	0.72	91.0	4.9	66.0
W00-1-120.95	Till	120.95	6.7	<2	5.86	1.1	13.0	620.0	533.8	1.30	0.55	2.8	0.64	0.77	85.0	4.3	46.0
W00-1-121.9	Till	121.90	8.0	<2	6.13	1.3	13.0	1100.0	808.4	1.35	0.54	2.7	0.70	0.86	88.0	4.7	64.0
W00-1-123.7	Till	123.70	7.9	<2	5.84	0.6	8.3	590.0	491.0	1.35	0.45	1.9	0.28	1.64	100.0	3.1	64.0
W00-1-124.6	Till	124.60	8.5	5.0	6.06	0.6	8.1	580.0	444.0	1.15	0.39	1.5	0.40	1.68	92.0	3.0	68.0
W00-1-125.55	Till	125.55	7.4	<2	6.23	0.6	6.9	630.0	625.6	1.60	0.57	1.2	0.40	1.61	92.0	3.7	64.0
W00-1-127.0	Sand	127.00	7.6	<2	6.03	0.7	8.0	680.0	464.5	1.00	0.42	1.5	0.34	1.41	98.0	3.4	74.0
W00-1-153.0	Till	153.00	8.2	<2	5.83	1.0	16.0	380.0	338.5	1.45	0.58	3.0	0.62	0.75	95.0	4.7	61.0
W00-1-154.0	Till	154.00	8.3	<2	6.06	1.0	17.0	560.0	433.0	1.50	0.56	2.7	0.54	0.70	94.0	5.0	62.0
W00-1-155.0	Till	155.00	7.3	<2	5.69	1.0	15.0	410.0	349.0	1.55	0.62	2.4	0.60	0.70	92.0	4.9	61.0
W00-1-156.0	Till	156.00	8.5	<2	5.81	1.0	15.0	460.0	309.5	1.35	0.53	2.7	0.54	0.67	93.0	4.7	59.0
W00-1-157.35	Till	157.35	8.9	<2	5.70	1.0	16.0	1200.0	313.5	1.60	0.67	2.8	0.62	0.65	92.0	4.9	66.0
* W00-1-157.35	Till	157.35	6.5	<2	5.78	1.0	16.0	1200.0	197.5	1.55	0.61	2.6	0.60	0.66	91.0	5.1	73.0
W00-1-158.4	Till	158.40	6.6	7.0	5.76	1.0	16.0	770.0	239.0	1.55	0.58	2.7	0.56	0.62	87.0	5.0	76.0

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-1-93.4	Till	93.40	55.0	11.0	25.6	<1	13.30	1.40	11.0	<50	2.7	37.0	15.5	36.4	0.4	0.90	380
W00-1-95.1	Till	95.10	48.0	12.0	24.6	1.0	12.05	1.30	9.0	<50	2.6	34.0	15.0	30.0	0.4	0.96	465
W00-1-96.0	Till	96.00	51.0	10.0	20.8	1.0	10.05	1.05	8.0	<50	2.9	36.0	14.0	26.8	0.4	0.94	435
W00-1-96.9	Till	96.90	52.0	15.0	26.2	2.0	13.45	1.35	10.0	<50	2.8	36.0	18.5	36.6	0.4	0.85	355
W00-1-98.05	Till	98.05	54.0	11.0	25.6	1.0	13.20	1.30	10.0	<50	2.8	36.0	18.5	37.6	0.4	0.87	365
W00-1-99.0	Till	99.00	57.0	12.0	26.2	1.0	14.25	1.45	10.0	<50	2.9	36.0	16.0	40.2	0.3	0.94	385
W00-1-100.0	Till	100.00	54.0	13.0	25.2	<1	13.00	1.35	10.0	<50	2.7	34.0	16.0	36.6	0.3	0.89	365
W00-1-101.0	Till	101.00	54.0	11.0	26.0	2.0	13.60	1.50	10.0	<50	2.6	39.0	15.5	37.8	0.3	0.93	390
W00-1-102.0	Till	102.00	53.0	10.0	25.2	2.0	13.50	1.30	10.0	<50	2.8	38.0	15.5	36.2	0.3	0.89	370
W00-1-104.6	Till	104.60	54.0	13.0	25.8	1.0	13.55	1.40	11.0	<50	3.1	37.0	18.5	37.2	0.4	0.90	380
W00-1-105.7	Till	105.70	54.0	13.0	24.8	<1	13.30	1.35	10.0	<50	2.7	36.0	15.0	35.8	0.3	0.91	375
* W00-1-105.7	Till	105.70	55.0	12.0	27.2	<1	13.45	1.50	10.0	<50	3.0	38.0	15.5	37.0	0.3	0.87	360
W00-1-106.7	Till	106.70	53.0	10.0	25.6	2.0	13.40	1.45	12.0	<50	3.0	39.0	15.0	36.4	0.4	0.89	375
W00-1-107.7	Till	107.70	53.0	12.0	25.4	<1	13.35	1.45	11.0	<50	3.1	38.0	15.0	37.0	0.3	0.90	370
W00-1-108.7	Till	108.70	54.0	11.0	28.0	2.0	13.85	1.40	12.0	<50	2.9	34.0	27.0	37.0	0.3	0.87	365
W00-1-110.9	Till	110.90	53.0	12.0	25.4	2.0	14.00	1.45	11.0	<50	2.7	34.0	15.5	39.0	0.3	0.93	385
W00-1-115.4	Till	115.40	54.0	11.0	28.8	2.0	13.80	1.60	12.0	<50	2.8	40.0	19.0	34.4	0.3	0.63	715
W00-1-117.3	Till	117.30	57.0	12.0	31.2	2.0	14.00	1.45	13.0	<50	2.9	42.0	20.0	35.6	0.4	0.65	430
W00-1-120.05	Till	120.05	57.0	12.0	29.8	1.0	13.85	1.50	12.0	<50	3.0	42.0	20.0	33.6	0.4	0.64	460
W00-1-120.95	Till	120.95	54.0	13.0	28.4	1.0	13.35	1.45	12.0	<50	2.8	40.0	20.5	33.0	0.4	0.63	545
W00-1-121.9	Till	121.90	55.0	12.0	29.2	<1	13.30	1.40	12.0	<50	3.0	43.0	18.5	33.2	0.5	0.65	505
W00-1-123.7	Till	123.70	48.0	13.0	24.2	1.0	12.70	1.25	13.0	<50	2.9	47.0	16.0	28.8	0.4	0.89	675
W00-1-124.6	Till	124.60	51.0	13.0	20.8	<1	10.70	1.15	12.0	<50	2.8	47.0	16.5	24.6	0.5	0.95	720
W00-1-125.55	Till	125.55	54.0	15.0	32.0	2.0	17.15	1.60	13.0	<50	3.0	48.0	20.0	40.6	0.4	0.97	625
W00-1-127.0	Sand	127.00	53.0	13.0	25.0	1.0	11.70	1.15	13.0	<50	3.2	46.0	14.5	28.0	0.4	0.90	620
W00-1-153.0	Till	153.00	52.0	13.0	30.2	2.0	13.50	1.60	11.0	<50	3.1	44.0	19.5	28.8	0.4	0.61	310
W00-1-154.0	Till	154.00	53.0	13.0	30.4	1.0	13.65	1.55	11.0	<50	3.1	44.0	19.0	30.4	0.4	0.59	350
W00-1-155.0	Till	155.00	52.0	13.0	30.0	1.0	13.10	1.55	10.0	<50	3.0	45.0	23.0	28.6	0.4	0.60	285
W00-1-156.0	Till	156.00	52.0	13.0	25.6	1.0	11.55	1.45	11.0	<50	3.0	44.0	19.5	24.8	0.4	0.61	290
W00-1-157.35	Till	157.35	51.0	13.0	35.2	1.0	14.30	1.65	10.0	<50	2.9	44.0	26.0	31.8	0.5	0.59	285
* W00-1-157.35	Till	157.35	52.0	15.0	34.2	1.0	13.25	1.55	11.0	<50	3.1	42.0	29.5	28.6	0.4	0.58	280
W00-1-158.4	Till	158.40	51.0	12.0	28.0	2.0	12.75	1.60	12.0	<50	3.1	45.0	18.5	28.6	0.4	0.58	300

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-1-93.4	Till	93.40	30.0	1.15	22.8	10.9	640	1.63	71.7	6.0	11.0	<5	0.40	0.72	137.0	0.9	<0.05
W00-1-95.1	Till	95.10	20.0	1.00	20.0	10.2	640	1.67	65.8	5.8	10.0	<5	0.35	0.83	147.5	1.0	0.05
W00-1-96.0	Till	96.00	30.0	0.85	18.0	8.0	620	1.61	54.3	5.9	10.0	<5	0.25	0.75	142.5	0.8	<0.05
W00-1-96.9	Till	96.90	30.0	1.10	23.2	10.3	620	1.59	71.2	5.9	11.0	<5	0.35	0.69	131.0	1.1	<0.05
W00-1-98.05	Till	98.05	30.0	1.15	22.8	10.5	600	1.60	69.2	5.9	11.0	<5	0.30	0.63	129.0	1.3	<0.05
W00-1-99.0	Till	99.00	40.0	1.20	24.2	11.0	630	1.63	73.3	6.0	11.0	<5	0.35	0.63	137.0	1.2	<0.05
W00-1-100.0	Till	100.00	30.0	1.15	23.2	10.0	610	1.59	70.3	5.6	11.0	<5	0.35	0.63	130.5	1.1	<0.05
W00-1-101.0	Till	101.00	30.0	1.35	26.4	10.6	600	1.60	71.7	5.9	11.0	<5	0.35	0.67	136.5	1.1	<0.05
W00-1-102.0	Till	102.00	30.0	1.10	22.8	10.5	620	1.58	69.8	5.9	11.0	<5	0.35	0.66	136.0	0.9	<0.05
W00-1-104.6	Till	104.60	30.0	1.10	23.0	10.3	590	1.59	68.7	6.2	11.0	<5	0.35	0.66	131.0	0.7	0.05
W00-1-105.7	Till	105.70	30.0	1.10	22.6	10.0	630	1.54	68.2	6.0	11.0	<5	0.30	0.72	136.5	1.2	<0.05
* W00-1-105.7	Till	105.70	30.0	1.15	23.0	10.8	620	1.67	73.9	6.1	11.0	<5	0.45	0.70	137.5	0.8	0.05
W00-1-106.7	Till	106.70	30.0	1.10	23.2	10.2	610	1.56	69.9	6.0	12.0	<5	0.35	0.68	135.0	1.0	<0.05
W00-1-107.7	Till	107.70	30.0	1.10	23.2	10.4	620	1.62	72.7	5.8	11.0	<5	0.35	0.69	141.5	0.9	<0.05
W00-1-108.7	Till	108.70	30.0	1.15	23.0	10.4	600	1.56	71.9	5.5	11.0	<5	0.35	0.60	136.5	1.0	0.05
W00-1-110.9	Till	110.90	30.0	1.20	23.8	10.6	600	1.59	71.7	5.8	10.0	<5	0.35	0.53	137.0	1.2	<0.05
W00-1-115.4	Till	115.40	30.0	3.85	27.0	12.1	760	1.41	70.9	6.6	10.0	<5	0.45	0.39	136.5	1.1	0.05
W00-1-117.3	Till	117.30	40.0	5.15	30.0	12.7	860	1.47	73.4	7.0	11.0	<5	0.40	0.39	146.0	1.3	0.05
W00-1-120.05	Till	120.05	30.0	5.05	29.6	12.2	900	1.42	69.9	7.2	11.0	<5	0.45	0.39	144.0	1.2	0.05
W00-1-120.95	Till	120.95	30.0	4.40	27.6	11.6	700	1.40	69.0	6.9	11.0	<5	0.40	0.40	142.5	1.4	0.05
W00-1-121.9	Till	121.90	40.0	4.75	27.6	11.5	730	1.46	68.4	7.0	11.0	<5	0.40	0.42	151.5	1.1	<0.05
W00-1-123.7	Till	123.70	30.0	1.20	21.6	11.1	670	1.79	73.5	7.4	10.0	<5	0.40	0.71	146.0	1.0	0.05
W00-1-124.6	Till	124.60	30.0	1.05	18.6	9.6	700	1.83	61.8	7.2	10.0	<5	0.35	0.75	156.0	1.2	<0.05
W00-1-125.55	Till	125.55	20.0	1.60	28.0	14.6	680	1.74	91.2	7.2	11.0	<5	0.45	0.69	163.0	1.0	0.05
W00-1-127.0	Sand	127.00	30.0	1.35	22.2	10.3	680	1.82	65.3	7.1	11.0	<5	0.35	0.68	129.0	1.2	0.05
W00-1-153.0	Till	153.00	40.0	3.75	25.6	13.0	900	1.44	73.0	7.4	11.0	<5	0.45	0.45	161.0	1.4	0.05
W00-1-154.0	Till	154.00	40.0	3.25	25.4	12.7	810	1.46	71.7	7.2	11.0	<5	0.45	0.42	156.5	1.3	0.05
W00-1-155.0	Till	155.00	40.0	3.55	25.0	12.4	860	1.38	70.6	7.3	11.0	<5	0.40	0.42	158.5	1.5	0.05
W00-1-156.0	Till	156.00	40.0	2.95	20.8	10.8	800	1.40	61.8	7.3	11.0	<5	0.40	0.42	144.5	1.3	0.05
W00-1-157.35	Till	157.35	40.0	3.65	26.2	13.6	840	1.39	77.2	7.2	10.0	<5	0.50	0.39	175.0	1.3	0.05
* W00-1-157.35	Till	157.35	40.0	3.30	24.0	12.8	840	1.40	69.3	7.3	11.0	<5	0.40	0.40	167.5	1.1	0.05
W00-1-158.4	Till	158.40	40.0	3.00	23.4	12.6	790	1.40	69.8	7.4	11.0	<5	0.40	0.47	158.5	1.2	0.05

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-1-93.4	Till	93.40	0.90	0.50	10.0	<100	0.29	1.7	3.4	96.0	3.0	20.5	<100	470
W00-1-95.1	Till	95.10	0.90	0.46	9.5	<100	0.28	0.8	2.9	80.0	3.0	19.8	<100	420
W00-1-96.0	Till	96.00	0.80	0.38	10.0	<100	0.28	0.9	2.7	89.0	2.0	15.5	<100	<200
W00-1-96.9	Till	96.90	0.80	0.46	10.0	<100	0.28	0.8	2.8	93.0	2.0	19.4	<100	330
W00-1-98.05	Till	98.05	0.70	0.46	10.0	<100	0.28	1.2	3.2	95.0	2.0	18.9	<100	<200
W00-1-99.0	Till	99.00	0.60	0.48	10.0	<100	0.29	0.9	2.8	99.0	2.0	20.0	<100	420
W00-1-100.0	Till	100.00	0.60	0.46	10.0	<100	0.29	0.9	2.9	99.0	2.0	19.4	<100	580
W00-1-101.0	Till	101.00	0.60	0.50	10.0	<100	0.29	1.0	3.1	93.0	3.0	20.4	<100	460
W00-1-102.0	Till	102.00	<0.5	0.48	10.0	<100	0.28	0.9	3.2	95.0	3.0	19.8	<100	420
W00-1-104.6	Till	104.60	0.80	0.48	10.0	<100	0.28	0.8	3.2	96.0	<2	19.3	<100	<200
W00-1-105.7	Till	105.70	0.80	0.46	10.0	<100	0.28	0.9	3.1	96.0	2.0	19.2	<100	470
* W00-1-105.7	Till	105.70	0.70	0.50	11.0	<100	0.30	1.0	3.2	93.0	3.0	20.5	<100	340
W00-1-106.7	Till	106.70	0.80	0.48	11.0	<100	0.28	1.8	3.2	95.0	2.0	19.4	100	360
W00-1-107.7	Till	107.70	0.80	0.50	10.0	<100	0.28	0.9	2.9	95.0	3.0	19.6	<100	420
W00-1-108.7	Till	108.70	0.70	0.48	10.0	<100	0.28	1.2	2.6	95.0	<2	19.9	<100	400
W00-1-110.9	Till	110.90	1.00	0.50	10.0	<100	0.29	0.9	2.9	97.0	<2	20.1	<100	<200
W00-1-115.4	Till	115.40	0.90	0.72	11.0	<100	0.30	1.1	4.2	117.0	2.0	24.6	<100	<200
W00-1-117.3	Till	117.30	1.00	0.84	12.0	<100	0.31	1.3	4.5	134.0	2.0	26.2	<100	490
W00-1-120.05	Till	120.05	1.00	0.86	11.0	<100	0.31	1.6	5.1	135.0	3.0	25.5	<100	520
W00-1-120.95	Till	120.95	1.10	0.76	11.0	<100	0.29	2.0	4.4	126.0	3.0	24.2	<100	<200
W00-1-121.9	Till	121.90	0.90	0.82	11.0	<100	0.31	1.6	4.6	133.0	3.0	24.5	<100	<200
W00-1-123.7	Till	123.70	0.90	0.52	13.0	<100	0.31	1.0	3.6	82.0	3.0	23.3	<100	530
W00-1-124.6	Till	124.60	0.60	0.46	13.0	<100	0.31	2.5	3.9	84.0	3.0	20.1	<100	770
W00-1-125.55	Till	125.55	0.90	0.66	13.0	<100	0.33	3.0	3.7	92.0	3.0	27.8	<100	<200
W00-1-127.0	Sand	127.00	0.90	0.48	12.0	<100	0.32	1.0	3.5	88.0	3.0	20.7	<100	670
W00-1-153.0	Till	153.00	0.80	0.78	12.0	<100	0.30	1.3	4.7	112.0	3.0	28.1	<100	360
W00-1-154.0	Till	154.00	1.20	0.72	13.0	<100	0.31	1.9	4.5	112.0	3.0	26.0	<100	380
W00-1-155.0	Till	155.00	1.10	0.78	12.0	<100	0.29	1.4	4.5	109.0	3.0	27.1	150	<200
W00-1-156.0	Till	156.00	0.90	0.70	12.0	<100	0.29	1.2	4.9	109.0	3.0	22.9	120	390
W00-1-157.35	Till	157.35	1.10	0.88	12.0	<100	0.29	1.6	4.6	107.0	3.0	29.0	<100	410
* W00-1-157.35	Till	157.35	1.00	0.78	12.0	<100	0.29	1.5	4.7	103.0	3.0	26.5	<100	570
W00-1-158.4	Till	158.40	1.10	0.72	12.0	<100	0.30	2.6	4.8	102.0	3.0	25.4	<100	720

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-1-159.3	Till	159.30	7.6	<2	6.08	1.0	15.0	620.0	543.5	1.45	0.60	3.0	0.58	0.70	89.0	5.0	62.0
W00-1-160.2	Till	160.20	6.6	<2	5.85	0.8	15.0	650.0	555.8	1.50	0.59	1.9	0.58	0.63	97.0	4.6	68.0
W00-1-162.2	Till	162.20	7.3	<2	5.92	0.7	15.0	470.0	393.0	1.60	0.59	2.5	0.52	0.68	86.0	5.3	83.0
W00-1-164.35	Till	164.35	8.0	<2	6.05	0.6	14.0	600.0	477.5	1.65	0.59	2.1	0.64	0.69	92.0	4.8	68.0
W00-1-165.4	Till	165.40	7.6	<2	6.20	0.8	12.0	570.0	475.5	1.50	0.58	2.1	0.84	0.74	90.0	4.3	73.0
W0O-1-166.4	Till	166.40	7.4	<2	6.10	1.0	13.0	750.0	653.5	1.55	0.60	2.6	0.60	0.80	98.0	4.3	35.0
W00-1-167.6	Till	167.60	7.7	<2	6.60	1.8	17.0	710.0	402.0	1.75	0.64	4.3	1.08	1.24	91.0	5.1	65.0
W00-1-168.9	Till	168.90	6.2	5.0	6.85	2.6	19.0	660.0	389.0	1.65	0.63	4.6	1.62	1.31	91.0	5.2	84.0
W00-1-169.9	Till	169.90	7.6	<2	6.92	2.7	19.0	670.0	439.0	1.65	0.63	4.7	2.06	1.25	85.0	5.8	76.0
W00-1-171.0	Till	171.00	6.3	<2	6.69	3.0	19.0	680.0	559.6	1.85	0.62	4.8	1.90	1.22	88.0	4.9	88.0
W00-1-172.0	Till	172.00	5.9	8.0	6.75	2.6	19.0	680.0	494.5	1.70	0.64	4.4	1.88	1.22	92.0	5.7	91.0
W00-1-173.0	Till	173.00	6.3	<2	7.09	2.7	20.0	730.0	544.5	1.40	0.59	4.5	1.82	1.27	99.0	4.9	93.0

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-1-159.3	Till	159.30	60.0	13.0	29.0	2.0	13.30	1.65	11.0	<50	3.0	43.0	21.0	30.0	0.4	0.67	350
W00-1-160.2	Till	160.20	50.0	12.0	31.0	3.0	13.20	1.55	11.0	<50	3.2	43.0	28.0	31.0	0.4	0.57	385
W00-1-162.2	Till	162.20	53.0	12.0	29.2	1.0	13.55	1.60	11.0	<50	3.0	43.0	23.5	31.0	0.3	0.62	370
W00-1-164.35	Till	164.35	54.0	14.0	29.0	1.0	13.80	1.60	10.0	<50	3.1	45.0	20.0	31.0	0.4	0.61	340
W00-1-165.4	Till	165.40	55.0	13.0	28.2	1.0	13.95	1.50	12.0	<50	2.8	43.0	19.0	34.0	0.3	0.60	390
W0O-1-166.4	Till	166.40	57.0	12.0	30.0	2.0	14.05	1.45	13.0	<50	3.1	43.0	19.5	34.6	0.5	0.63	435
W00-1-167.6	Till	167.60	70.0	13.0	37.4	1.0	15.45	1.50	9.0	<50	3.0	38.0	23.5	37.0	0.4	0.75	405
W00-1-168.9	Till	168.90	71.0	15.0	46.4	<1	15.85	1.50	8.0	<50	3.3	42.0	20.5	37.6	0.4	0.74	400
W00-1-169.9	Till	169.90	72.0	16.0	46.4	2.0	15.65	1.55	9.0	<50	3.2	42.0	21.5	38.6	0.3	0.73	415
W00-1-171.0	Till	171.00	69.0	13.0	42.4	2.0	15.30	1.55	9.0	<50	3.3	46.0	21.0	36.4	0.4	0.70	400
W00-1-172.0	Till	172.00	72.0	16.0	44.2	2.0	15.80	1.55	9.0	<50	3.4	45.0	20.5	38.6	0.4	0.70	420
W00-1-173.0	Till	173.00	75.0	19.0	41.6	2.0	14.00	1.30	9.0	<50	3.3	47.0	18.5	32.8	0.4	0.76	415

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-1-159.3	Till	159.30	40.0	3.50	32.4	12.7	910	1.46	73.0	7.1	11.0	<5	0.40	0.39	180.5	1.3	0.05
W00-1-160.2	Till	160.20	40.0	2.45	24.6	12.4	810	1.42	69.6	7.1	11.0	<5	0.40	0.42	157.0	1.1	0.10
W00-1-162.2	Till	162.20	40.0	2.50	24.2	12.7	850	1.44	72.1	7.3	11.0	<5	0.40	0.42	152.0	1.2	<0.05
W00-1-164.35	Till	164.35	30.0	2.35	23.8	12.5	900	1.43	72.6	7.1	12.0	<5	0.40	0.39	151.0	1.2	0.05
W00-1-165.4	Till	165.40	30.0	2.75	25.6	12.4	750	1.41	72.5	6.7	11.0	<5	0.40	0.42	148.5	1.3	0.05
W0O-1-166.4	Till	166.40	30.0	3.60	27.8	12.7	710	1.41	72.2	6.7	12.0	<5	0.40	0.43	162.0	1.2	0.05
W00-1-167.6	Till	167.60	50.0	7.15	38.0	12.8	980	1.54	81.1	6.9	11.0	<5	0.50	0.37	196.0	1.1	0.05
W00-1-168.9	Till	168.90	50.0	10.35	42.2	12.5	990	1.52	80.3	7.5	13.0	<5	0.50	0.42	181.0	1.2	0.10
W00-1-169.9	Till	169.90	50.0	9.75	42.4	12.8	890	1.55	80.7	7.3	12.0	<5	0.50	0.42	179.0	1.3	0.05
W00-1-171.0	Till	171.00	60.0	9.15	40.8	12.5	850	1.50	76.7	7.5	12.0	6.0	0.50	0.45	171.0	0.9	0.10
W00-1-172.0	Till	172.00	50.0	9.25	42.0	12.8	940	1.52	80.3	7.5	13.0	<5	0.50	0.44	170.5	1.5	0.05
W00-1-173.0	Till	173.00	50.0	7.90	37.2	11.3	910	1.59	71.0	7.5	13.0	<5	0.45	0.49	170.0	1.3	0.10

Table A3-6: Geochemical analysis of samples from core hole WEPA00-1

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-1-159.3	Till	159.30	1.00	0.76	12.0	<100	0.30	1.2	4.4	119.0	3.0	27.0	<100	400
W00-1-160.2	Till	160.20	0.90	0.68	12.0	<100	0.30	2.1	4.4	95.0	3.0	26.3	110	<200
W00-1-162.2	Till	162.20	0.80	0.66	12.0	<100	0.30	1.4	4.4	99.0	3.0	26.7	130	490
W00-1-164.35	Till	164.35	1.10	0.64	12.0	<100	0.30	1.4	4.5	98.0	3.0	26.7	<100	450
W00-1-165.4	Till	165.40	0.90	0.64	11.0	<100	0.31	1.3	4.2	107.0	2.0	24.5	<100	560
W0O-1-166.4	Till	166.40	1.20	0.78	12.0	<100	0.31	1.3	4.6	123.0	2.0	24.5	<100	590
W00-1-167.6	Till	167.60	0.90	1.12	11.0	<100	0.30	1.3	5.2	207.0	<2	28.2	130	530
W00-1-168.9	Till	168.90	0.90	1.40	12.0	<100	0.30	1.3	6.4	243.0	3.0	29.3	140	340
W00-1-169.9	Till	169.90	0.80	1.38	12.0	<100	0.31	2.9	6.4	239.0	3.0	28.9	<100	360
W00-1-171.0	Till	171.00	1.00	1.38	13.0	<100	0.30	1.4	6.3	239.0	3.0	27.8	120	510
W00-1-172.0	Till	172.00	1.00	1.36	13.0	<100	0.30	1.3	6.1	233.0	3.0	28.9	150	340
W00-1-173.0	Till	173.00	0.90	1.26	13.0	<100	0.32	1.3	6.1	245.0	2.0	24.8	140	380

Notes: < denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* W00-1-9.3 denotes sample duplicate of W00-1-9.3

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-2-5.7	Till	5.70	9.0	<2	5.61	0.5	5.0	490.0	427.0	1.25	0.47	1.5	0.52	2.96	72.0	3.1	66.0
W00-2-8.6	Till	8.60	9.4	<2	6.05	0.5	4.2	530.0	460.0	1.30	0.50	1.5	0.32	3.07	72.0	3.2	75.0
W00-2-9.5	Till	9.50	8.1	<2	5.92	0.6	5.7	550.0	463.5	1.20	0.49	1.7	0.30	3.16	72.0	3.4	75.0
W00-2-13.2	Till	13.20	8.1	<2	6.08	0.6	6.1	520.0	448.0	1.15	0.49	1.7	0.36	3.29	72.0	3.3	69.0
W00-2-14.2	Till	14.20	9.0	<2	6.08	0.6	6.4	520.0	456.0	1.25	0.47	2.0	0.32	3.20	73.0	3.2	72.0
* W00-2-14.2	Till	14.20	7.2	<2	5.87	0.6	6.6	550.0	434.5	1.15	0.46	1.9	0.38	3.22	69.0	3.9	55.0
W00-2-15.2	Till	15.20	8.7	5.0	6.02	0.6	6.0	500.0	537.7	1.35	0.54	1.6	0.64	3.10	74.0	3.4	68.0
W00-2-15.6	Till	15.60	8.5	<2	5.99	0.6	5.9	540.0	490.5	1.15	0.52	1.6	0.86	3.27	70.0	3.6	68.0
W00-2-16.75	Till	16.75	7.7	5.0	5.81	0.6	7.3	500.0	418.0	1.25	0.47	1.7	0.34	3.08	70.0	3.5	63.0
W00-2-18.3	Till	18.30	9.7	<2	5.77	0.5	5.7	540.0	416.0	1.00	0.44	1.8	1.32	3.47	70.0	3.1	63.0
W00-2-19.6	Till	19.60	6.6	<2	5.60	0.6	7.7	520.0	437.5	1.25	0.51	2.1	0.32	3.05	73.0	3.9	74.0
W00-2-20.6	Till	20.60	8.0	<2	5.60	0.5	6.0	490.0	416.5	1.10	0.47	1.8	0.54	3.53	69.0	3.5	75.0
W00-2-21.6	Till	21.60	7.3	<2	5.61	0.5	5.9	490.0	417.5	1.15	0.44	1.4	0.28	3.40	65.0	2.8	59.0
W00-2-22.8	Till	22.80	5.5	<2	5.81	0.5	5.0	520.0	458.0	1.15	0.47	1.8	0.32	3.58	63.0	3.1	61.0
W00-2-25.9	Till	25.90	6.7	4.0	5.92	0.5	6.4	500.0	445.0	1.15	0.46	1.9	0.40	3.62	76.0	3.4	73.0
W00-2-26.9	Till	26.90	6.8	<2	6.07	0.6	5.5	540.0	464.0	1.35	0.46	1.7	1.04	3.62	74.0	2.9	61.0
W00-2-27.9	Till	27.90	8.3	<2	6.22	0.8	11.0	690.0	444.0	1.25	0.46	2.3	0.78	3.50	81.0	4.6	77.0
W00-2-29.0	Till	29.00	7.6	<2	6.11	0.5	6.2	540.0	443.5	1.30	0.45	1.9	0.58	3.65	70.0	3.2	65.0
W00-2-30.1	Till	30.10	6.3	<2	6.00	0.5	6.1	570.0	438.5	1.25	0.44	2.3	0.42	3.73	64.0	3.5	55.0
W00-2-31.4	Till	31.40	7.1	<2	6.00	0.6	5.9	510.0	463.5	1.20	0.49	2.2	0.56	3.77	71.0	3.0	64.0
W00-2-32.3	Till	32.30	9.0	<2	5.98	0.6	5.9	550.0	428.0	1.35	0.47	1.6	1.54	3.17	69.0	3.5	67.0
W00-2-46.7	Silt & Clay	46.70	10.4	<2	4.99	0.5	6.6	520.0	405.5	1.00	0.45	1.8	0.28	1.87	69.0	3.4	66.0
W00-2-87.9	Till	87.90	10.2	<2	5.74	0.6	9.0	560.0	447.0	1.25	0.47	1.4	0.50	2.74	75.0	2.6	60.0
W00-2-89.1	Till	89.10	9.2	<2	5.78	0.6	7.7	570.0	419.5	1.05	0.46	1.3	0.32	2.80	75.0	3.9	64.0
* W00-2-89.1	Till	89.10	7.8	<2	5.85	0.6	7.6	520.0	448.5	1.35	0.49	1.5	0.42	2.79	76.0	3.5	59.0
W00-2-90.10	Till	90.10	7.4	<2	5.60	0.6	7.5	580.0	426.0	1.15	0.50	1.8	0.28	2.79	73.0	3.6	69.0
W00-2-91.1	Till	91.10	10.1	<2	5.60	0.6	7.8	570.0	459.0	1.30	0.48	2.0	0.38	2.72	75.0	3.8	64.0
W00-2-92.15	Till	92.15	11.6	<2	5.79	0.6	7.5	570.0	430.5	1.30	0.46	1.8	1.02	2.92	71.0	3.8	86.0
W00-2-93.2	Till	93.20	8.5	<2	5.66	0.6	7.4	500.0	437.5	1.15	0.45	2.0	0.44	2.75	73.0	3.0	75.0
W00-2-93.9	Till	93.90	10.4	<2	5.56	0.6	7.6	540.0	443.0	1.20	0.45	1.6	0.36	2.72	77.0	3.5	62.0
W00-2-95.2	Till	95.20	6.7	<2	6.80	0.6	7.1	530.0	528.1	1.55	0.49	1.8	0.52	2.14	68.0	3.7	64.0
W00-2-96.3	Till	96.30	10.8	<2	6.29	0.8	8.6	700.0	496.0	1.50	0.50	1.4	0.34	1.96	98.0	4.7	95.0

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

Sample #	Material	Depth	IMS Cr* ppm	IMS Co ppm	IMS Cu ppm	NAA Eu ppm	IMS Ga ppm	IMS Ge ppm	NAA Hf ppm	NAA Ir ppb	NAA Fe %	NAA La ppm	IMS Pb ppm	IMS Li ppm	NAA Lu ppm	IMS Mg %	IMS Mn ppm
W00-2-5.7	Till	5.70	55.0	17.0	35.8	<1	12.00	1.20	8.0	<50	2.5	35.0	21.0	33.6	0.3	1.56	395
W00-2-8.6	Till	8.60	58.0	12.0	38.2	<1	13.05	1.30	8.0	<50	2.7	35.0	16.5	35.6	0.3	1.71	485
W00-2-9.5	Till	9.50	57.0	10.0	42.2	<1	13.50	1.15	8.0	<50	2.7	35.0	16.5	35.2	0.3	1.70	480
W00-2-13.2	Till	13.20	57.0	12.0	39.8	1.0	12.95	1.20	7.0	<50	2.6	35.0	15.0	35.2	0.3	1.78	485
W00-2-14.2	Till	14.20	57.0	13.0	25.8	<1	13.00	1.25	8.0	<50	2.7	35.0	15.5	35.4	0.3	1.75	485
* W00-2-14.2	Till	14.20	53.0	11.0	30.2	2.0	12.65	1.25	7.0	<50	2.6	31.0	14.0	34.4	0.2	1.70	480
W00-2-15.2	Till	15.20	56.0	12.0	32.4	<1	14.35	1.35	8.0	<50	2.6	36.0	21.0	38.4	0.3	1.65	470
W00-2-15.6	Till	15.60	55.0	12.0	37.8	<1	13.70	1.25	8.0	<50	2.6	36.0	23.0	36.8	0.3	1.69	490
W00-2-16.75	Till	16.75	54.0	12.0	26.6	2.0	12.05	1.20	9.0	<50	2.6	34.0	18.0	36.0	0.3	1.45	395
W00-2-18.3	Till	18.30	57.0	12.0	24.4	<1	11.55	1.10	9.0	<50	2.7	33.0	13.5	33.2	0.3	1.82	450
W00-2-19.6	Till	19.60	51.0	12.0	25.4	2.0	12.30	1.25	8.0	<50	2.5	33.0	15.0	35.4	0.3	1.40	380
W00-2-20.6	Till	20.60	55.0	12.0	23.8	<1	11.85	1.15	9.0	<50	2.6	33.0	14.5	33.4	0.3	1.77	445
W00-2-21.6	Till	21.60	50.0	9.0	26.0	<1	11.70	1.20	8.0	<50	2.5	32.0	17.5	33.0	0.2	1.75	440
W00-2-22.8	Till	22.80	50.0	10.0	33.8	1.0	12.85	1.20	7.0	<50	2.4	33.0	22.5	34.4	0.2	1.90	465
W00-2-25.9	Till	25.90	53.0	9.0	28.8	<1	12.85	1.25	7.0	<50	2.6	32.0	15.0	36.4	0.3	1.81	455
W00-2-26.9	Till	26.90	59.0	12.0	32.2	<1	13.35	1.25	8.0	<50	2.7	33.0	27.5	35.6	0.3	1.91	485
W00-2-27.9	Till	27.90	58.0	11.0	28.6	1.0	12.50	1.20	9.0	<50	3.4	35.0	14.5	34.0	0.3	1.97	490
W00-2-29.0	Till	29.00	53.0	19.0	29.4	<1	12.75	1.15	8.0	<50	2.4	30.0	14.0	34.6	<0.2	1.94	490
W00-2-30.1	Till	30.10	57.0	8.0	32.6	<1	13.05	1.20	8.0	<50	2.5	31.0	21.5	34.2	0.2	1.95	490
W00-2-31.4	Till	31.40	58.0	10.0	29.2	<1	13.60	1.25	7.0	<50	2.7	33.0	15.5	36.6	<0.2	1.97	490
W00-2-32.3	Till	32.30	55.0	10.0	36.2	2.0	12.60	1.25	8.0	<50	2.6	33.0	16.5	35.8	0.3	1.72	470
W00-2-46.7	Silt & Clay	46.70	40.0	11.0	28.4	2.0	10.05	1.30	8.0	<50	2.6	33.0	15.5	25.4	0.3	1.03	490
W00-2-87.9	Till	87.90	52.0	11.0	25.2	1.0	12.40	1.30	11.0	<50	2.6	35.0	15.0	37.4	0.4	1.47	435
W00-2-89.1	Till	89.10	55.0	9.0	26.0	<1	12.10	1.25	8.0	<50	2.8	35.0	15.5	35.8	0.3	1.48	445
* W00-2-89.1	Till	89.10	53.0	13.0	36.2	1.0	13.00	1.25	9.0	<50	2.8	35.0	16.0	39.2	0.3	1.53	465
W00-2-90.10	Till	90.10	51.0	10.0	26.6	1.0	12.25	1.25	10.0	<50	2.8	36.0	14.0	36.2	0.3	1.43	420
W00-2-91.1	Till	91.10	52.0	12.0	31.6	1.0	13.05	1.20	9.0	<50	2.7	35.0	15.5	38.4	0.3	1.41	425
W00-2-92.15	Till	92.15	57.0	12.0	24.4	2.0	12.30	1.25	8.0	<50	2.8	36.0	15.0	37.6	0.3	1.54	455
W00-2-93.2	Till	93.20	55.0	12.0	24.8	<1	12.30	1.30	9.0	<50	2.6	33.0	14.5	37.0	0.3	1.46	440
W00-2-93.9	Till	93.90	52.0	13.0	31.8	<1	11.85	1.30	9.0	<50	2.9	36.0	34.0	34.8	0.3	1.44	450
W00-2-95.2	Till	95.20	62.0	11.0	32.8	2.0	15.15	1.55	10.0	<50	2.6	35.0	17.5	35.6	0.3	1.02	590
W00-2-96.3	Till	96.30	63.0	11.0	28.8	3.0	14.00	1.50	11.0	<50	3.5	45.0	17.0	32.8	0.4	1.02	515

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-2-5.7	Till	5.70	60.0	1.00	23.8	10.4	550	1.57	63.8	5.4	10.0	<5	0.30	0.70	134.5	1.1	<0.05
W00-2-8.6	Till	8.60	40.0	1.00	24.2	10.4	580	1.68	68.5	5.5	10.0	<5	0.30	0.70	148.0	1.0	<0.05
W00-2-9.5	Till	9.50	40.0	1.15	25.8	10.7	590	1.66	69.3	5.5	10.0	<5	0.30	0.76	146.0	0.9	<0.05
W00-2-13.2	Till	13.20	40.0	1.15	24.6	10.8	580	1.71	68.6	5.5	10.0	<5	0.30	0.76	160.5	1.0	<0.05
W00-2-14.2	Till	14.20	30.0	1.25	25.6	10.5	620	1.68	68.4	5.4	10.0	<5	0.40	0.77	156.0	0.9	<0.05
* W00-2-14.2	Till	14.20	30.0	1.15	24.0	9.9	580	1.69	67.2	5.5	9.5	<5	0.30	0.70	152.0	1.0	<0.05
W00-2-15.2	Till	15.20	30.0	1.95	28.2	11.5	590	1.66	74.8	5.5	10.0	<5	0.40	0.77	164.0	0.8	0.05
W00-2-15.6	Till	15.60	40.0	1.35	25.8	10.7	580	1.72	71.9	5.6	10.0	<5	0.45	0.77	162.0	1.1	0.05
W00-2-16.75	Till	16.75	40.0	1.25	21.6	10.1	590	1.53	63.7	5.4	10.0	<5	0.30	0.61	141.5	1.1	<0.05
W00-2-18.3	Till	18.30	30.0	1.00	22.4	9.3	660	1.57	61.1	5.3	10.0	<5	0.35	0.71	155.5	0.6	0.05
W00-2-19.6	Till	19.60	50.0	1.60	23.2	10.5	580	1.53	64.7	5.3	10.0	<5	0.30	0.60	139.5	0.9	0.05
W00-2-20.6	Till	20.60	30.0	1.05	22.4	9.6	580	1.59	62.0	5.2	9.3	<5	0.30	0.70	150.5	0.6	<0.05
W00-2-21.6	Till	21.60	30.0	1.05	22.2	9.3	570	1.57	61.5	5.1	9.1	<5	0.30	0.69	148.5	1.0	<0.05
W00-2-22.8	Till	22.80	30.0	1.15	25.0	10.2	560	1.66	66.6	5.1	9.3	<5	0.30	0.75	152.5	1.1	<0.05
W00-2-25.9	Till	25.90	30.0	1.25	25.4	10.2	570	1.66	68.0	5.1	9.4	<5	0.35	0.71	151.0	1.1	<0.05
W00-2-26.9	Till	26.90	20.0	1.25	25.6	10.2	620	1.75	70.4	5.1	10.0	<5	0.35	0.75	157.0	0.9	<0.05
W00-2-27.9	Till	27.90	40.0	1.20	26.8	10.0	610	1.67	66.7	5.4	12.0	<5	0.40	0.53	156.0	0.8	<0.05
W00-2-29.0	Till	29.00	40.0	1.15	25.4	10.1	560	1.72	68.9	5.2	8.0	<5	0.30	0.61	156.0	0.9	<0.05
W00-2-30.1	Till	30.10	30.0	1.25	25.6	10.0	630	1.73	67.7	5.2	8.9	<5	0.30	0.67	153.0	0.7	<0.05
W00-2-31.4	Till	31.40	30.0	1.25	26.4	10.8	590	1.72	71.0	5.5	10.0	<5	0.35	0.74	156.0	0.6	<0.05
W00-2-32.3	Till	32.30	30.0	1.15	23.6	10.1	590	1.65	67.3	5.7	9.3	<5	0.30	0.71	148.0	0.9	<0.05
W00-2-46.7	Silt & Clay	46.70	30.0	1.15	19.0	10.5	630	1.41	53.9	5.6	10.0	<5	0.35	0.71	126.0	0.8	<0.05
W00-2-87.9	Till	87.90	30.0	1.15	23.0	10.2	610	1.55	64.3	6.1	8.3	<5	0.35	0.65	145.0	1.4	0.05
W00-2-89.1	Till	89.10	30.0	1.10	22.2	9.8	610	1.57	63.6	5.6	10.0	<5	0.30	0.65	141.5	0.7	<0.05
* W00-2-89.1	Till	89.10	40.0	1.20	24.4	10.8	610	1.58	69.3	5.6	10.0	<5	0.35	0.64	149.5	1.0	<0.05
W00-2-90.10	Till	90.10	30.0	1.15	22.4	9.9	570	1.51	64.0	5.8	11.0	<5	0.35	0.67	143.5	1.1	0.05
W00-2-91.1	Till	91.10	40.0	1.25	23.6	11.2	590	1.57	68.1	5.5	10.0	<5	0.35	0.69	142.5	0.8	0.05
W00-2-92.15	Till	92.15	30.0	1.25	22.8	9.0	650	1.58	65.4	5.7	11.0	<5	0.35	0.71	147.5	1.0	<0.05
W00-2-93.2	Till	93.20	30.0	1.25	23.2	9.3	630	1.55	65.2	5.5	10.0	<5	0.35	0.73	139.5	1.0	<0.05
W00-2-93.9	Till	93.90	30.0	1.20	21.8	9.7	640	1.55	63.4	5.6	11.0	<5	0.40	0.74	144.5	1.2	<0.05
W00-2-95.2	Till	95.20	30.0	1.85	26.8	12.4	730	1.67	76.9	5.7	10.0	<5	0.40	0.69	150.5	1.1	0.05
W00-2-96.3	Till	96.30	40.0	1.70	24.4	11.5	800	1.63	72.9	7.0	13.0	<5	0.40	0.68	147.5	1.2	0.05

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-2-5.7	Till	5.70	0.6	0.48	9.1	<100	0.28	0.9	2.6	91.0	2.0	17.9	<100	390
W00-2-8.6	Till	8.60	0.7	0.54	10.0	<100	0.30	1.0	2.7	98.0	<2	18.9	<100	<200
W00-2-9.5	Till	9.50	0.5	0.52	10.0	<100	0.30	0.9	2.7	96.0	<2	18.9	<100	330
W00-2-13.2	Till	13.20	0.7	0.52	10.0	<100	0.30	0.9	2.8	96.0	<2	18.3	<100	<200
W00-2-14.2	Till	14.20	0.6	0.52	10.0	<100	0.29	0.9	2.7	97.0	2.0	18.8	<100	260
* W00-2-14.2	Till	14.20	0.9	0.48	10.0	<100	0.28	0.9	2.8	90.0	2.0	17.9	<100	<200
W00-2-15.2	Till	15.20	0.7	0.62	10.0	<100	0.29	1.0	2.7	103.0	2.0	21.0	<100	390
W00-2-15.6	Till	15.60	0.6	0.54	10.0	<100	0.29	1.2	2.6	94.0	<2	19.1	<100	<200
W00-2-16.75	Till	16.75	0.7	0.48	9.5	<100	0.29	1.0	3.0	93.0	2.0	18.3	<100	520
W00-2-18.3	Till	18.30	<0.5	0.44	9.5	<100	0.27	0.8	2.5	99.0	<2	16.9	<100	290
W00-2-19.6	Till	19.60	0.6	0.50	9.2	<100	0.29	1.0	2.9	92.0	<2	18.8	<100	340
W00-2-20.6	Till	20.60	0.8	0.46	9.1	<100	0.29	0.8	2.6	91.0	<2	17.4	<100	<200
W00-2-21.6	Till	21.60	0.6	0.46	8.9	<100	0.27	0.8	2.6	86.0	<2	17.1	<100	430
W00-2-22.8	Till	22.80	0.7	0.48	9.2	<100	0.29	0.9	2.5	92.0	<2	18.0	<100	540
W00-2-25.9	Till	25.90	0.8	0.52	9.0	<100	0.29	1.1	2.6	93.0	<2	18.2	<100	550
W00-2-26.9	Till	26.90	<0.5	0.52	10.0	<100	0.29	1.2	2.5	101.0	2.0	18.9	160	<200
W00-2-27.9	Till	27.90	0.8	0.50	10.0	<100	0.30	0.9	2.7	96.0	<2	18.2	<100	360
W00-2-29.0	Till	29.00	0.7	0.48	10.0	<100	0.29	1.0	2.8	93.0	<2	17.8	<100	<200
W00-2-30.1	Till	30.10	0.5	0.50	9.2	<100	0.29	1.0	2.8	98.0	<2	17.6	<100	<200
W00-2-31.4	Till	31.40	0.7	0.52	10.0	<100	0.29	1.3	2.8	98.0	<2	18.7	100	<200
W00-2-32.3	Till	32.30	0.8	0.50	10.0	<100	0.29	1.1	2.7	95.0	<2	18.4	<100	290
W00-2-46.7	Silt & Clay	46.70	0.5	0.46	9.4	<100	0.31	0.9	2.7	68.0	2.0	20.5	<100	<200
W00-2-87.9	Till	87.90	0.9	0.50	10.0	<100	0.29	0.8	3.4	93.0	3.0	18.8	<100	360
W00-2-89.1	Till	89.10	0.5	0.48	10.0	<100	0.29	0.9	2.8	94.0	<2	18.3	<100	340
* W00-2-89.1	Till	89.10	0.6	0.52	10.0	<100	0.30	0.9	2.6	95.0	2.0	19.8	<100	<200
W00-2-90.10	Till	90.10	0.9	0.46	10.0	<100	0.29	0.8	2.8	89.0	2.0	18.3	120	340
W00-2-91.1	Till	91.10	0.8	0.48	10.0	<100	0.29	0.9	2.8	89.0	2.0	19.4	<100	640
W00-2-92.15	Till	92.15	0.7	0.48	10.0	<100	0.27	0.7	2.7	98.0	2.0	18.7	130	480
W00-2-93.2	Till	93.20	0.6	0.46	10.0	<100	0.27	0.9	2.6	93.0	2.0	18.8	<100	<200
W00-2-93.9	Till	93.90	0.8	0.46	10.0	<100	0.29	0.9	2.9	89.0	<2	19.5	120	420
W00-2-95.2	Till	95.20	0.7	0.58	10.0	<100	0.35	1.1	2.7	116.0	2.0	22.8	130	400
W00-2-96.3	Till	96.30	1.0	0.54	12.0	<100	0.31	1.0	3.9	106.0	3.0	23.1	<100	340

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-2-97.3	Till	97.30	6.8	<2	7.09	0.6	7.8	620.0	533.0	1.60	0.49	1.5	0.42	2.11	89.0	4.5	74.0
W00-2-98.3	Till	98.30	8.9	10.0	7.16	0.9	16.0	650.0	543.3	1.65	0.50	2.1	0.42	2.15	97.0	4.9	81.0
W00-2-99.3	Till	99.30	5.5	<2	6.94	0.9	8.4	630.0	546.0	1.60	0.50	1.9	0.44	2.21	90.0	4.4	71.0
W00-2-100.3	Till	100.30	10.9	<2	6.90	0.9	13.0	790.0	566.5	1.65	0.49	1.8	1.70	2.22	76.0	5.3	87.0
W00-2-101.3	Till	101.30	7.5	<2	6.89	0.8	8.0	690.0	580.2	1.60	0.51	1.4	0.42	2.19	95.0	4.6	75.0
W00-2-102.3	Till	102.30	7.8	<2	6.79	0.8	7.4	700.0	537.0	1.45	0.47	1.6	0.36	2.22	100.0	4.0	95.0
W00-2-103.3	Till	103.30	8.0	8.0	6.78	0.8	7.7	660.0	525.7	1.60	0.47	1.2	0.42	2.17	100.0	3.9	81.0
W00-2-104.45	Till	104.45	6.7	<2	6.85	0.8	8.5	670.0	536.2	1.60	0.49	1.9	0.56	2.11	83.0	4.2	72.0
W00-2-105.5	Till	105.50	5.2	<2	6.76	0.8	7.3	630.0	561.1	1.65	0.46	2.0	0.52	2.18	78.0	4.2	67.0
W00-2-107.7	Till	107.70	7.2	<2	7.06	1.0	17.0	710.0	588.8	1.70	0.48	1.7	0.46	1.91	84.0	4.1	83.0
W00-2-108.7	Till	108.70	6.5	<2	6.36	0.9	7.3	720.0	563.1	1.40	0.46	1.0	0.96	2.23	82.0	5.0	75.0
W00-2-109.6	Till	109.60	7.4	<2	6.50	0.9	11.0	710.0	601.5	1.50	0.49	1.6	0.72	2.28	76.0	4.3	58.0
W00-2-111.45	Silt & Clay	111.45	6.4	7.0	6.05	0.9	6.5	700.0	556.0	1.30	0.44	2.3	0.72	3.70	74.0	3.5	60.0

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-2-97.3	Till	97.30	68.0	15.0	31.8	2.0	15.65	1.45	10.0	<50	3.1	40.0	17.0	37.2	0.4	1.07	635
W00-2-98.3	Till	98.30	65.0	14.0	32.2	1.0	16.00	1.60	11.0	<50	3.3	46.0	18.5	37.8	0.4	1.06	665
W00-2-99.3	Till	99.30	68.0	14.0	31.4	1.0	15.30	1.50	11.0	<50	3.3	46.0	18.5	36.0	0.3	1.10	645
W00-2-100.3	Till	100.30	67.0	14.0	30.2	2.0	15.40	1.50	9.0	<50	3.4	35.0	18.5	35.8	0.3	1.07	610
W00-2-101.3	Till	101.30	70.0	17.0	29.8	1.0	15.70	1.50	12.0	<50	3.4	45.0	18.0	37.2	0.3	1.09	635
W00-2-102.3	Till	102.30	66.0	15.0	28.6	2.0	14.95	1.50	12.0	<50	3.2	46.0	17.0	35.0	0.4	1.13	655
W00-2-103.3	Till	103.30	64.0	14.0	27.6	<1	14.80	1.60	12.0	<50	3.5	45.0	23.5	34.6	0.4	1.05	605
W00-2-104.45	Till	104.45	68.0	11.0	30.2	1.0	15.20	1.45	10.0	<50	2.7	36.0	21.5	35.4	0.2	1.06	620
W00-2-105.5	Till	105.50	63.0	13.0	29.8	3.0	15.35	1.60	9.0	<50	2.8	36.0	18.0	35.4	0.3	1.05	600
W00-2-107.7	Till	107.70	65.0	10.0	31.4	3.0	15.55	1.65	10.0	<50	3.1	43.0	17.5	38.6	0.4	0.95	500
W00-2-108.7	Till	108.70	59.0	14.0	26.2	1.0	14.00	1.40	9.0	<50	3.3	41.0	16.0	31.8	0.3	1.05	610
W00-2-109.6	Till	109.60	63.0	13.0	30.4	1.0	15.05	1.50	10.0	<50	2.7	39.0	17.5	34.6	0.3	1.07	600
W00-2-111.45	Silt & Clay	111.45	55.0	14.0	25.8	2.0	12.95	1.30	11.0	<50	2.9	40.0	15.0	29.8	0.4	1.64	595

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-2-97.3	Till	97.30	30.0	1.95	32.4	11.4	750	1.71	78.8	6.7	11.0	<5	0.35	0.63	154.5	1.2	<0.05
W00-2-98.3	Till	98.30	40.0	2.10	28.4	12.7	730	1.74	80.8	7.0	14.0	<5	0.40	0.68	154.5	1.1	0.05
W00-2-99.3	Till	99.30	40.0	2.00	28.2	11.5	800	1.70	77.9	6.9	13.0	<5	0.35	0.62	160.5	1.4	<0.05
W00-2-100.3	Till	100.30	30.0	1.80	28.4	12.0	720	1.72	77.3	5.8	12.0	<5	0.35	0.55	158.5	1.0	0.05
W00-2-101.3	Till	101.30	30.0	2.00	29.6	11.7	790	1.69	80.3	6.7	12.0	<5	0.35	0.68	158.0	0.7	0.05
W00-2-102.3	Till	102.30	30.0	1.90	27.2	11.5	730	1.69	75.5	6.7	13.0	<5	0.35	0.69	158.0	1.0	0.05
W00-2-103.3	Till	103.30	40.0	2.00	28.0	11.4	730	1.66	74.0	6.5	12.0	<5	0.35	0.68	152.0	1.3	0.05
W00-2-104.45	Till	104.45	30.0	2.05	26.4	11.9	740	1.70	76.6	6.5	10.0	<5	0.35	0.54	153.5	1.2	0.05
W00-2-105.5	Till	105.50	30.0	2.50	30.8	11.5	930	1.67	76.2	6.5	10.0	<5	0.35	0.56	160.0	1.3	0.05
W00-2-107.7	Till	107.70	40.0	2.25	27.8	11.7	910	1.68	79.6	7.3	11.0	<5	0.40	0.62	149.0	1.0	0.05
W00-2-108.7	Till	108.70	30.0	1.55	26.6	11.1	720	1.63	70.0	7.1	11.0	<5	0.30	0.50	158.5	1.2	0.05
W00-2-109.6	Till	109.60	30.0	1.60	27.6	11.6	740	1.66	74.8	6.8	11.0	<5	0.35	0.67	164.0	0.9	<0.05
W00-2-111.45	Silt & Clay	111.45	20.0	1.40	23.8	9.6	680	1.71	66.6	6.6	11.0	<5	0.35	0.65	186.0	0.7	0.05

Table A3-7: Geochemical analysis of samples from core hole WEPA00-2

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-2-97.3	Till	97.30	0.8	0.60	11.0	<100	0.32	1.1	3.5	124.0	3.0	22.5	<100	<200
W00-2-98.3	Till	98.30	0.8	0.60	12.0	<100	0.34	1.1	4.0	120.0	3.0	24.0	<100	<200
W00-2-99.3	Till	99.30	0.9	0.58	12.0	<100	0.32	2.7	4.5	126.0	3.0	23.2	<100	<200
W00-2-100.3	Till	100.30	0.8	0.58	10.0	<100	0.33	3.1	2.9	122.0	3.0	22.6	120	<200
W00-2-101.3	Till	101.30	1.1	0.58	11.0	<100	0.32	1.1	4.1	121.0	2.0	23.3	120	<200
W00-2-102.3	Till	102.30	1.0	0.56	12.0	<100	0.33	1.5	3.6	126.0	3.0	21.7	<100	550
W00-2-103.3	Till	103.30	0.8	0.56	12.0	<100	0.33	1.5	3.5	120.0	2.0	21.3	140	<200
W00-2-104.45	Till	104.45	0.9	0.58	12.0	<100	0.33	1.1	3.7	125.0	<2	21.7	<100	<200
W00-2-105.5	Till	105.50	0.9	0.60	11.0	<100	0.32	1.0	3.6	118.0	<2	27.9	<100	590
W00-2-107.7	Till	107.70	1.1	0.60	12.0	<100	0.32	1.2	5.1	131.0	3.0	23.6	<100	440
W00-2-108.7	Till	108.70	1.0	0.54	12.0	<100	0.31	0.9	3.7	113.0	<2	21.1	<100	520
W00-2-109.6	Till	109.60	0.6	0.56	11.0	<100	0.33	1.5	4.3	119.0	2.0	22.6	100	380
W00-2-111.45	Silt & Clay	111.45	1.0	0.52	12.0	<100	0.30	0.8	3.8	103.0	2.0	20.5	<100	<200

Notes: < denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* W00-2-14.2 denotes sample duplicate of W00-2-14.2

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-1.3	Till	1.30	6.9	<2	5.60	0.9	5.2	660.0	413.5	1.20	0.43	1.7	0.40	3.21	74.0	3.0	63.0
W00-3-4.0	Till	4.00	8.1	13.0	4.03	0.5	4.0	540.0	329.0	0.95	0.40	1.7	0.20	3.17	70.0	2.8	65.0
W00-3-5.0	Till	5.00	7.5	<2	4.88	0.4	4.5	400.0	393.0	1.10	0.41	2.1	0.60	3.28	56.0	2.2	63.0
W00-3-6.5	Till	6.50	10.7	<2	5.64	0.5	6.4	500.0	422.0	1.15	0.43	1.3	0.68	3.58	64.0	2.6	55.0
W00-3-7.6	Till	7.60	8.1	3.0	5.65	0.6	4.8	550.0	407.5	1.20	0.43	1.6	0.24	3.42	75.0	3.0	68.0
W00-3-8.75	Till	8.75	7.4	4.0	5.81	0.5	6.5	510.0	409.5	1.15	0.42	1.6	0.60	3.55	67.0	3.1	68.0
W00-3-17.5	Till	17.50	8.6	<2	5.68	0.5	6.4	530.0	420.5	1.25	0.42	2.2	0.52	4.20	69.0	3.1	76.0
W00-3-18.5	Till	18.50	11.0	4.0	5.58	0.6	6.4	520.0	437.5	1.10	0.46	1.7	0.52	3.22	64.0	3.2	71.0
W00-3-19.5	Till	19.50	7.0	<2	6.11	0.5	5.7	520.0	444.0	1.10	0.46	1.3	0.32	3.01	65.0	3.4	75.0
W00-3-20.5	Till	20.50	8.3	<2	5.95	0.6	6.8	540.0	410.5	1.30	0.42	2.4	0.34	3.16	70.0	3.7	77.0
W00-3-22.25	Till	22.25	6.9	<2	5.96	0.6	6.2	500.0	438.5	1.30	0.43	2.3	0.32	2.85	56.0	3.5	72.0
W00-3-23.5	Till	23.50	8.3	<2	5.99	0.6	5.7	540.0	446.5	1.35	0.42	2.2	0.34	2.88	75.0	3.4	60.0
W00-3-26.7	Till	26.70	9.2	<2	5.59	0.9	13.0	770.0	407.0	1.20	0.41	2.2	0.58	3.02	76.0	5.0	83.0
W00-3-27.3	Till	27.30	9.2	<2	5.10	0.6	7.0	510.0	408.5	1.15	0.41	2.3	0.96	2.75	70.0	3.5	73.0
W00-3-28.5	Till	28.50	7.0	<2	5.55	0.9	11.0	700.0	413.5	1.35	0.42	1.6	0.54	3.33	85.0	3.9	79.0
W00-3-29.5	Till	29.50	6.4	<2	5.28	0.5	5.8	500.0	430.5	1.15	0.43	1.4	0.40	3.26	62.0	3.0	75.0
* W00-3-29.5	Till	29.50	6.2	<2	5.46	0.6	6.7	540.0	418.5	1.25	0.42	1.9	0.28	3.29	72.0	3.3	55.0
W00-3-30.5	Till	30.50	5.2	<2	5.71	0.5	5.8	520.0	486.5	1.20	0.42	1.5	0.40	3.22	57.0	2.9	43.0
W00-3-32.2	Till	32.20	6.4	<2	6.58	0.5	6.8	510.0	531.8	1.55	0.51	1.9	0.36	3.81	73.0	2.9	70.0
W00-3-33.35	Till	33.35	9.0	<2	5.65	0.6	6.1	580.0	412.0	1.10	0.42	1.7	0.34	3.67	73.0	3.3	65.0
W00-3-34.3	Till	34.30	6.5	<2	5.19	0.5	5.6	550.0	428.0	1.15	0.42	1.8	0.38	3.99	62.0	2.6	57.0
W00-3-35.55	Till	35.55	7.2	4.0	5.55	0.5	5.3	530.0	427.0	1.35	0.43	2.2	0.40	3.95	57.0	2.5	68.0
W00-3-36.65	Till	36.65	8.3	<2	5.55	0.5	5.7	500.0	424.5	1.25	0.43	1.8	0.50	3.37	68.0	3.1	63.0
W00-3-38.0	Till	38.00	7.3	<2	5.78	0.5	5.8	560.0	441.0	1.25	0.43	1.8	5.42	3.38	63.0	3.3	62.0
W00-3-39.8	Till	39.80	8.3	<2	6.41	0.5	6.4	500.0	455.5	1.60	0.45	1.9	0.34	2.69	66.0	3.7	56.0
W00-3-41.2	Till	41.20	9.4	<2	6.17	0.6	7.7	610.0	433.0	1.20	0.45	2.0	0.38	3.09	67.0	4.3	75.0
W00-3-43.2	Till	43.20	11.3	<2	4.71	0.6	6.7	570.0	339.5	1.10	0.34	1.7	0.28	2.51	73.0	3.6	65.0
W00-3-44.2	Till	44.20	6.4	<2	5.59	0.6	6.9	530.0	446.0	1.20	0.44	2.1	0.50	3.20	73.0	3.1	65.0
W00-3-45.2	Till	45.20	8.2	<2	5.83	0.9	13.0	760.0	480.5	1.35	0.43	2.3	0.46	3.44	69.0	4.8	72.0
W00-3-46.25	Till	46.25	7.4	<2	5.76	0.6	5.8	540.0	435.0	1.15	0.42	1.4	1.34	3.45	68.0	4.0	67.0
W00-3-47.3	Till	47.30	7.0	<2	5.89	0.5	6.7	560.0	438.0	1.40	0.44	1.9	0.44	3.44	71.0	3.4	66.0
W00-3-48.3	Till	48.30	6.2	<2	5.94	0.6	6.7	560.0	476.0	1.15	0.42	2.2	0.34	3.40	73.0	3.4	59.0

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-3-1.3	Till	1.30	55.0	12.0	25.0	1.0	12.15	1.25	10.0	<50	2.1	35.0	15.0	32.4	0.3	1.63	190
W00-3-4.0	Till	4.00	38.0	11.0	17.6	1.0	8.65	1.10	9.0	<50	2.2	34.0	11.5	25.2	0.3	1.38	190
W00-3-5.0	Till	5.00	47.0	7.0	24.4	<1	10.60	1.20	10.0	<50	1.9	26.0	18.0	28.4	0.3	1.61	365
W00-3-6.5	Till	6.50	56.0	8.0	27.8	<1	12.85	1.25	9.0	<50	2.5	31.0	17.5	34.0	0.3	1.83	260
W00-3-7.6	Till	7.60	54.0	9.0	24.8	<1	11.85	1.15	8.0	<50	2.4	34.0	13.5	31.8	0.3	1.78	560
W00-3-8.75	Till	8.75	59.0	11.0	28.0	<1	12.20	1.15	7.0	<50	3.1	34.0	14.5	31.6	0.3	1.86	300
W00-3-17.5	Till	17.50	58.0	10.0	31.2	1.0	12.60	1.20	8.0	<50	3.1	36.0	15.0	35.0	0.3	2.08	500
W00-3-18.5	Till	18.50	54.0	9.0	29.2	2.0	13.05	1.30	7.0	<50	2.8	34.0	18.5	36.0	0.3	1.64	445
W00-3-19.5	Till	19.50	61.0	12.0	33.4	2.0	14.15	1.40	9.0	<50	2.6	35.0	17.5	40.2	0.3	1.65	485
W00-3-20.5	Till	20.50	57.0	13.0	25.8	1.0	12.30	1.15	8.0	<50	2.9	35.0	15.5	35.2	0.3	1.74	485
W00-3-22.25	Till	22.25	60.0	12.0	26.6	<1	13.45	1.25	8.0	<50	2.6	35.0	15.0	36.6	0.2	1.59	485
W00-3-23.5	Till	23.50	59.0	12.0	29.4	1.0	13.50	1.30	8.0	<50	2.8	36.0	24.5	38.0	0.3	1.62	485
W00-3-26.7	Till	26.70	53.0	11.0	26.4	1.0	12.30	1.30	9.0	<50	3.3	34.0	13.5	33.6	0.3	1.53	450
W00-3-27.3	Till	27.30	47.0	17.0	22.2	<1	11.15	1.25	8.0	<50	2.6	33.0	12.5	31.2	0.3	1.36	395
W00-3-28.5	Till	28.50	54.0	9.0	25.0	<1	12.05	1.15	12.0	<50	2.9	41.0	13.5	34.8	0.4	1.68	445
W00-3-29.5	Till	29.50	51.0	13.0	25.6	2.0	12.40	1.15	9.0	<50	2.8	33.0	14.0	36.6	0.3	1.59	420
* W00-3-29.5	Till	29.50	52.0	13.0	24.0	3.0	12.15	1.25	7.0	<50	2.6	34.0	14.0	36.0	0.2	1.62	435
W00-3-30.5	Till	30.50	56.0	12.0	26.4	2.0	12.90	1.25	8.0	<50	2.4	28.0	15.0	37.0	<0.2	1.66	460
W00-3-32.2	Till	32.20	69.0	7.0	33.4	1.0	15.85	1.55	8.0	<50	2.5	32.0	19.0	45.8	0.2	1.91	520
W00-3-33.35	Till	33.35	55.0	10.0	34.2	2.0	12.25	1.15	8.0	<50	2.6	33.0	16.0	34.0	0.2	1.86	465
W00-3-34.3	Till	34.30	50.0	11.0	27.2	<1	11.60	1.15	7.0	<50	2.5	30.0	25.0	31.8	0.3	1.94	455
W00-3-35.55	Till	35.55	55.0	10.0	26.0	<1	12.35	1.15	7.0	<50	2.3	30.0	17.5	34.8	0.3	1.92	455
W00-3-36.65	Till	36.65	56.0	9.0	24.6	<1	12.25	1.20	7.0	<50	2.5	32.0	13.5	34.8	0.3	1.72	445
W00-3-38.0	Till	38.00	59.0	11.0	27.8	<1	13.05	1.25	7.0	<50	2.4	32.0	17.0	37.4	0.3	1.74	470
W00-3-39.8	Till	39.80	63.0	12.0	30.2	1.0	14.70	1.40	7.0	<50	2.6	33.0	15.5	42.8	0.3	1.60	505
W00-3-41.2	Till	41.20	61.0	12.0	29.8	1.0	13.45	1.20	7.0	<50	3.0	37.0	23.5	38.8	0.3	1.71	490
W00-3-43.2	Till	43.20	48.0	14.0	21.4	<1	10.20	1.00	7.0	<50	2.7	34.0	12.0	30.0	0.3	1.32	375
W00-3-44.2	Till	44.20	54.0	13.0	25.2	1.0	12.70	1.25	8.0	<50	2.7	34.0	15.5	36.6	0.3	1.62	450
W00-3-45.2	Till	45.20	57.0	12.0	26.0	1.0	12.95	1.20	9.0	<50	3.1	34.0	16.0	36.2	0.3	1.77	480
W00-3-46.25	Till	46.25	57.0	16.0	26.8	1.0	12.85	1.25	7.0	<50	2.6	33.0	15.5	36.2	0.3	1.77	475
W00-3-47.3	Till	47.30	59.0	12.0	26.4	1.0	12.70	1.20	7.0	<50	2.6	35.0	14.0	35.6	0.3	1.80	485
W00-3-48.3	Till	48.30	56.0	10.0	25.6	2.0	12.60	1.20	7.0	<50	2.8	34.0	16.5	35.6	0.3	1.81	490

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-1.3	Till	1.30	30.0	0.80	19.4	9.0	550	1.59	63.1	5.8	9.3	<5	0.55	0.85	129.0	1.1	<0.05
W00-3-4.0	Till	4.00	30.0	0.75	16.8	7.1	440	1.21	45.7	5.3	10.0	<5	0.40	0.73	111.5	1.0	<0.05
W00-3-5.0	Till	5.00	30.0	0.90	19.2	8.7	540	1.43	55.9	4.4	7.4	<5	0.30	0.56	126.0	0.6	<0.05
W00-3-6.5	Till	6.50	30.0	1.05	26.8	9.6	560	1.70	66.5	5.0	9.0	<5	0.35	0.71	135.0	1.0	0.05
W00-3-7.6	Till	7.60	40.0	1.15	24.2	9.1	570	1.60	61.9	5.3	10.0	<5	0.25	0.76	134.5	1.1	<0.05
W00-3-8.75	Till	8.75	40.0	0.90	19.6	9.5	640	1.69	64.1	5.2	10.0	<5	0.30	0.73	134.5	0.9	<0.05
W00-3-17.5	Till	17.50	30.0	1.30	25.2	9.6	560	1.65	64.8	5.4	11.0	<5	0.30	0.75	148.0	0.8	<0.05
W00-3-18.5	Till	18.50	30.0	1.15	25.0	10.1	570	1.63	66.2	5.2	10.0	<5	0.35	0.75	139.0	1.0	<0.05
W00-3-19.5	Till	19.50	20.0	1.20	27.6	10.5	590	1.73	72.3	5.4	10.0	<5	0.40	0.74	144.5	0.9	<0.05
W00-3-20.5	Till	20.50	30.0	0.90	23.6	8.9	580	1.66	64.2	5.5	11.0	<5	0.25	0.74	142.0	1.0	<0.05
W00-3-22.25	Till	22.25	20.0	1.05	25.2	10.0	610	1.70	69.1	5.3	10.0	<5	0.30	0.73	144.0	0.8	<0.05
W00-3-23.5	Till	23.50	30.0	1.05	27.6	10.4	600	1.71	70.1	5.5	10.0	<5	0.60	0.74	144.5	0.9	0.05
W00-3-26.7	Till	26.70	20.0	1.05	22.8	9.6	580	1.58	61.8	5.7	12.0	<5	0.30	0.57	136.0	1.0	<0.05
W00-3-27.3	Till	27.30	10.0	0.85	21.0	8.9	520	1.45	58.7	5.4	10.0	<5	0.90	0.72	130.5	1.3	<0.05
W00-3-28.5	Till	28.50	30.0	1.00	23.2	9.0	600	1.59	60.9	6.4	11.0	<5	0.35	0.73	140.0	1.0	<0.05
W00-3-29.5	Till	29.50	30.0	1.10	24.2	8.9	540	1.59	64.6	4.9	9.5	<5	0.35	0.69	139.5	0.9	<0.05
* W00-3-29.5	Till	29.50	20.0	1.10	23.6	8.9	540	1.62	62.7	5.5	10.0	<5	0.30	0.76	138.5	1.0	<0.05
W00-3-30.5	Till	30.50	20.0	1.15	25.0	9.3	580	1.68	66.7	4.6	7.9	<5	0.40	0.57	143.5	0.8	<0.05
W00-3-32.2	Till	32.20	30.0	1.35	31.2	11.2	710	2.01	82.3	5.1	9.3	<5	0.35	0.68	172.5	0.9	<0.05
W00-3-33.35	Till	33.35	30.0	1.25	23.8	9.4	580	1.66	62.5	5.3	9.3	<5	0.30	0.71	142.5	0.9	<0.05
W00-3-34.3	Till	34.30	20.0	0.95	22.6	9.1	580	1.62	61.3	5.0	8.8	<5	0.30	0.70	149.0	0.8	<0.05
W00-3-35.55	Till	35.55	30.0	1.05	25.6	9.3	570	1.65	64.8	4.8	8.5	<5	0.40	0.71	146.5	0.7	<0.05
W00-3-36.65	Till	36.65	30.0	1.00	23.6	8.9	570	1.61	64.1	5.0	9.0	<5	0.50	0.72	139.0	0.7	<0.05
W00-3-38.0	Till	38.00	30.0	1.10	26.2	9.8	600	1.69	69.4	5.1	9.5	<5	0.50	0.71	144.0	0.9	<0.05
W00-3-39.8	Till	39.80	30.0	1.15	29.2	11.0	620	1.79	76.0	5.3	10.0	<5	0.60	0.70	143.0	1.0	<0.05
W00-3-41.2	Till	41.20	40.0	1.05	26.0	9.4	610	1.75	69.9	5.9	12.0	<5	0.55	0.70	142.5	1.1	0.05
W00-3-43.2	Till	43.20	30.0	0.85	19.8	7.2	480	1.35	53.2	5.6	10.0	<5	0.50	0.71	108.0	1.1	<0.05
W00-3-44.2	Till	44.20	30.0	1.00	24.6	9.0	570	1.66	66.3	5.5	11.0	<5	0.50	0.69	136.5	1.0	<0.05
W00-3-45.2	Till	45.20	20.0	1.35	25.2	8.9	590	1.72	68.4	5.8	11.0	<5	0.45	0.50	146.5	0.9	<0.05
W00-3-46.25	Till	46.25	20.0	1.10	25.6	9.3	580	1.71	67.5	5.5	10.0	<5	0.50	0.72	148.0	0.7	<0.05
W00-3-47.3	Till	47.30	30.0	1.20	25.6	9.1	610	1.71	67.3	5.6	10.0	<5	0.50	0.75	142.5	1.0	<0.05
W00-3-48.3	Till	48.30	30.0	1.15	24.8	9.1	560	1.71	65.0	5.5	10.0	<5	0.45	0.73	142.5	1.1	0.05

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-3-1.3	Till	1.30	0.9	0.44	10.0	<100	0.27	0.8	4.1	91.0	2.0	17.3	<100	<200
W00-3-4.0	Till	4.00	0.8	0.34	9.5	<100	0.22	0.5	2.5	62.0	<2	14.8	<100	<200
W00-3-5.0	Till	5.00	<0.5	0.40	7.7	<100	0.26	0.9	2.3	78.0	<2	16.6	<100	510
W00-3-6.5	Till	6.50	<0.5	0.48	8.8	<100	0.27	0.7	2.3	92.0	<2	17.3	<100	<200
W00-3-7.6	Till	7.60	0.6	0.44	9.4	<100	0.28	0.7	2.6	96.0	<2	17.0	110	<200
W00-3-8.75	Till	8.75	0.9	0.42	9.1	<100	0.28	0.7	2.7	96.0	<2	17.2	<100	270
W00-3-17.5	Till	17.50	0.6	0.50	10.0	<100	0.28	0.8	2.4	102.0	<2	17.0	<100	270
W00-3-18.5	Till	18.50	0.7	0.48	8.9	<100	0.28	0.8	2.6	88.0	<2	18.3	<100	340
W00-3-19.5	Till	19.50	0.5	0.50	9.1	<100	0.30	0.8	2.5	101.0	<2	18.8	<100	410
W00-3-20.5	Till	20.50	0.6	0.44	10.0	<100	0.28	0.7	2.8	98.0	2.0	17.6	110	<200
W00-3-22.25	Till	22.25	0.6	0.46	9.2	<100	0.29	0.8	2.8	98.0	<2	18.5	<100	330
W00-3-23.5	Till	23.50	0.7	0.50	10.0	<100	0.29	0.8	2.7	99.0	<2	18.0	<100	<200
W00-3-26.7	Till	26.70	0.7	0.44	10.0	<100	0.28	0.8	2.9	88.0	2.0	17.1	110	<200
W00-3-27.3	Till	27.30	<0.5	0.42	9.3	<100	0.26	0.7	2.8	79.0	<2	16.6	<100	<200
W00-3-28.5	Till	28.50	0.8	0.44	11.0	<100	0.27	0.7	4.1	90.0	3.0	17.4	<100	480
W00-3-29.5	Till	29.50	0.7	0.44	9.0	<100	0.25	0.7	2.3	87.0	<2	17.8	110	<200
* W00-3-29.5	Till	29.50	0.6	0.46	10.0	<100	0.27	0.7	2.9	86.0	<2	17.8	<100	<200
W00-3-30.5	Till	30.50	<0.5	0.48	8.5	<100	0.27	0.7	2.5	97.0	<2	17.7	<100	340
W00-3-32.2	Till	32.20	0.8	0.56	10.0	<100	0.33	0.9	2.7	108.0	<2	22.0	<100	<200
W00-3-33.35	Till	33.35	0.6	0.46	9.3	<100	0.27	0.8	2.6	94.0	<2	16.9	<100	330
W00-3-34.3	Till	34.30	0.7	0.44	9.0	<100	0.26	0.8	2.6	83.0	<2	17.2	<100	330
W00-3-35.55	Till	35.55	0.5	0.50	8.4	<100	0.26	0.8	2.4	94.0	<2	17.2	<100	290
W00-3-36.65	Till	36.65	0.6	0.44	9.1	<100	0.26	0.7	2.6	92.0	<2	17.3	<100	<200
W00-3-38.0	Till	38.00	0.6	0.50	9.1	<100	0.28	0.8	2.6	98.0	<2	18.4	<100	<200
W00-3-39.8	Till	39.80	0.7	0.52	9.3	<100	0.31	0.8	2.7	109.0	<2	19.1	<100	290
W00-3-41.2	Till	41.20	0.8	0.50	11.0	<100	0.28	1.0	2.6	104.0	<2	18.2	<100	<200
W00-3-43.2	Till	43.20	0.7	0.38	10.0	<100	0.22	0.6	2.7	80.0	<2	14.0	<100	<200
W00-3-44.2	Till	44.20	0.6	0.48	10.0	<100	0.27	0.7	2.7	92.0	2.0	17.9	<100	<200
W00-3-45.2	Till	45.20	0.7	0.48	10.0	<100	0.27	0.7	2.8	97.0	2.0	18.1	120	390
W00-3-46.25	Till	46.25	0.6	0.50	10.0	<100	0.27	0.7	2.7	95.0	2.0	17.9	<100	360
W00-3-47.3	Till	47.30	0.7	0.48	10.0	<100	0.27	0.7	2.7	98.0	<2	17.8	<100	500
W00-3-48.3	Till	48.30	0.6	0.48	10.0	<100	0.28	0.6	2.9	92.0	<2	18.0	<100	<200

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-49.3	Till	49.30	6.0	<2	6.08	0.5	6.4	520.0	451.5	1.40	0.44	1.6	0.36	3.46	74.0	3.8	67.0
W00-3-50.5	Till	50.50	7.2	<2	5.65	0.6	6.4	520.0	431.0	1.30	0.42	1.7	0.32	3.34	66.0	3.2	58.0
W00-3-51.5	Till	51.50	6.3	<2	6.06	0.6	5.9	530.0	430.5	1.25	0.42	2.1	0.36	3.48	65.0	2.9	68.0
* W00-3-51.5	Till	51.50	5.2	<2	6.15	0.6	5.8	540.0	441.0	1.30	0.44	1.9	0.40	3.52	72.0	4.1	64.0
W00-3-52.5	Till	52.50	5.1	<2	5.63	0.6	6.4	520.0	416.5	1.15	0.41	1.7	0.36	3.29	66.0	3.2	55.0
W00-3-53.5	Till	53.50	7.3	<2	6.18	0.6	7.0	530.0	410.0	1.35	0.41	1.8	0.26	3.08	79.0	3.3	75.0
W00-3-54.5	Till	54.50	6.5	<2	5.87	0.6	6.5	510.0	441.0	1.35	0.44	1.6	0.26	3.16	71.0	3.0	71.0
W00-3-55.5	Till	55.50	6.6	<2	6.72	0.5	5.5	480.0	448.5	1.50	0.45	1.8	0.32	2.75	69.0	2.5	68.0
W00-3-56.6	Till	56.60	10.5	<2	7.14	0.6	7.4	530.0	456.0	1.85	0.47	2.0	0.40	2.53	81.0	3.7	70.0
W00-3-57.6	Till	57.60	6.2	<2	6.87	0.7	9.4	660.0	452.5	1.55	0.44	2.2	0.32	2.63	81.0	4.4	72.0
W00-3-58.6	Till	58.60	6.0	<2	7.00	0.6	7.4	590.0	468.5	1.60	0.48	1.8	0.32	2.68	73.0	4.6	80.0
W00-3-59.6	Till	59.60	7.3	<2	6.48	0.9	13.0	800.0	479.0	1.50	0.47	2.3	0.34	2.78	72.0	5.0	78.0
W00-3-60.6	Till	60.60	6.3	<2	6.95	0.6	7.6	650.0	450.5	1.65	0.46	2.1	0.38	2.67	80.0	4.2	76.0
W00-3-62.0	Till	62.00	6.4	<2	5.94	0.6	7.5	540.0	458.0	1.45	0.42	1.7	0.36	2.77	79.0	4.0	73.0
W00-3-63.0	Till	63.00	5.7	<2	6.39	0.6	6.6	560.0	438.0	1.45	0.41	1.9	0.56	2.97	69.0	3.6	61.0
W00-3-64.1	Till	64.10	6.5	<2	6.19	0.5	6.0	560.0	434.5	1.35	0.41	1.7	0.44	2.86	70.0	2.9	62.0
W00-3-65.45	Till	65.45	7.1	6.0	6.73	0.6	6.5	580.0	473.5	1.45	0.46	2.1	0.34	2.59	76.0	4.2	72.0
W00-3-66.5	Till	66.50	7.1	<2	6.37	0.6	7.6	590.0	475.5	1.55	0.43	1.7	0.34	2.88	74.0	3.9	81.0
W00-3-68.0	Till	68.00	6.2	<2	6.67	0.6	6.3	570.0	452.0	1.45	0.44	2.1	0.30	2.82	81.0	4.2	63.0
W00-3-68.9	Till	68.90	6.3	<2	6.83	0.6	6.8	590.0	430.0	1.50	0.44	1.5	0.38	2.53	78.0	3.6	63.0
W00-3-73.3	Till	73.30	7.2	<2	6.32	0.6	7.1	540.0	429.0	1.40	0.43	1.7	3.70	3.00	82.0	4.1	75.0
W00-3-77.05	Till & Clay	77.05	6.5	<2	6.10	0.6	6.6	550.0	446.0	1.30	0.43	1.9	0.34	3.14	77.0	3.3	62.0
* W00-3-77.05	Till & Clay	77.05	7.5	<2	6.09	0.6	6.3	570.0	438.0	1.35	0.43	1.9	0.52	3.12	71.0	3.2	58.0
W00-3-77.85	Till	77.85	7.1	<2	5.82	0.6	5.7	570.0	457.0	1.50	0.43	2.0	0.26	1.01	72.0	3.2	70.0
W00-3-78.35	Till	78.35	8.3	<2	5.92	0.6	11.0	560.0	424.0	1.30	0.41	1.3	0.48	1.01	78.0	4.0	68.0
W00-3-78.85	Till	78.85	6.8	<2	5.92	0.6	26.0	550.0	428.0	1.45	0.46	1.7	0.42	0.95	75.0	4.5	70.0
W00-3-79.85	Till	79.85	9.7	<2	6.00	0.6	12.0	560.0	427.5	1.40	0.42	1.2	0.42	1.28	83.0	3.9	57.0
W00-3-80.85	Till	80.85	7.5	5.0	6.14	0.6	6.7	550.0	428.0	1.45	0.45	1.2	1.04	1.24	84.0	3.4	67.0
W00-3-82.55	Till	82.55	7.3	5.0	6.19	0.6	7.3	520.0	408.5	1.30	0.43	1.4	0.24	1.25	85.0	4.3	80.0
W00-3-83.60	Till	83.60	7.3	<2	6.13	0.9	12.0	710.0	434.5	1.35	0.44	2.1	0.32	1.27	84.0	4.3	85.0
W00-3-84.6	Till	84.60	5.7	<2	6.06	0.5	7.1	550.0	420.5	1.35	0.44	1.7	0.22	1.26	92.0	4.0	70.0
W00-3-92.0	Till	92.00	6.7	<2	6.10	0.6	7.9	610.0	480.5	1.30	0.43	1.5	0.24	1.39	81.0	3.7	63.0

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-3-49.3	Till	49.30	59.0	10.0	25.8	1.0	12.80	1.25	8.0	<50	2.7	34.0	16.5	36.6	0.3	1.85	495
W00-3-50.5	Till	50.50	53.0	11.0	25.8	1.0	12.35	1.20	7.0	<50	2.7	33.0	15.5	35.0	0.3	1.75	470
W00-3-51.5	Till	51.50	57.0	11.0	25.4	1.0	12.90	1.20	8.0	<50	2.5	32.0	14.5	36.0	0.3	1.85	495
* W00-3-51.5	Till	51.50	57.0	12.0	26.6	2.0	13.05	1.30	8.0	<50	2.8	34.0	13.5	37.8	0.3	1.89	515
W00-3-52.5	Till	52.50	63.0	11.0	25.0	<1	12.20	1.20	8.0	<50	2.6	32.0	15.5	36.2	0.3	1.69	465
W00-3-53.5	Till	53.50	58.0	10.0	25.0	2.0	12.75	1.15	8.0	<50	2.7	32.0	13.5	37.0	0.2	1.74	495
W00-3-54.5	Till	54.50	56.0	11.0	26.6	2.0	12.80	1.20	8.0	<50	2.7	34.0	16.5	37.6	0.3	1.68	475
W00-3-55.5	Till	55.50	63.0	11.0	29.6	<1	14.50	1.35	8.0	<50	2.5	32.0	18.5	42.6	0.3	1.65	515
W00-3-56.6	Till	56.60	73.0	10.0	33.2	2.0	15.90	1.30	8.0	<50	3.0	35.0	16.0	48.2	0.3	1.70	590
W00-3-57.6	Till	57.60	66.0	11.0	29.8	3.0	14.80	1.30	7.0	<50	3.3	38.0	16.0	42.8	0.3	1.74	550
W00-3-58.6	Till	58.60	69.0	17.0	41.6	<1	15.85	1.40	8.0	<50	3.2	38.0	46.5	46.8	0.3	1.78	590
W00-3-59.6	Till	59.60	66.0	13.0	29.2	1.0	14.35	1.30	8.0	<50	3.3	34.0	15.0	41.2	0.3	1.74	540
W00-3-60.6	Till	60.60	71.0	16.0	30.8	1.0	15.35	1.40	8.0	<50	3.1	37.0	15.0	44.6	0.3	1.77	590
W00-3-62.0	Till	62.00	57.0	12.0	28.0	1.0	13.60	1.30	6.0	<50	3.1	38.0	15.0	39.2	0.3	1.55	500
W00-3-63.0	Till	63.00	60.0	15.0	27.2	<1	13.05	1.25	8.0	<50	2.8	34.0	17.5	37.4	0.2	1.68	540
W00-3-64.1	Till	64.10	57.0	12.0	25.8	<1	13.00	1.20	6.0	<50	2.6	34.0	15.0	37.6	0.2	1.62	510
W00-3-65.45	Till	65.45	65.0	11.0	31.2	2.0	14.60	1.35	8.0	<50	3.0	35.0	18.5	43.2	0.2	1.62	520
W00-3-66.5	Till	66.50	62.0	11.0	31.8	2.0	13.80	1.35	7.0	<50	2.9	37.0	21.5	40.4	0.3	1.66	505
W00-3-68.0	Till	68.00	62.0	15.0	30.0	<1	14.35	1.30	7.0	<50	2.8	36.0	19.0	42.4	0.2	1.65	500
W00-3-68.9	Till	68.90	65.0	13.0	30.2	2.0	14.85	1.35	7.0	<50	3.1	37.0	15.0	43.2	0.3	1.61	520
W00-3-73.3	Till	73.30	62.0	14.0	27.8	1.0	13.55	1.25	7.0	<50	2.9	38.0	13.5	39.6	0.3	1.77	530
W00-3-77.05	Till & Clay	77.05	56.0	12.0	27.2	<1	13.15	1.25	8.0	<50	2.7	35.0	16.0	37.6	0.3	1.80	575
* W00-3-77.05	Till & Clay	77.05	55.0	13.0	26.4	<1	12.80	1.20	8.0	<50	2.7	34.0	15.0	37.2	0.3	1.79	580
W00-3-77.85	Till	77.85	49.0	12.0	23.6	2.0	12.45	1.50	8.0	<50	2.7	35.0	18.0	32.0	<0.2	0.76	455
W00-3-78.35	Till	78.35	49.0	13.0	24.8	2.0	12.35	1.50	11.0	<50	3.1	40.0	15.0	31.4	0.3	0.77	395
W00-3-78.85	Till	78.85	50.0	11.0	25.0	2.0	12.65	1.45	12.0	<50	3.1	40.0	16.0	33.0	0.3	0.75	350
W00-3-79.85	Till	79.85	49.0	11.0	23.8	2.0	12.30	1.45	12.0	<50	3.0	40.0	15.5	34.6	0.3	0.90	530
W00-3-80.85	Till	80.85	56.0	13.0	27.2	<1	12.85	1.45	12.0	<50	2.6	39.0	24.0	37.8	0.4	0.94	500
W00-3-82.55	Till	82.55	55.0	13.0	24.0	<1	12.75	1.40	10.0	<50	2.7	37.0	16.5	37.8	0.3	0.95	475
W00-3-83.60	Till	83.60	54.0	11.0	26.0	<1	13.55	1.50	9.0	<50	3.6	35.0	15.0	39.8	0.3	0.94	460
W00-3-84.6	Till	84.60	52.0	17.0	25.8	1.0	13.05	1.40	12.0	<50	2.9	39.0	16.0	38.6	0.3	0.96	455
W00-3-92.0	Till	92.00	51.0	11.0	27.8	2.0	13.50	1.45	12.0	<50	2.9	40.0	22.5	38.8	0.4	0.93	430

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-49.3	Till	49.30	30.0	1.10	25.2	9.2	580	1.76	66.7	5.5	10.0	<5	0.50	0.75	150.5	1.0	<0.05
W00-3-50.5	Till	50.50	30.0	1.05	23.8	8.7	530	1.69	64.4	5.5	9.4	<5	0.30	0.72	138.0	0.8	<0.05
W00-3-51.5	Till	51.50	30.0	1.10	25.2	9.3	560	1.72	66.5	5.4	9.3	<5	0.30	0.70	150.0	1.1	<0.05
* W00-3-51.5	Till	51.50	20.0	1.20	26.2	9.7	570	1.75	68.1	5.8	11.0	<5	0.30	0.73	148.5	1.3	<0.05
W00-3-52.5	Till	52.50	20.0	1.15	24.6	9.1	560	1.64	64.1	5.4	9.5	<5	0.30	0.74	138.0	1.1	<0.05
W00-3-53.5	Till	53.50	30.0	1.05	23.8	9.0	570	1.69	65.2	5.3	10.0	<5	0.30	0.69	138.0	0.9	<0.05
W00-3-54.5	Till	54.50	40.0	1.00	24.8	9.2	560	1.70	67.2	5.2	10.0	<5	0.30	0.67	142.5	0.8	<0.05
W00-3-55.5	Till	55.50	30.0	1.15	29.0	10.5	600	1.81	75.6	5.0	9.0	<5	0.30	0.67	147.0	0.6	<0.05
W00-3-56.6	Till	56.60	30.0	1.25	32.2	11.5	650	1.91	83.1	5.6	10.0	<5	0.35	0.64	147.0	1.1	0.05
W00-3-57.6	Till	57.60	30.0	1.10	29.2	10.6	630	1.85	76.1	6.3	12.0	<5	0.30	0.71	144.5	1.0	<0.05
W00-3-58.6	Till	58.60	30.0	1.20	31.8	11.2	620	1.90	82.9	6.1	12.0	<5	0.35	0.72	152.5	1.2	<0.05
W00-3-59.6	Till	59.60	30.0	1.05	28.2	10.6	610	1.77	73.2	5.9	11.0	<5	0.30	0.50	147.0	1.0	<0.05
W00-3-60.6	Till	60.60	30.0	1.15	30.4	11.2	650	1.87	78.4	6.0	11.0	<5	0.40	0.73	144.0	1.1	<0.05
W00-3-62.0	Till	62.00	20.0	1.00	26.4	10.3	550	1.72	70.0	6.1	12.0	<5	0.30	0.73	138.5	1.1	0.05
W00-3-63.0	Till	63.00	20.0	1.05	26.4	9.7	580	1.78	67.8	5.8	10.0	<5	0.40	0.70	139.0	1.1	0.05
W00-3-64.1	Till	64.10	30.0	0.95	25.4	9.2	570	1.73	67.3	5.7	10.0	<5	0.30	0.70	132.5	1.1	<0.05
W00-3-65.45	Till	65.45	30.0	1.15	28.8	10.9	580	1.80	76.1	5.8	10.0	<5	0.30	0.75	139.5	1.0	0.05
W00-3-66.5	Till	66.50	30.0	1.05	27.8	10.5	580	1.77	71.9	5.8	11.0	<5	0.40	0.69	140.0	0.9	<0.05
W00-3-68.0	Till	68.00	30.0	1.10	28.4	10.3	560	1.82	74.0	5.8	10.0	<5	0.35	0.73	140.0	1.1	<0.05
W00-3-68.9	Till	68.90	30.0	1.10	29.8	10.6	600	1.84	75.1	5.9	12.0	<5	0.35	0.74	139.5	0.9	0.05
W00-3-73.3	Till	73.30	30.0	1.05	27.0	9.7	620	1.74	70.1	5.9	11.0	<5	0.30	0.70	143.0	1.0	<0.05
W00-3-77.05	Till & Clay	77.05	30.0	1.00	25.6	9.6	580	1.69	67.8	5.6	10.0	<5	0.25	0.78	150.5	0.9	<0.05
* W00-3-77.05	Till & Clay	77.05	30.0	1.05	25.4	9.4	550	1.69	66.7	5.4	10.0	<5	0.30	0.74	145.0	0.9	<0.05
W00-3-77.85	Till	77.85	30.0	2.25	22.6	10.5	630	1.62	66.0	5.7	10.0	<5	0.35	0.79	125.0	0.9	0.05
W00-3-78.35	Till	78.35	30.0	2.65	22.8	10.2	740	1.62	64.0	6.6	10.0	<5	0.35	0.73	119.0	1.2	<0.05
W00-3-78.85	Till	78.85	40.0	4.00	23.6	10.6	740	1.64	65.4	6.5	10.0	<5	0.30	0.70	123.5	1.1	<0.05
W00-3-79.85	Till	79.85	30.0	1.10	21.2	10.6	580	1.65	65.7	6.6	11.0	<5	0.30	0.68	128.5	1.2	<0.05
W00-3-80.85	Till	80.85	30.0	1.00	22.2	10.4	580	1.61	67.0	6.5	10.0	<5	0.35	0.65	129.0	1.6	<0.05
W00-3-82.55	Till	82.55	40.0	0.95	22.4	10.2	580	1.63	66.1	6.2	11.0	<5	0.30	0.62	130.5	0.9	<0.05
W00-3-83.60	Till	83.60	30.0	1.05	23.2	11.4	580	1.64	70.3	5.5	12.0	<5	0.35	0.50	134.0	1.0	0.05
W00-3-84.6	Till	84.60	30.0	1.35	22.8	10.5	560	1.64	67.8	6.2	11.0	<5	0.35	0.69	130.5	1.3	<0.05
W00-3-92.0	Till	92.00	30.0	1.15	23.2	10.3	590	1.66	68.7	6.6	11.0	<5	0.35	0.73	135.0	1.1	<0.05

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	Material	Depth	Tb	Tl	Th	Sn	Ti	W	U	V	Yb	Y	Zn	Zr
			ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
W00-3-49.3	Till	49.30	0.6	0.48	10.0	<100	0.28	0.7	2.8	96.0	<2	17.9	<100	<200
W00-3-50.5	Till	50.50	0.8	0.46	10.0	<100	0.27	0.8	2.7	87.0	<2	17.2	<100	340
W00-3-51.5	Till	51.50	0.6	0.48	10.0	<100	0.28	0.7	2.6	94.0	<2	17.9	<100	<200
* W00-3-51.5	Till	51.50	0.7	0.48	10.0	<100	0.30	0.8	2.7	96.0	<2	18.1	<100	<200
W00-3-52.5	Till	52.50	<0.5	0.46	9.5	<100	0.28	0.7	2.9	93.0	<2	17.4	<100	370
W00-3-53.5	Till	53.50	0.8	0.46	9.4	<100	0.29	0.8	2.7	96.0	<2	17.6	100	<200
W00-3-54.5	Till	54.50	0.8	0.48	10.0	<100	0.28	0.8	2.6	93.0	<2	18.2	<100	<200
W00-3-55.5	Till	55.50	0.8	0.52	8.9	<100	0.32	0.8	2.6	107.0	<2	19.5	120	350
W00-3-56.6	Till	56.60	0.6	0.56	11.0	<100	0.33	0.9	2.7	123.0	<2	20.0	<100	<200
W00-3-57.6	Till	57.60	0.6	0.52	11.0	<100	0.33	0.8	2.9	117.0	<2	18.9	<100	<200
W00-3-58.6	Till	58.60	0.7	0.56	11.0	<100	0.33	1.0	2.8	121.0	2.0	20.1	<100	<200
W00-3-59.6	Till	59.60	0.8	0.54	10.0	<100	0.31	0.8	3.2	111.0	2.0	19.1	<100	340
W00-3-60.6	Till	60.60	0.5	0.52	11.0	140	0.33	0.9	2.9	122.0	<2	19.1	140	<200
W00-3-62.0	Till	62.00	0.8	0.50	11.0	<100	0.30	0.8	2.9	94.0	2.0	18.1	<100	<200
W00-3-63.0	Till	63.00	0.7	0.48	10.0	<100	0.31	0.9	2.8	98.0	<2	18.1	<100	<200
W00-3-64.1	Till	64.10	0.7	0.46	10.0	<100	0.30	0.7	2.6	97.0	<2	17.9	<100	400
W00-3-65.45	Till	65.45	0.7	0.52	10.0	<100	0.32	0.8	2.8	107.0	<2	19.0	<100	<200
W00-3-66.5	Till	66.50	0.9	0.52	10.0	<100	0.31	0.9	2.8	101.0	<2	18.8	<100	<200
W00-3-68.0	Till	68.00	0.8	0.52	10.0	<100	0.30	0.8	2.9	103.0	<2	18.8	<100	370
W00-3-68.9	Till	68.90	0.6	0.52	11.0	<100	0.33	0.8	2.9	109.0	<2	18.3	<100	<200
W00-3-73.3	Till	73.30	0.8	0.50	11.0	<100	0.29	0.8	3.0	104.0	<2	18.3	<100	<200
W00-3-77.05	Till & Clay	77.05	<0.5	0.52	9.4	<100	0.29	0.8	2.7	95.0	<2	18.1	<100	<200
* W00-3-77.05	Till & Clay	77.05	0.7	0.54	9.4	<100	0.29	0.7	3.2	91.0	<2	17.9	160	<200
W00-3-77.85	Till	77.85	0.6	0.46	10.0	<100	0.31	0.9	3.4	81.0	<2	19.9	<100	<200
W00-3-78.35	Till	78.35	0.9	0.46	12.0	<100	0.31	0.8	2.9	84.0	3.0	19.4	110	480
W00-3-78.85	Till	78.85	0.9	0.50	12.0	<100	0.31	0.8	2.8	82.0	3.0	20.2	<100	380
W00-3-79.85	Till	79.85	0.9	0.46	11.0	<100	0.32	0.9	2.8	83.0	2.0	19.2	<100	480
W00-3-80.85	Till	80.85	0.9	0.44	11.0	<100	0.30	1.3	3.3	91.0	2.0	18.7	<100	<200
W00-3-82.55	Till	82.55	0.9	0.44	11.0	<100	0.31	0.8	3.2	89.0	<2	18.7	<100	<200
W00-3-83.60	Till	83.60	0.8	0.48	10.0	<100	0.32	0.9	2.8	89.0	2.0	19.5	<100	440
W00-3-84.6	Till	84.60	0.8	0.44	11.0	<100	0.32	0.8	3.5	86.0	2.0	18.9	<100	580
W00-3-92.0	Till	92.00	0.9	0.46	12.0	<100	0.31	1.0	3.5	90.0	3.0	19.1	<100	500

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-93.0	Till	93.00	8.1	<2	6.22	0.7	8.0	590.0	451.5	1.50	0.43	1.5	0.54	1.21	80.0	4.0	72.0
W00-3-93.9	Till	93.90	7.1	<2	6.35	0.7	8.2	580.0	466.5	1.50	0.44	1.6	0.32	1.21	78.0	4.1	73.0
W00-2-108.7	Till	108.70	6.9	<2	6.27	0.4	6.9	470.0	562.0	1.30	0.46	1.6	0.52	2.29	65.0	2.7	52.0
W00-3-109.75	Till	109.75	7.4	<2	6.34	0.6	8.6	580.0	406.0	1.30	0.41	1.6	1.48	1.18	76.0	4.5	61.0
W00-3-110.7	Till	110.70	7.2	<2	6.86	0.6	10.0	530.0	411.0	1.40	0.46	1.0	0.66	1.25	80.0	4.6	85.0
W00-3-111.75	Till	111.75	7.7	<2	5.64	0.6	11.0	500.0	421.0	1.30	0.53	1.5	0.16	1.28	82.0	4.2	73.0
W00-3-112.8	Till	112.80	6.6	<2	6.22	0.7	9.1	540.0	477.0	1.45	0.51	1.7	0.28	1.15	85.0	4.9	75.0
W00-3-113.85	Till	113.85	6.0	<2	6.26	0.6	8.8	570.0	474.0	1.45	0.52	1.4	0.38	1.03	81.0	4.9	80.0
W00-3-114.9	Till	114.90	7.5	<2	5.93	0.8	10.0	680.0	496.5	1.30	0.51	2.1	0.34	1.15	88.0	5.0	66.0
W00-3-115.95	Till	115.95	6.0	8.0	6.08	0.8	10.0	660.0	487.5	1.30	0.50	1.4	0.28	1.23	91.0	4.8	70.0
* W00-3-115.95	Till	115.95	6.9	<2	6.20	0.8	9.0	600.0	509.8	1.40	0.51	2.1	1.88	1.24	89.0	4.4	90.0
W00-3-117.05	Till	117.05	7.5	<2	5.87	0.7	10.0	620.0	499.5	1.30	0.50	1.4	0.32	1.16	84.0	5.0	68.0
W00-3-118.05	Till	118.05	6.4	<2	6.15	0.7	10.0	630.0	505.9	1.30	0.52	1.7	0.52	1.19	85.0	4.5	62.0
W00-3-119.05	Till	119.05	7.4	<2	5.83	0.7	10.0	640.0	487.0	1.25	0.50	1.8	0.28	1.10	83.0	4.6	70.0
W00-3-120.10	Till	120.10	7.9	<2	6.40	0.7	8.8	650.0	499.5	1.40	0.49	1.7	0.22	1.06	76.0	4.9	78.0
W00-3-121.0	Till	121.00	7.8	9.0	5.70	0.6	5.9	550.0	427.0	1.35	0.45	1.0	0.20	1.06	99.0	3.9	77.0
W00-3-125.5	Till	125.50	8.8	7.0	4.68	0.7	10.0	540.0	387.5	1.10	0.43	1.5	0.68	0.60	81.0	3.3	72.0
W00-3-127.7	Till	127.70	8.2	<2	4.26	0.6	8.8	520.0	379.0	1.05	0.41	1.2	0.24	0.56	77.0	3.4	66.0
W00-3-129.05	Till	129.05	8.4	<2	5.51	0.6	10.0	530.0	418.0	1.30	0.49	1.4	0.30	0.57	86.0	4.0	69.0
W00-3-131.95	Till	131.95	7.1	<2	5.19	0.6	9.4	530.0	407.0	1.25	0.47	1.8	0.24	0.57	99.0	4.1	70.0
W00-3-133.0	Till	133.00	8.3	<2	5.48	0.7	10.0	550.0	435.5	1.30	0.49	1.8	0.26	0.60	99.0	4.0	73.0
W00-3-134.25	Till	134.25	7.0	<2	5.77	0.6	8.8	450.0	404.0	1.35	0.50	1.5	0.26	0.62	98.0	3.8	59.0
W00-3-135.3	Till	135.30	6.6	<2	6.33	4.0	23.0	670.0	101.5	1.55	0.58	6.0	2.22	1.50	91.0	5.7	94.0
W00-3-136.25	Till	136.25	7.3	<2	5.70	0.8	10.0	560.0	439.5	1.35	0.48	1.6	0.36	0.91	96.0	3.6	66.0
W00-3-138.2	Till	138.20	7.7	<2	5.19	0.8	12.0	550.0	437.5	1.30	0.51	1.4	0.34	0.91	94.0	3.9	60.0
W00-3-139.2	Till	139.20	7.2	<2	5.08	0.8	11.0	520.0	209.0	1.15	0.49	2.3	0.34	0.97	94.0	3.9	79.0
W00-3-140.2	Till	140.20	7.1	6.0	5.47	0.8	12.0	590.0	236.5	1.45	0.50	2.2	0.32	0.92	99.0	4.4	68.0
W00-3-141.65	Till	141.65	5.9	<2	5.74	0.7	11.0	600.0	218.0	1.35	0.49	1.8	0.36	0.91	97.0	4.0	67.0
W00-3-143.1	Till	143.10	9.6	<2	5.87	0.8	8.3	640.0	493.0	1.30	0.47	1.5	0.58	1.61	100.0	4.2	78.0
* W00-3-143.1	Till	143.10	5.9	<4	5.77	0.9	8.3	760.0	504.8	1.30	0.46	1.8	0.54	1.58	90.0	3.5	61.0
W00-3-144.2	Till	144.20	6.1	<2	5.44	0.6	6.3	630.0	473.5	1.40	0.44	1.1	0.30	1.66	88.0	3.6	61.0
W00-3-145.15	Till	145.15	6.8	<2	5.47	2.7	23.0	680.0	184.0	1.65	0.61	4.7	1.88	1.20	82.0	4.2	74.0

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-3-93.0	Till	93.00	55.0	13.0	25.2	1.0	13.75	1.55	10.0	<50	2.8	39.0	14.5	40.4	0.3	0.92	405
W00-3-93.9	Till	93.90	55.0	11.0	26.4	1.0	13.80	1.55	10.0	<50	2.9	38.0	15.5	41.0	0.3	0.92	400
W00-2-108.7	Till	108.70	57.0	12.0	28.4	<1	13.65	1.50	9.0	<50	2.4	30.0	17.0	32.8	<0.2	1.05	605
W00-3-109.75	Till	109.75	57.0	12.0	25.4	2.0	13.55	1.50	10.0	<50	3.1	38.0	19.5	45.0	0.3	0.96	345
W00-3-110.7	Till	110.70	60.0	14.0	26.6	<1	14.85	1.50	9.0	<50	3.1	37.0	15.0	48.6	0.3	1.04	365
W00-3-111.75	Till	111.75	49.0	14.0	27.0	2.0	13.25	1.20	11.0	<50	2.8	37.0	14.5	40.8	0.3	0.96	305
W00-3-112.8	Till	112.80	57.0	12.0	29.8	2.0	14.95	1.40	10.0	<50	3.1	39.0	14.0	44.2	0.3	0.98	365
W00-3-113.85	Till	113.85	55.0	12.0	30.2	1.0	14.90	1.50	10.0	<50	3.2	39.0	15.0	41.8	0.3	0.85	345
W00-3-114.9	Till	114.90	55.0	14.0	29.8	1.0	14.25	1.40	10.0	<50	3.1	41.0	15.0	38.6	0.4	0.83	400
W00-3-115.95	Till	115.95	55.0	13.0	30.2	1.0	14.00	1.45	10.0	<50	3.2	42.0	15.5	38.4	0.3	0.87	430
* W00-3-115.95	Till	115.95	54.0	13.0	30.2	2.0	14.30	1.40	11.0	<50	3.1	37.0	15.0	38.6	0.3	0.87	425
W00-3-117.05	Till	117.05	53.0	13.0	28.8	1.0	13.70	1.40	10.0	<50	3.1	39.0	14.5	37.8	0.4	0.82	405
W00-3-118.05	Till	118.05	54.0	12.0	30.0	1.0	14.30	1.50	9.0	<50	3.2	39.0	15.0	38.4	0.3	0.87	420
W00-3-119.05	Till	119.05	52.0	13.0	28.6	2.0	13.45	1.40	10.0	<50	3.1	40.0	15.5	35.0	0.4	0.80	380
W00-3-120.10	Till	120.10	57.0	14.0	29.8	1.0	14.35	1.40	9.0	<50	3.2	40.0	12.0	41.0	0.3	0.87	365
W00-3-121.0	Till	121.00	47.0	13.0	26.0	1.0	13.65	1.30	13.0	<50	3.0	47.0	12.5	35.2	0.4	0.74	575
W00-3-125.5	Till	125.50	39.0	16.0	25.0	2.0	10.25	1.25	14.0	<50	2.7	40.0	12.0	32.4	0.5	0.52	425
W00-3-127.7	Till	127.70	35.0	14.0	23.6	1.0	9.70	1.30	17.0	<50	2.7	39.0	12.5	30.0	0.5	0.46	425
W00-3-129.05	Till	129.05	47.0	12.0	27.2	2.0	12.70	1.45	14.0	<50	3.0	44.0	14.5	30.8	0.4	0.62	555
W00-3-131.95	Till	131.95	43.0	14.0	27.0	2.0	11.75	1.40	16.0	<50	2.7	44.0	14.5	31.4	0.4	0.59	540
W00-3-133.0	Till	133.00	46.0	16.0	27.4	2.0	12.75	1.40	14.0	<50	2.8	46.0	14.5	32.6	0.4	0.61	495
W00-3-134.25	Till	134.25	49.0	13.0	29.8	3.0	13.20	1.45	15.0	<50	2.7	43.0	16.0	33.6	0.4	0.64	490
W00-3-135.3	Till	135.30	65.0	14.0	46.6	1.0	14.30	1.35	10.0	<50	3.3	42.0	16.0	37.8	0.3	0.72	405
W00-3-136.25	Till	136.25	45.0	17.0	29.2	1.0	12.80	1.35	13.0	<50	3.1	48.0	15.0	31.6	0.5	0.72	535
W00-3-138.2	Till	138.20	44.0	14.0	30.8	2.0	11.95	1.40	13.0	<50	2.7	44.0	17.5	29.0	0.4	0.67	445
W00-3-139.2	Till	139.20	42.0	12.0	28.4	1.0	11.25	1.35	15.0	<50	2.9	45.0	15.5	26.4	0.5	0.63	480
W00-3-140.2	Till	140.20	46.0	10.0	30.0	1.0	12.40	1.35	13.0	<50	2.9	46.0	16.0	30.2	0.5	0.68	440
W00-3-141.65	Till	141.65	47.0	15.0	29.2	2.0	12.60	1.40	13.0	<50	2.8	46.0	16.0	30.6	0.4	0.73	475
W00-3-143.1	Till	143.10	49.0	16.0	29.4	2.0	13.65	1.25	13.0	<50	3.0	48.0	14.5	32.2	0.4	0.87	550
* W00-3-143.1	Till	143.10	49.0	11.0	28.6	2.0	13.45	1.25	13.0	<50	3.0	45.0	14.0	31.6	0.4	0.86	540
W00-3-144.2	Till	144.20	46.0	13.0	26.8	2.0	13.15	1.20	13.0	<50	2.8	48.0	13.5	31.2	0.4	0.83	525
W00-3-145.15	Till	145.15	54.0	17.0	43.0	2.0	13.20	1.50	11.0	<50	3.4	47.0	16.5	31.0	0.4	0.62	500

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	Material	Depth	Hg	Mo	Ni	Nb	P	K	Rb	Sm	Sc	Se	Ag	Na	Sr	Ta	Te
			ppb	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm
W00-3-93.0	Till	93.00	30.0	1.05	22.8	10.4	630	1.71	71.9	6.3	12.0	<5	0.30	0.73	130.5	0.8	<0.05
W00-3-93.9	Till	93.90	30.0	1.05	23.2	10.2	620	1.71	72.4	6.2	12.0	<5	0.35	0.72	136.5	1.2	<0.05
W00-2-108.7	Till	108.70	30.0	1.70	27.0	11.2	710	1.58	69.1	4.8	9.0	<5	0.35	0.65	157.0	0.8	0.05
W00-3-109.75	Till	109.75	40.0	1.20	24.0	9.8	550	1.69	69.9	6.1	12.0	<5	0.30	0.60	125.5	1.2	0.05
W00-3-110.7	Till	110.70	30.0	1.15	25.2	10.4	610	1.77	75.7	6.2	13.0	<5	0.30	0.64	128.0	1.3	<0.05
W00-3-111.75	Till	111.75	30.0	2.05	24.0	9.9	550	1.48	73.1	6.1	11.0	<5	0.25	0.60	127.0	1.2	0.05
W00-3-112.8	Till	112.80	40.0	1.25	26.2	10.8	600	1.61	83.3	6.2	12.0	<5	0.30	0.60	144.5	1.2	<0.05
W00-3-113.85	Till	113.85	50.0	1.25	24.8	11.1	610	1.56	81.8	6.4	12.0	<5	0.25	0.60	147.0	1.3	0.05
W00-3-114.9	Till	114.90	40.0	2.05	25.6	11.0	670	1.44	76.2	6.5	12.0	<5	0.25	0.62	143.5	1.3	0.05
W00-3-115.95	Till	115.95	30.0	1.85	25.8	10.5	660	1.43	75.5	6.7	12.0	<5	0.25	0.63	147.0	1.0	<0.05
* W00-3-115.95	Till	115.95	30.0	1.80	25.4	11.4	640	1.62	80.8	6.5	11.0	<5	0.30	0.59	150.5	1.1	<0.05
W00-3-117.05	Till	117.05	40.0	1.80	24.8	10.5	620	1.53	77.9	6.4	12.0	<5	0.25	0.60	143.5	1.0	0.05
W00-3-118.05	Till	118.05	30.0	1.85	25.8	11.1	660	1.56	80.0	6.6	12.0	<5	0.25	0.58	150.5	1.1	<0.05
W00-3-119.05	Till	119.05	30.0	1.50	23.8	10.6	630	1.46	73.6	6.6	12.0	<5	0.25	0.64	146.0	1.5	<0.05
W00-3-120.10	Till	120.10	40.0	1.20	25.8	10.7	620	1.64	82.5	6.4	13.0	<5	0.25	0.62	144.5	1.3	<0.05
W00-3-121.0	Till	121.00	30.0	1.00	22.8	11.0	520	1.49	75.1	7.5	11.0	<5	0.25	0.70	130.0	1.3	<0.05
W00-3-125.5	Till	125.50	30.0	1.40	19.8	9.1	500	1.26	56.5	6.8	11.0	<5	0.20	0.62	103.5	1.3	<0.05
W00-3-127.7	Till	127.70	30.0	1.40	18.2	9.1	470	1.19	54.2	6.8	10.0	<5	0.20	0.64	99.8	1.4	<0.05
W00-3-129.05	Till	129.05	30.0	1.35	22.8	11.7	590	1.42	69.0	7.5	11.0	<5	0.30	0.50	117.5	1.6	<0.05
W00-3-131.95	Till	131.95	20.0	1.30	21.6	11.2	550	1.34	66.8	7.4	11.0	<5	0.30	0.54	114.0	1.1	<0.05
W00-3-133.0	Till	133.00	30.0	1.55	22.0	11.0	600	1.34	70.3	7.2	11.0	<5	0.25	0.48	122.0	1.5	<0.05
W00-3-134.25	Till	134.25	30.0	1.75	22.6	12.5	600	1.45	74.4	6.8	10.0	<5	0.30	0.52	129.0	1.2	<0.05
W00-3-135.3	Till	135.30	80.0	15.85	46.8	11.6	900	1.49	79.9	7.4	12.0	5.0	0.45	0.49	183.5	1.4	0.05
W00-3-136.25	Till	136.25	40.0	1.95	22.0	12.0	640	1.62	76.5	7.7	11.0	<5	0.25	0.59	142.5	1.3	<0.05
W00-3-138.2	Till	138.20	40.0	2.15	24.4	10.9	730	1.40	69.0	7.8	11.0	<5	0.30	0.54	141.5	1.2	<0.05
W00-3-139.2	Till	139.20	40.0	2.20	22.8	11.3	760	1.44	65.9	7.9	10.0	<5	0.30	0.56	142.0	1.5	<0.05
W00-3-140.2	Till	140.20	30.0	2.10	23.6	11.8	710	1.47	71.1	7.8	12.0	<5	0.30	0.56	143.0	1.3	<0.05
W00-3-141.65	Till	141.65	30.0	1.80	24.0	11.7	700	1.46	71.6	7.6	11.0	<5	0.30	0.59	148.0	1.5	<0.05
W00-3-143.1	Till	143.10	30.0	2.15	24.0	12.2	640	1.61	75.3	7.5	12.0	<5	0.30	0.70	164.5	1.3	<0.05
* W00-3-143.1	Till	143.10	30.0	2.20	23.4	11.8	650	1.60	74.0	7.4	12.0	<5	0.25	0.69	160.0	1.3	<0.05
W00-3-144.2	Till	144.20	30.0	1.40	22.6	11.3	580	1.63	74.3	7.4	11.0	<5	0.20	0.70	148.0	1.4	<0.05
W00-3-145.15	Till	145.15	60.0	8.50	38.8	12.3	940	1.41	77.0	7.8	11.0	<5	0.45	0.45	179.0	1.3	<0.05

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-3-93.0	Till	93.00	0.9	0.48	11.0	<100	0.31	0.8	3.2	96.0	2.0	19.3	<100	310
W00-3-93.9	Till	93.90	0.7	0.48	11.0	<100	0.30	0.8	3.1	97.0	2.0	19.1	<100	510
W00-2-108.7	Till	108.70	0.6	0.52	8.4	<100	0.32	0.9	2.4	113.0	<2	21.6	<100	<200
W00-3-109.75	Till	109.75	0.7	0.44	10.0	<100	0.31	0.8	3.0	98.0	2.0	17.6	<100	470
W00-3-110.7	Till	110.70	0.8	0.44	10.0	<100	0.32	0.8	3.2	104.0	2.0	19.0	<100	<200
W00-3-111.75	Till	111.75	0.8	0.46	10.0	<100	0.28	0.9	3.1	90.0	2.0	18.5	<100	<200
W00-3-112.8	Till	112.80	0.9	0.52	11.0	<100	0.30	0.9	3.3	108.0	3.0	20.0	<100	390
W00-3-113.85	Till	113.85	0.8	0.54	11.0	<100	0.31	1.0	2.8	103.0	3.0	20.2	130	330
W00-3-114.9	Till	114.90	1.0	0.58	11.0	<100	0.30	1.0	3.7	108.0	2.0	21.2	<100	360
W00-3-115.95	Till	115.95	0.6	0.56	11.0	<100	0.29	0.9	3.9	105.0	2.0	20.9	110	720
* W00-3-115.95	Till	115.95	0.8	0.58	11.0	<100	0.32	0.9	3.7	105.0	<2	21.3	<100	490
W00-3-117.05	Till	117.05	1.0	0.56	11.0	<100	0.30	0.9	3.6	102.0	2.0	20.5	<100	380
W00-3-118.05	Till	118.05	0.9	0.56	11.0	<100	0.30	1.0	3.8	105.0	3.0	21.8	140	500
W00-3-119.05	Till	119.05	0.8	0.52	11.0	<100	0.29	1.0	3.6	100.0	3.0	21.2	<100	<200
W00-3-120.10	Till	120.10	0.8	0.54	11.0	<100	0.31	1.2	3.3	107.0	2.0	20.0	100	550
W00-3-121.0	Till	121.00	0.8	0.48	13.0	<100	0.31	0.9	4.0	83.0	3.0	22.5	<100	550
W00-3-125.5	Till	125.50	0.9	0.42	10.0	<100	0.29	0.8	3.7	70.0	3.0	18.8	<100	520
W00-3-127.7	Till	127.70	1.0	0.40	11.0	<100	0.28	0.7	3.6	63.0	3.0	18.7	<100	570
W00-3-129.05	Till	129.05	1.0	0.48	12.0	<100	0.33	1.0	4.3	83.0	3.0	22.2	<100	490
W00-3-131.95	Till	131.95	0.9	0.44	12.0	<100	0.32	1.0	4.0	81.0	3.0	21.7	<100	510
W00-3-133.0	Till	133.00	0.9	0.48	12.0	<100	0.31	1.3	4.2	86.0	3.0	22.4	<100	530
W00-3-134.25	Till	134.25	1.1	0.54	11.0	<100	0.35	1.2	4.0	88.0	3.0	23.2	<100	510
W00-3-135.3	Till	135.30	1.1	1.66	11.0	<100	0.30	1.2	8.5	282.0	3.0	26.8	160	<200
W00-3-136.25	Till	136.25	1.1	0.58	12.0	<100	0.34	1.1	3.6	80.0	3.0	23.5	<100	360
W00-3-138.2	Till	138.20	1.1	0.62	12.0	<100	0.29	1.1	4.5	85.0	3.0	24.4	<100	520
W00-3-139.2	Till	139.20	1.1	0.58	13.0	<100	0.31	1.1	4.4	78.0	3.0	24.5	<100	620
W00-3-140.2	Till	140.20	0.8	0.58	12.0	<100	0.32	1.1	4.6	86.0	3.0	24.3	150	500
W00-3-141.65	Till	141.65	0.8	0.58	12.0	<100	0.32	1.1	4.4	85.0	3.0	23.8	<100	480
W00-3-143.1	Till	143.10	1.1	0.64	13.0	<100	0.32	1.0	4.4	96.0	3.0	23.4	<100	480
* W00-3-143.1	Till	143.10	0.8	0.62	13.0	<100	0.31	1.0	4.2	97.0	3.0	22.6	<100	660
W00-3-144.2	Till	144.20	1.0	0.52	12.0	<100	0.31	0.9	3.7	80.0	3.0	21.5	<100	530
W00-3-145.15	Till	145.15	1.0	1.50	12.0	<100	0.28	1.1	6.7	200.0	3.0	29.3	<100	<200

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-147.1	Till	147.10	7.7	<2	5.44	2.7	22.0	680.0	157.5	1.60	0.60	4.0	1.90	1.22	88.0	4.8	84.0
W00-3-148.0	Till	148.00	6.3	<2	5.38	2.3	20.0	550.0	126.0	1.55	0.58	3.7	1.52	1.13	91.0	4.7	55.0
W00-3-149.3	Till	149.30	5.8	<2	5.27	1.3	15.0	640.0	439.5	1.35	0.50	2.6	0.98	0.82	86.0	4.8	66.0
W00-3-151.0	Till	151.00	6.8	<2	6.44	2.4	19.0	1100.0	174.5	1.65	0.60	3.9	1.58	1.33	98.0	4.3	66.0
W00-3-152.15	Till	152.15	5.9	<5	5.98	2.4	19.0	750.0	244.5	1.55	0.55	2.8	1.54	1.57	92.0	4.8	84.0

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-3-147.1	Till	147.10	53.0	16.0	40.8	2.0	12.75	1.40	11.0	<50	3.2	44.0	16.5	29.6	0.4	0.62	480
W00-3-148.0	Till	148.00	52.0	15.0	37.6	1.0	12.50	1.35	10.0	<50	3.4	44.0	16.0	29.0	0.5	0.60	530
W00-3-149.3	Till	149.30	47.0	14.0	30.4	2.0	12.00	1.35	11.0	<50	3.1	47.0	14.5	28.4	0.4	0.58	365
W00-3-151.0	Till	151.00	59.0	13.0	41.8	<1	15.00	1.50	11.0	<50	3.3	44.0	17.0	35.8	0.4	0.69	450
W00-3-152.15	Till	152.15	57.0	15.0	40.2	2.0	14.05	1.40	9.0	<50	3.5	46.0	17.5	33.4	0.4	0.72	505

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-3-147.1	Till	147.10	50.0	8.25	36.4	11.4	930	1.34	70.0	7.6	11.0	<5	0.40	0.45	173.0	1.4	0.05
W00-3-148.0	Till	148.00	50.0	7.05	32.2	11.1	920	1.31	68.9	7.8	11.0	6.0	0.40	0.49	166.5	1.1	<0.05
W00-3-149.3	Till	149.30	40.0	3.75	25.4	10.7	710	1.31	68.6	7.5	12.0	<5	0.30	0.55	158.5	1.3	<0.05
W00-3-151.0	Till	151.00	50.0	8.10	38.4	12.5	900	1.62	85.1	7.5	12.0	5.0	0.45	0.55	189.5	1.6	<0.05
W00-3-152.15	Till	152.15	50.0	8.75	38.2	11.7	910	1.53	78.1	7.4	12.0	<5	0.40	0.60	179.5	1.0	<0.05

Table A3-8: Geochemical analysis of samples from core hole WEPA00-3

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-3-147.1	Till	147.10	0.9	1.38	12.0	<100	0.27	1.2	6.1	199.0	3.0	27.2	100	650
W00-3-148.0	Till	148.00	0.8	1.18	12.0	<100	0.28	1.2	6.0	168.0	3.0	26.9	110	400
W00-3-149.3	Till	149.30	1.0	0.76	12.0	<100	0.28	1.0	4.7	111.0	2.0	23.1	<100	<200
W00-3-151.0	Till	151.00	0.9	1.32	13.0	<100	0.32	1.1	5.6	184.0	3.0	27.9	100	<200
W00-3-152.15	Till	152.15	1.0	1.30	11.0	<100	0.29	1.2	6.5	179.0	3.0	25.8	<100	<200

Notes: < denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* W00-3-29.5 denotes sample duplicate of W00-3-29.5

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-4-10.1	Till	10.10	6.0	<2	4.86	0.6	10.0	520.0	333.5	1.00	0.45	2.0	0.14	0.59	94.0	3.3	48.0
W00-4-11.5	Till	11.50	7.3	<2	5.87	0.6	7.3	540.0	422.0	1.35	0.47	<0.5	0.14	0.85	89.0	4.0	61.0
W00-4-12.2	Till	12.20	8.8	<2	5.40	0.7	8.6	520.0	414.5	1.40	0.46	1.6	0.16	0.77	92.0	3.5	53.0
W00-4-13.1	Till	13.10	7.8	<2	6.05	0.7	11.0	590.0	448.5	1.35	0.49	1.2	0.20	0.78	87.0	4.0	52.0
W00-4-16.1	Till	16.10	11.2	<2	6.49	0.6	10.0	590.0	446.5	1.50	0.50	1.2	0.22	1.17	93.0	5.7	77.0
W00-4-17.1	Till	17.10	8.7	<2	5.87	0.6	7.5	590.0	455.0	1.30	0.45	2.0	0.28	2.36	86.0	3.5	81.0
W00-4-23.1	Till	23.10	7.6	<2	6.11	0.8	8.7	560.0	463.5	1.45	0.49	1.7	0.28	1.43	88.0	3.9	78.0
W00-4-34.0	Till	34.00	10.4	<2	5.74	0.7	8.6	610.0	473.0	1.30	0.46	1.1	0.32	1.61	79.0	4.1	74.0
W00-4-34.9	Till	34.90	7.0	<2	6.59	0.8	11.0	590.0	481.5	1.50	0.50	1.6	0.22	1.04	76.0	5.4	88.0
W00-4-40.0	Sand & Clay	40.00	9.0	8.0	6.29	0.9	7.9	670.0	509.3	1.40	0.50	1.5	0.42	1.88	81.0	4.8	71.0
W00-4-41.0	Till	41.00	7.5	<2	6.47	0.9	8.6	640.0	510.4	1.55	0.50	1.9	0.36	1.85	85.0	4.7	78.0
* W00-4-41.0	Till	41.00	6.4	<2	6.34	0.9	8.9	620.0	504.4	1.55	0.49	1.6	0.32	1.82	87.0	4.6	76.0
W00-4-41.7	Till	41.70	7.0	<2	5.92	0.7	8.4	590.0	468.5	1.35	0.47	1.5	1.04	1.48	83.0	4.2	72.0
W00-4-43.2	Till	43.20	6.7	<2	5.75	0.7	8.7	620.0	446.5	1.30	0.44	1.2	0.22	1.42	88.0	3.8	64.0
W00-4-44.05	Till	44.05	9.1	<2	6.58	0.8	9.4	660.0	523.3	1.50	0.47	1.4	0.32	1.75	79.0	4.0	67.0
W00-4-52.8	Till	52.80	6.0	<2	6.09	0.8	13.0	760.0	543.4	1.45	0.53	2.5	0.26	0.75	85.0	5.0	74.0
W00-4-54.05	Till	54.05	7.5	<2	5.43	0.7	9.3	630.0	509.0	1.30	0.48	1.8	0.28	0.75	75.0	3.8	63.0
W00-4-57.9	Till	57.90	5.8	<2	5.85	0.6	9.3	540.0	410.5	1.40	0.47	1.4	0.16	0.84	88.0	4.7	60.0
W00-4-58.45	Till	58.45	6.6	<2	6.15	0.7	12.0	580.0	452.0	1.60	0.50	1.8	0.20	0.76	83.0	5.0	77.0
W00-4-59.4	Till	59.40	6.1	<2	6.05	0.8	12.0	630.0	480.5	1.50	0.53	2.4	0.28	0.74	79.0	5.4	63.0
W00-4-60.4	Till	60.40	8.9	<2	6.02	0.7	13.0	650.0	482.5	1.35	0.52	2.7	0.24	0.73	79.0	4.9	70.0
W00-4-61.9	Till	61.90	9.3	<2	6.01	0.7	12.0	580.0	473.0	1.60	0.51	2.4	0.64	0.76	79.0	5.0	65.0
W00-4-63.1	Till	63.10	7.6	<2	6.27	0.8	12.0	610.0	510.3	1.65	0.53	2.0	0.26	0.73	82.0	5.1	73.0
W00-4-64.1	Till	64.10	6.0	<2	6.19	0.8	12.0	580.0	460.0	1.55	0.52	2.4	0.26	0.73	86.0	5.5	77.0
W00-4-70.3	Clay	70.30	7.7	<2	6.20	0.9	14.0	610.0	499.5	1.55	0.53	3.1	0.64	0.74	82.0	5.2	83.0
W00-4-74.5	Till	74.50	6.1	<2	5.22	0.6	7.9	470.0	399.0	1.25	0.45	1.1	0.14	0.58	83.0	3.8	57.0
W00-4-75.5	Till	75.50	8.5	<2	4.93	0.6	9.0	550.0	436.0	1.25	0.45	1.4	0.14	0.56	94.0	4.0	66.0
W00-4-76.7	Till	76.70	9.1	<2	4.92	0.6	9.2	510.0	393.5	1.20	0.46	1.6	0.16	0.56	91.0	3.7	54.0
W00-4-77.7	Till	77.70	7.1	4.0	4.50	0.5	8.0	440.0	436.5	1.10	0.43	0.9	0.14	0.52	70.0	2.6	36.0
W00-4-78.7	Till	78.70	7.4	<2	4.73	0.5	8.6	410.0	389.0	1.15	0.43	1.2	0.14	0.55	100.0	3.2	70.0
* W00-4-78.7	Till	78.70	8.0	<2	4.78	0.6	9.3	440.0	380.5	1.25	0.43	1.6	0.12	0.55	92.0	3.7	76.0
W00-4-80.0	Till	80.00	6.7	<2	5.26	0.6	10.0	450.0	400.5	1.35	0.48	1.1	0.14	0.59	81.0	3.9	58.0

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-4-10.1	Till	10.10	39.0	14.0	24.2	1.0	10.85	1.40	14.0	<50	2.7	40.0	14.5	29.4	0.4	0.58	470
W00-4-11.5	Till	11.50	48.0	13.0	26.6	1.0	13.55	1.40	12.0	<50	2.8	44.0	14.5	40.6	0.5	0.79	510
W00-4-12.2	Till	12.20	45.0	13.0	25.2	2.0	12.70	1.45	13.0	<50	2.9	41.0	14.0	39.6	0.5	0.66	435
W00-4-13.1	Till	13.10	51.0	13.0	29.2	2.0	13.90	1.40	12.0	<50	3.3	44.0	16.0	45.0	0.4	0.73	400
W00-4-16.1	Till	16.10	61.0	16.0	31.0	1.0	15.10	1.50	9.0	<50	3.5	45.0	15.0	41.4	0.4	0.94	370
W00-4-17.1	Till	17.10	53.0	13.0	27.6	<1	12.95	1.25	10.0	<50	3.1	35.0	12.5	37.0	0.3	1.33	445
W00-4-23.1	Till	23.10	54.0	14.0	37.4	1.0	14.05	1.35	13.0	<50	3.0	38.0	30.5	38.4	0.3	0.94	515
W00-4-34.0	Till	34.00	52.0	14.0	28.8	<1	13.10	1.45	11.0	<50	3.1	39.0	19.0	36.8	0.3	0.95	410
W00-4-34.9	Till	34.90	61.0	10.0	34.2	2.0	15.60	1.50	7.0	<50	3.5	37.0	20.0	43.4	0.4	0.88	340
W00-4-40.0	Sand & Clay	40.00	57.0	13.0	33.6	2.0	15.10	1.45	10.0	<50	3.2	41.0	17.0	40.0	0.3	1.02	440
W00-4-41.0	Till	41.00	58.0	13.0	31.6	1.0	15.10	1.45	10.0	<50	3.1	42.0	14.0	41.0	0.3	1.04	490
* W00-4-41.0	Till	41.00	56.0	14.0	31.8	2.0	14.80	1.40	10.0	<50	3.2	40.0	14.5	40.6	0.3	1.01	480
W00-4-41.7	Till	41.70	51.0	13.0	28.2	1.0	13.80	1.40	11.0	<50	2.8	39.0	14.5	40.2	0.4	0.90	505
W00-4-43.2	Till	43.20	50.0	14.0	27.8	<1	13.40	1.35	12.0	<50	2.7	39.0	13.0	39.2	0.4	0.89	505
W00-4-44.05	Till	44.05	58.0	15.0	32.6	1.0	15.95	1.45	9.0	<50	3.0	41.0	15.0	45.2	0.3	1.03	525
W00-4-52.8	Till	52.80	59.0	15.0	32.0	2.0	14.60	1.55	9.0	<50	3.1	38.0	16.5	44.8	0.3	0.76	385
W00-4-54.05	Till	54.05	47.0	14.0	28.4	2.0	12.70	1.45	11.0	<50	2.8	38.0	16.0	40.2	0.4	0.72	380
W00-4-57.9	Till	57.90	51.0	14.0	28.6	2.0	13.55	1.40	10.0	<50	3.0	42.0	14.0	45.2	0.3	0.85	405
W00-4-58.45	Till	58.45	56.0	18.0	30.2	2.0	14.10	1.50	10.0	<50	3.2	40.0	14.0	46.4	0.3	0.75	380
W00-4-59.4	Till	59.40	55.0	15.0	31.2	<1	14.50	1.60	10.0	<50	3.3	38.0	14.0	45.2	0.3	0.76	355
W00-4-60.4	Till	60.40	54.0	13.0	30.6	2.0	14.10	1.60	10.0	<50	3.2	39.0	16.0	43.8	0.4	0.75	350
W00-4-61.9	Till	61.90	55.0	15.0	31.0	2.0	13.90	1.55	10.0	<50	3.1	40.0	16.0	45.0	0.4	0.78	355
W00-4-63.1	Till	63.10	57.0	14.0	33.0	2.0	15.10	1.65	10.0	<50	3.3	40.0	15.5	47.2	0.4	0.75	340
W00-4-64.1	Till	64.10	57.0	13.0	32.4	1.0	14.45	1.55	10.0	<50	3.1	38.0	15.0	46.2	0.3	0.77	350
W00-4-70.3	Clay	70.30	59.0	16.0	32.8	2.0	14.60	1.65	9.0	<50	3.4	39.0	16.0	45.6	0.4	0.74	350
W00-4-74.5	Till	74.50	44.0	16.0	25.0	<1	12.25	1.45	13.0	<50	2.7	38.0	13.5	37.6	0.4	0.59	500
W00-4-75.5	Till	75.50	42.0	11.0	24.6	<1	11.45	1.45	15.0	<50	2.6	38.0	13.0	34.4	0.4	0.56	425
W00-4-76.7	Till	76.70	42.0	13.0	24.2	1.0	11.45	1.50	15.0	<50	2.6	41.0	15.5	33.2	0.4	0.57	430
W00-4-77.7	Till	77.70	36.0	14.0	23.2	<1	9.80	1.50	15.0	<50	2.3	35.0	13.0	29.0	0.4	0.49	410
W00-4-78.7	Till	78.70	40.0	12.0	23.4	1.0	10.80	1.50	19.0	<50	3.2	45.0	13.5	32.6	0.6	0.54	435
* W00-4-78.7	Till	78.70	40.0	15.0	24.0	<1	10.90	1.45	17.0	<50	2.8	43.0	13.0	32.8	0.5	0.55	445
W00-4-80.0	Till	80.00	46.0	16.0	27.2	<1	12.30	1.50	13.0	<50	2.6	40.0	16.0	36.8	0.4	0.61	465

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-4-10.1	Till	10.10	30.0	0.95	19.4	10.5	570	1.39	64.1	6.8	10.0	<5	0.20	0.59	121.0	1.1	<0.05
W00-4-11.5	Till	11.50	20.0	1.15	23.2	11.3	530	1.57	75.1	6.9	12.0	<5	0.25	0.59	127.0	1.6	<0.05
W00-4-12.2	Till	12.20	30.0	1.05	22.2	10.9	530	1.49	71.4	6.7	11.0	<5	0.25	0.65	123.5	1.4	<0.05
W00-4-13.1	Till	13.10	40.0	1.60	23.8	11.0	580	1.65	80.4	6.8	13.0	<5	0.30	0.55	132.0	1.3	<0.05
W00-4-16.1	Till	16.10	30.0	1.35	26.2	11.6	640	1.62	84.9	6.6	14.0	<5	0.30	0.59	159.0	1.3	<0.05
W00-4-17.1	Till	17.10	30.0	1.10	24.2	9.6	570	1.58	72.5	5.6	11.0	<5	0.25	0.74	163.0	1.2	<0.05
W00-4-23.1	Till	23.10	30.0	1.60	25.8	10.8	580	1.59	77.2	6.6	11.0	<5	0.25	0.59	138.0	1.0	<0.05
W00-4-34.0	Till	34.00	30.0	1.35	24.0	9.6	590	1.53	74.7	6.3	12.0	<5	0.25	0.70	142.0	1.0	<0.05
W00-4-34.9	Till	34.90	30.0	1.30	26.6	10.6	600	1.68	85.4	6.1	13.0	<5	0.25	0.62	133.5	1.1	<0.05
W00-4-40.0	Sand & Clay	40.00	30.0	2.05	27.6	11.6	700	1.71	83.6	6.8	12.0	<5	0.25	0.68	149.0	1.4	<0.05
W00-4-41.0	Till	41.00	30.0	2.15	26.8	11.2	630	1.72	84.5	6.7	12.0	<5	0.25	0.65	153.0	1.3	<0.05
* W00-4-41.0	Till	41.00	20.0	2.10	26.6	10.8	590	1.67	83.0	6.5	12.0	<5	0.25	0.65	150.0	1.1	<0.05
W00-4-41.7	Till	41.70	30.0	1.40	24.0	10.7	570	1.58	76.4	6.7	11.0	<5	0.25	0.71	143.0	1.3	<0.05
W00-4-43.2	Till	43.20	10.0	1.30	23.6	10.1	550	1.53	74.0	6.7	11.0	<5	0.25	0.67	139.5	1.1	<0.05
W00-4-44.05	Till	44.05	10.0	1.60	27.6	11.9	600	1.73	86.9	6.6	13.0	<5	0.25	0.67	151.5	1.1	<0.05
W00-4-52.8	Till	52.80	50.0	2.75	27.0	11.1	660	1.55	81.8	6.7	13.0	<5	0.30	0.53	141.5	1.3	<0.05
W00-4-54.05	Till	54.05	40.0	1.65	25.0	10.5	570	1.48	71.3	6.6	11.0	<5	0.30	0.58	127.0	1.0	<0.05
W00-4-57.9	Till	57.90	30.0	1.20	22.6	10.3	590	1.61	75.9	6.9	12.0	<5	0.20	0.58	127.5	1.5	<0.05
W00-4-58.45	Till	58.45	40.0	2.10	26.8	10.5	620	1.51	77.9	6.7	12.0	<5	0.25	0.55	136.5	1.2	<0.05
W00-4-59.4	Till	59.40	40.0	2.45	26.6	10.9	630	1.51	81.1	6.6	12.0	<5	0.30	0.52	148.5	1.4	<0.05
W00-4-60.4	Till	60.40	40.0	2.45	25.6	10.8	640	1.52	79.4	6.7	12.0	<5	0.30	0.53	149.0	1.4	<0.05
W00-4-61.9	Till	61.90	40.0	2.20	25.6	10.9	660	1.57	79.7	6.7	12.0	<5	0.25	0.56	150.5	1.0	<0.05
W00-4-63.1	Till	63.10	40.0	2.70	27.2	12.3	660	1.63	86.2	6.8	12.0	<5	0.30	0.53	154.5	1.2	<0.05
W00-4-64.1	Till	64.10	40.0	2.45	26.4	11.6	640	1.63	83.1	6.8	12.0	<5	0.30	0.53	147.5	1.0	<0.05
W00-4-70.3	Clay	70.30	40.0	3.05	27.8	11.8	680	1.60	83.5	6.8	12.0	<5	0.30	0.55	157.5	1.3	<0.05
W00-4-74.5	Till	74.50	10.0	0.90	21.0	11.1	490	1.42	66.5	6.6	10.0	<5	0.25	0.58	116.5	1.1	<0.05
W00-4-75.5	Till	75.50	30.0	0.85	20.0	11.1	510	1.40	65.5	6.8	10.0	<5	0.25	0.62	122.5	1.2	<0.05
W00-4-76.7	Till	76.70	30.0	0.85	19.8	10.3	540	1.37	64.2	6.8	10.0	<5	0.20	0.63	123.5	1.4	<0.05
W00-4-77.7	Till	77.70	20.0	0.70	18.2	10.7	510	1.41	59.5	5.7	8.4	<5	0.25	0.57	123.0	1.2	<0.05
W00-4-78.7	Till	78.70	30.0	0.85	19.4	10.6	530	1.39	62.6	6.3	12.0	<5	0.20	0.80	121.5	1.4	<0.05
* W00-4-78.7	Till	78.70	30.0	0.85	19.6	10.2	520	1.34	62.1	6.7	11.0	<5	0.25	0.69	121.5	1.4	<0.05
W00-4-80.0	Till	80.00	20.0	0.90	22.0	12.5	560	1.49	70.3	7.0	11.0	<5	0.25	0.61	129.5	1.8	<0.05

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-4-10.1	Till	10.10	1.10	0.42	11.0	<100	0.31	0.9	3.3	70.0	3.0	20.3	<100	560
W00-4-11.5	Till	11.50	0.90	0.48	12.0	<100	0.33	0.9	3.5	85.0	3.0	21.2	<100	410
W00-4-12.2	Till	12.20	0.90	0.46	11.0	<100	0.32	0.9	3.3	79.0	3.0	20.5	<100	380
W00-4-13.1	Till	13.10	0.90	0.54	11.0	<100	0.31	0.9	3.6	93.0	3.0	21.0	<100	560
W00-4-16.1	Till	16.10	0.90	0.54	12.0	<100	0.31	1.3	3.6	113.0	2.0	20.7	<100	370
W00-4-17.1	Till	17.10	0.70	0.50	10.0	<100	0.28	0.9	2.8	98.0	<2	18.3	<100	590
W00-4-23.1	Till	23.10	0.60	0.54	11.0	<100	0.31	2.4	3.6	103.0	2.0	20.7	<100	410
W00-4-34.0	Till	34.00	0.80	0.50	11.0	<100	0.28	1.0	3.5	99.0	2.0	19.5	110	<200
W00-4-34.9	Till	34.90	0.90	0.54	11.0	<100	0.30	1.3	3.4	117.0	<2	18.9	<100	<200
W00-4-40.0	Sand & Clay	40.00	0.80	0.62	12.0	<100	0.32	1.2	3.5	119.0	2.0	21.4	<100	380
W00-4-41.0	Till	41.00	0.90	0.62	12.0	<100	0.32	0.9	3.9	117.0	2.0	21.0	<100	380
* W00-4-41.0	Till	41.00	0.70	0.62	12.0	<100	0.31	0.9	3.8	117.0	3.0	20.5	<100	<200
W00-4-41.7	Till	41.70	0.80	0.52	11.0	<100	0.31	1.1	3.5	94.0	2.0	20.3	<100	<200
W00-4-43.2	Till	43.20	0.80	0.50	11.0	<100	0.30	0.9	3.6	91.0	3.0	19.6	<100	450
W00-4-44.05	Till	44.05	0.80	0.60	11.0	<100	0.34	1.0	3.4	112.0	2.0	21.4	<100	320
W00-4-52.8	Till	52.80	1.10	0.64	11.0	140	0.31	1.1	4.2	111.0	2.0	21.3	<100	<200
W00-4-54.05	Till	54.05	0.70	0.52	11.0	<100	0.30	0.8	3.4	86.0	2.0	20.0	<100	<200
W00-4-57.9	Till	57.90	1.00	0.48	11.0	<100	0.33	0.9	3.0	89.0	2.0	19.3	<100	450
W00-4-58.45	Till	58.45	0.80	0.56	11.0	<100	0.31	0.9	3.8	102.0	2.0	20.3	130	<200
W00-4-59.4	Till	59.40	0.70	0.58	11.0	<100	0.30	0.9	3.3	105.0	3.0	20.9	<100	470
W00-4-60.4	Till	60.40	0.80	0.58	11.0	120	0.31	1.0	3.7	104.0	3.0	20.9	<100	290
W00-4-61.9	Till	61.90	1.00	0.58	11.0	<100	0.32	0.9	3.5	103.0	3.0	20.9	<100	<200
W00-4-63.1	Till	63.10	0.80	0.62	11.0	<100	0.34	1.6	3.8	109.0	3.0	22.1	150	320
W00-4-64.1	Till	64.10	0.90	0.60	11.0	<100	0.34	1.1	3.7	107.0	2.0	21.4	150	<200
W00-4-70.3	Clay	70.30	1.10	0.68	11.0	<100	0.33	2.8	4.0	114.0	3.0	21.7	<100	610
W00-4-74.5	Till	74.50	0.70	0.40	11.0	<100	0.32	1.0	3.5	76.0	3.0	20.1	<100	700
W00-4-75.5	Till	75.50	0.90	0.40	10.0	140	0.32	1.0	3.3	73.0	3.0	20.5	<100	620
W00-4-76.7	Till	76.70	0.90	0.38	11.0	<100	0.30	0.9	3.3	75.0	3.0	20.3	<100	450
W00-4-77.7	Till	77.70	1.00	0.38	8.8	<100	0.32	0.9	3.1	64.0	3.0	20.0	<100	<200
W00-4-78.7	Till	78.70	1.10	0.40	10.0	<100	0.31	1.0	3.3	71.0	4.0	20.2	<100	560
* W00-4-78.7	Till	78.70	1.10	0.38	10.0	<100	0.30	1.0	3.4	71.0	4.0	20.1	<100	390
W00-4-80.0	Till	80.00	1.00	0.42	11.0	<100	0.36	1.0	3.6	79.0	3.0	22.1	<100	770

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			NAA	NAA	IMS	NAA	NAA	NAA	IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA
Sample #	**Material**	**Depth**	**Wt**	**Au**	**Al**	**Sb**	**As**	**Ba**	**Ba***	**Be**	**Bi**	**Br**	**Cd**	**Ca**	**Ce**	**Cs**	**Cr**
			grams	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-4-81.1	Till	81.10	8.2	<2	5.31	0.6	8.7	470.0	403.0	1.35	0.47	1.3	0.54	0.59	80.0	4.0	66.0
W00-4-82.1	Till	82.10	7.6	<2	6.34	0.8	11.0	520.0	417.5	1.75	0.54	1.1	0.18	0.71	87.0	5.3	70.0
W00-4-83.0	Till	83.00	6.9	<2	4.84	0.5	8.8	500.0	390.0	1.25	0.45	1.4	0.14	0.56	84.0	3.5	60.0
W00-4-84.1	Till	84.10	9.7	5.0	4.86	0.6	9.1	510.0	403.0	1.20	0.45	1.4	0.14	0.58	84.0	3.7	65.0
W00-4-85.95	Till	85.95	8.3	<2	5.01	0.5	9.2	590.0	466.0	1.30	0.45	1.0	0.16	0.56	86.0	3.5	58.0
W00-4-87.7	Till	87.70	7.4	<2	4.90	0.6	10.0	470.0	396.0	1.15	0.43	1.5	0.36	0.57	87.0	3.2	56.0
W00-4-89.5	Till	89.50	10.0	<2	5.10	0.6	9.0	500.0	419.0	1.30	0.45	1.3	0.30	0.58	88.0	3.8	61.0

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			IMS	IMS	IMS	NAA	IMS	IMS	NAA	NAA	NAA	NAA	IMS	IMS	NAA	IMS	IMS
Sample #	**Material**	**Depth**	**Cr***	**Co**	**Cu**	**Eu**	**Ga**	**Ge**	**Hf**	**Ir**	**Fe**	**La**	**Pb**	**Li**	**Lu**	**Mg**	**Mn**
			ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
W00-4-81.1	Till	81.10	46.0	13.0	25.6	1.0	12.50	1.65	14.0	<50	2.6	39.0	16.0	38.2	0.5	0.61	455
W00-4-82.1	Till	82.10	51.0	12.0	28.4	<1	15.30	1.55	11.0	<50	3.1	41.0	17.0	54.4	0.4	0.77	3540
W00-4-83.0	Till	83.00	41.0	20.0	24.6	2.0	11.00	1.50	14.0	<50	2.5	39.0	13.5	33.2	0.4	0.56	450
W00-4-84.1	Till	84.10	41.0	12.0	25.2	1.0	11.70	1.55	14.0	<50	2.6	41.0	15.0	34.8	0.4	0.56	420
W00-4-85.95	Till	85.95	42.0	12.0	24.0	1.0	11.30	1.70	15.0	<50	2.5	41.0	14.0	34.8	0.4	0.58	460
W00-4-87.7	Till	87.70	42.0	12.0	22.8	<1	10.85	1.50	16.0	<50	2.6	40.0	14.0	32.6	0.6	0.57	425
W00-4-89.5	Till	89.50	43.0	14.0	26.2	2.0	11.85	1.50	14.0	<50	2.6	41.0	14.5	36.0	0.4	0.59	460

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			CVAA	IMS	IMS	IMS	IMS	IMS	IMS	NAA	NAA	NAA	IMS	NAA	IMS	NAA	IMS
Sample #	**Material**	**Depth**	**Hg**	**Mo**	**Ni**	**Nb**	**P**	**K**	**Rb**	**Sm**	**Sc**	**Se**	**Ag**	**Na**	**Sr**	**Ta**	**Te**
			ppb	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**
W00-4-81.1	Till	81.10	30.0	0.85	21.8	11.5	530	1.45	70.9	6.8	10.0	<5	0.25	0.59	128.0	1.6	<0.05
W00-4-82.1	Till	82.10	10.0	3.65	29.2	13.0	620	1.53	82.3	7.2	12.0	<5	0.30	0.56	143.5	1.2	0.05
W00-4-83.0	Till	83.00	10.0	0.85	19.8	11.5	540	1.45	63.5	6.6	9.5	<5	0.25	0.60	124.5	1.1	<0.05
W00-4-84.1	Till	84.10	20.0	0.80	20.8	11.2	530	1.40	66.0	6.8	10.0	<5	0.25	0.60	130.5	1.4	<0.05
W00-4-85.95	Till	85.95	20.0	0.85	20.2	10.8	570	1.41	65.1	6.8	10.0	<5	0.20	0.65	126.0	1.1	<0.05
W00-4-87.7	Till	87.70	30.0	0.75	19.2	10.2	570	1.32	62.3	7.0	10.0	<5	0.25	0.63	125.5	1.4	<0.05
W00-4-89.5	Till	89.50	30.0	0.85	21.2	11.2	600	1.50	69.6	6.9	10.0	<5	0.25	0.65	128.0	1.5	<0.05

Table A3-9: Geochemical analysis of samples from core hole WEPA00-4

			NAA	IMS	NAA	NAA	IMS	IMS	NAA	IMS	NAA	IMS	IMS	NAA
Sample #	**Material**	**Depth**	**Tb**	**Tl**	**Th**	**Sn**	**Ti**	**W**	**U**	**V**	**Yb**	**Y**	**Zn**	**Zr**
			ppm	**ppm**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
W00-4-81.1	Till	81.10	0.90	0.42	10.0	<100	0.33	0.9	3.5	77.0	3.0	21.3	<100	490
W00-4-82.1	Till	82.10	1.00	0.58	11.0	<100	0.34	1.2	3.2	99.0	3.0	24.7	<100	320
W00-4-83.0	Till	83.00	0.90	0.38	10.0	<100	0.34	1.0	3.5	71.0	3.0	21.0	<100	480
W00-4-84.1	Till	84.10	0.80	0.42	11.0	<100	0.32	0.9	3.7	74.0	3.0	21.2	<100	550
W00-4-85.95	Till	85.95	1.00	0.40	10.0	<100	0.31	0.8	3.6	71.0	3.0	20.3	<100	650
W00-4-87.7	Till	87.70	0.90	0.38	11.0	<100	0.29	0.8	3.8	71.0	3.0	20.3	<100	540
W00-4-89.5	Till	89.50	1.10	0.42	11.0	<100	0.32	0.9	3.5	73.0	3.0	21.0	<100	510

Notes: < denotes less than
NAA denotes neutron activation analysis
CVAA denotes analysis by cold vapour atomic absorption
IMS denotes plasma-mass spectrometry analysis
All results are reported on a dry basis.
Ba* and Cr* denotes acid soluble portion
* W00-4-41.0 denotes sample duplicate of W00-4-41.0

Appendix 4. Alberta Geological Survey Laboratory Grain-size and Carbonate-Content Analyses of Quaternary and Upper-Bedrock Samples

Table A4-1: Matrix grain size and carbonate analyses, core hole WEPA99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-1-22.4	Till	22.4	1.82	39.9	26.0	34.1	42.4	30.4	27.2	1.0	3.2	4.1	0.30
W99-1-25.1	Till	25.1	0.49	40.1	42.4	17.5	49.2	37.7	13.1	0.9	3.0	3.9	0.32
W99-1-32.6	Till	32.6	0.78	26.5	34.7	38.8	28.5	46.7	24.8	0.9	3.1	4.1	0.30
W99-1-33.0	Till	33.0	1.72	42.9	33.9	23.2	46.4	38.5	15.1	0.9	3.1	4.1	0.30
W99-1-39.5	Till	39.5	0.84	24.3	34.8	40.9	26.4	49.5	24.1	1.0	3.2	4.1	0.30
W99-1-40.2	Till	40.2	1.30	38.4	33.1	28.5	41.3	41.7	17.0	1.0	3.2	4.1	0.30
W99-1-41.4	Till	41.4	0.75	24.3	43.2	32.5	27.1	53.7	19.2	1.0	3.2	4.1	0.30
W99-1-42.3	Till	42.3	1.02	25.5	34.3	40.2	27.7	48.6	23.7	1.0	3.2	4.1	0.30
W99-1-43.3	Till	43.3	0.84	23.4	29.1	47.5	25.2	42.6	32.2	0.9	2.6	3.6	0.36
W99-1-44.7	Till	44.7	0.23	8.9	41.9	49.2	11.6	55.3	33.1	0.9	2.0	2.9	0.46
W99-1-47.3	Till	47.3	0.54	10.5	46.8	42.7	11.2	60.2	28.6	0.9	2.1	3.0	0.45
W99-1-48.3	Till	48.3	0.29	12.4	47.2	40.4	14.0	61.0	25.0	0.8	3.2	3.9	0.24
W99-1-49.5	Till	49.5	1.47	43.7	38.9	17.4	46.9	42.5	10.6	0.7	2.1	2.9	0.34
W99-1-50.4	Till	50.4	1.28	41.9	41.4	16.7	45.3	45.2	9.5	0.8	2.1	2.9	0.39
W99-1-51.5	Till	51.5	1.23	44.2	37.6	18.2	47.3	43.0	9.7	0.7	2.3	3.1	0.31
W99-1-52.5	Till	52.5	1.39	42.1	39.4	18.5	45.5	43.8	10.7	1.0	2.5	3.4	0.39
W99-1-53.5	Till	53.5	1.19	43.1	36.9	20.0	46.2	42.4	11.4	1.0	2.7	3.6	0.36
W99-1-54.4	Till	54.4	1.19	41.8	40.7	17.5	45.1	45.6	9.3	0.9	2.5	3.4	0.37
W99-1-55.5	Till	55.5	1.35	42.5	37.8	19.7	45.8	43.9	10.3	0.9	2.5	3.4	0.37
W99-1-56.4	Till	56.4	1.33	43.3	38.1	18.6	46.8	42.5	10.7	0.9	2.5	3.4	0.37
W99-1-57.9	Till	57.9	1.83	46.1	33.3	20.6	48.9	39.3	11.8	1.0	2.5	3.4	0.39
W99-1-61.0	Till	61.0	1.10	32.7	38.3	29.0	35.8	45.7	18.5	1.0	3.9	4.8	0.25
W99-1-61.7	Till	61.7	1.43	38.3	37.1	24.6	41.0	44.7	14.3	1.0	2.4	3.4	0.41
W99-1-62.1	Till	62.1	2.66	44.4	28.9	26.7	48.1	32.6	19.3	0.7	0.9	1.6	0.78
W99-1-63.1	Till	63.1	2.62	45.3	29.0	25.7	48.7	32.1	19.2	0.8	0.7	1.5	1.06
W99-1-63.9	Till	63.9	2.51	44.0	29.4	26.6	48.1	30.8	21.1	0.9	1.1	2.0	0.89
W99-1-67.2	Till	67.2	2.41	42.5	37.9	19.6	45.9	42.9	11.2	0.9	3.1	4.1	0.30
W99-1-68.2	Till	68.2	2.48	40.9	43.3	15.8	44.7	46.6	8.7	1.0	3.8	4.8	0.27
W99-1-69.2	Till	69.2	2.28	41.3	42.9	15.8	44.6	46.7	8.7	1.2	3.8	5.0	0.31
W99-1-70.0	Till	70.0	1.90	35.8	48.9	15.3	40.8	51.0	8.2	1.0	4.1	5.1	0.25
W99-1-71.0	Till	71.0	2.23	39.4	46.4	14.2	43.0	48.8	8.2	1.0	4.4	5.3	0.22

Table A4-1 Matrix grain size and carbonate analyses, core hole WEPA99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-1-72.0	Till	72.0	2.41	38.0	43.3	18.7	42.7	45.9	11.4	1.0	4.4	5.3	0.22
W99-1-73.3	Till	73.3	3.03	49.4	37.3	13.3	52.5	40.6	6.9	1.3	6.0	7.3	0.22
W99-1-74.3	Till	74.3	1.41	31.9	41.7	26.4	36.4	47.4	16.2	0.8	2.5	3.2	0.31
W99-1-75.3	Till	75.3	4.53	52.4	36.2	11.4	55.4	37.7	6.9	1.6	7.8	9.4	0.21
W99-1-76.3	Till	76.3	3.82	50.8	35.4	13.8	54.7	36.7	8.6	1.5	7.7	9.2	0.20
W99-1-77.3	Till	77.3	3.54	51.3	33.7	15.0	54.1	37.0	8.9	1.3	6.3	7.6	0.22
W99-1-78.3	Till	78.3	4.01	51.0	37.5	11.5	54.5	37.8	7.7	1.0	7.1	8.1	0.16
W99-1-79.3	Till	79.3	3.68	50.6	36.1	13.3	53.8	38.6	7.6	1.4	8.2	9.6	0.19
W99-1-80.3	Till	80.3	3.66	51.0	33.7	15.3	54.1	36.3	9.6	1.3	5.3	6.6	0.25
W99-1-80.7	Till	80.7	4.25	49.4	34.9	15.7	52.1	39.6	8.3	1.2	6.7	8.0	0.19
W99-1-81.1	Till	81.1	4.08	49.4	35.2	15.4	52.8	38.9	8.3	1.4	6.4	7.8	0.23
W99-1-87.1	Till	87.1	2.06	37.7	38.9	23.4	40.8	44.1	15.1	1.3	3.0	4.3	0.43
W99-1-88.0	Till	88.0	2.23	35.4	42.2	22.4	39.5	47.3	13.2	1.2	2.8	4.0	0.45
W99-1-89.7	Till	89.7	2.19	36.3	40.9	22.8	39.5	48.2	12.3	1.1	3.0	4.1	0.38
W99-1-91.4	Till	91.4	2.12	33.1	44.4	22.5	37.8	48.6	13.6	1.1	2.6	3.8	0.43
W99-1-92.4	Till	92.4	2.28	34.9	42.4	22.7	38.3	48.2	13.5	1.0	2.8	3.8	0.34
W99-1-93.3	Till	93.3	1.95	33.0	42.8	24.2	37.3	49.1	13.6	0.9	2.5	3.4	0.37
W99-1-95.1	Till	95.1	2.33	37.8	40.1	22.1	41.0	47.2	11.8	0.8	3.5	4.3	0.22
W99-1-95.5	Till	95.5	2.33	39.7	38.8	21.5	43.5	46.0	10.5	1.2	2.9	4.1	0.40
W99-1-96.5	Till	96.5	2.73	30.6	53.3	16.1	33.1	57.6	9.3	1.7	4.7	6.4	0.37
W99-1-97.5	Till	97.5	3.02	29.1	56.5	14.4	33.2	57.4	9.4	1.4	4.8	6.1	0.29
W99-1-98.1	Till	98.1	3.28	33.0	48.5	18.5	35.5	53.9	10.6	1.4	4.8	6.1	0.29
W99-1-99.2	Till	99.2	3.47	29.8	39.1	31.1	34.0	47.6	18.4	1.3	5.2	6.5	0.27
W99-1-100.2	Till	100.2	2.85	33.5	48.9	17.6	36.0	53.5	10.5	1.5	5.5	7.0	0.28
W99-1-101.3	Till	101.3	1.15	9.9	72.4	17.7	11.7	78.9	9.4	1.5	4.4	5.9	0.35
W99-1-102.2	Till	102.2	0.39	11.8	73.9	14.3	14.2	77.0	8.8	0.8	1.0	1.8	0.78
W99-1-103.4	Till	103.4	0.88	12.2	70.4	17.4	15.2	75.7	9.1	0.7	1.7	2.4	0.41
W99-1-104.4	Till	104.4	2.90	33.3	36.0	30.7	36.0	45.4	18.6	1.7	5.6	7.4	0.32
W99-1-105.4	Till	105.4	1.84	19.5	51.7	28.8	23.5	56.3	20.2	1.2	3.8	5.0	0.31
W99-1-106.3	Till	106.3	3.17	37.2	31.5	31.3	40.1	39.4	20.5	1.4	5.6	7.0	0.26
W99-1-109.0	Till	109.0	2.19	34.0	46.7	19.3	38.5	51.3	10.2	1.0	2.1	3.1	0.45

Table A4-1 Matrix grain size and carbonate analyses, core hole WEPA99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-1-110.0	Till	110.0	2.11	36.5	41.5	22.0	39.9	47.1	13.0	1.0	1.4	2.4	0.67
W99-1-111.0	Till	111.0	2.75	41.8	41.9	16.3	45.5	45.4	9.1	0.8	1.2	2.0	0.62
W99-1-112.0	Till	112.0	1.94	36.9	43.9	19.2	40.3	50.1	9.6	0.8	1.5	2.4	0.55
W99-1-113.0	Till	113.0	1.99	34.6	42.2	23.2	38.6	49.8	11.6	0.8	1.5	2.4	0.55
W99-1-114.0	Till	114.0	2.07	34.2	43.4	22.4	37.5	51.2	11.3	0.8	1.3	2.2	0.63
W99-1-115.0	Till	115.0	2.19	35.9	43.4	20.7	38.4	51.0	10.6	0.8	1.2	2.0	0.66
W99-1-116.0	Till	116.0	1.70	34.4	44.4	21.2	38.2	49.7	12.1	0.9	1.0	1.8	0.91
W99-1-117.0	Till	117.0	1.86	33.4	39.5	27.1	35.7	49.3	15.0	0.9	1.3	2.2	0.67
W99-1-118.0	Till	118.0	1.98	38.2	39.8	22.0	41.4	45.0	13.6	0.7	1.1	1.8	0.66
W99-1-119.0	Till	119.0	2.02	36.3	40.7	23.0	39.3	46.4	14.3	0.8	1.2	2.0	0.61
W99-1-120.0	Till	120.0	1.56	33.7	38.9	27.4	37.0	45.9	17.1	0.7	1.4	2.1	0.47
W99-1-121.0	Till	121.0	2.15	33.4	40.0	26.6	36.4	47.1	16.5	0.7	1.3	2.0	0.52
W99-1-121.9	Till	121.9	2.36	35.3	43.5	21.2	38.5	48.3	13.2	0.8	1.1	1.8	0.72
W99-1-122.4	Till	122.4	0.19	2.1	66.6	31.3	2.8	79.8	17.4	0.8	1.1	1.8	0.72
W99-1-123.1	Till	123.1	2.24	36.2	41.5	22.3	39.7	47.0	13.3	0.8	1.2	2.0	0.61
W99-1-124.1	Till	124.1	2.11	34.7	43.2	22.1	38.1	48.7	13.2	0.9	1.7	2.7	0.54
W99-1-125.1	Till	125.1	1.70	33.6	37.8	28.6	36.6	47.0	16.4	0.7	1.4	2.1	0.50
W99-1-126.1	Till	126.1	2.10	33.0	39.7	27.3	36.2	48.7	15.1	0.9	1.1	2.0	0.77
W99-1-127.1	Till	127.1	1.64	31.0	35.6	33.4	33.7	46.4	19.9	0.9	1.6	2.5	0.61
W99-1-128.1	Till	128.1	1.59	31.5	36.5	32.0	34.4	47.3	18.3	0.7	1.3	2.0	0.57
W99-1-129.1	Till	129.1	1.48	30.5	36.0	33.5	33.3	45.9	20.8	0.7	1.1	1.8	0.61
W99-1-130.6	Till	130.6	2.03	33.0	38.3	28.7	36.1	46.0	17.9	0.7	1.2	2.0	0.58
W99-1-131.6	Till	131.6	1.76	40.5	31.2	28.3	43.6	39.0	17.4	0.8	1.5	2.3	0.55
W99-1-132.5	Till	132.5	2.01	42.2	33.6	24.2	45.3	39.8	14.9	0.7	1.3	2.0	0.52
W99-1-133.5	Till	133.5	1.88	45.0	31.7	23.3	48.1	39.1	12.8	0.9	1.4	2.3	0.63
W99-1-134.5	Till	134.5	1.98	39.6	39.9	20.5	42.8	45.5	11.7	1.0	1.1	2.0	0.90
W99-1-135.5	Till	135.5	1.00	34.6	42.5	22.9	38.4	49.0	12.6	0.8	1.0	1.8	0.84
W99-1-137.0	Till	137.0	1.99	33.3	41.3	25.4	36.4	49.4	14.2	0.8	1.3	2.2	0.62
W99-1-138.0	Till	138.0	2.23	36.1	45.4	18.5	40.0	48.2	11.8	0.9	1.1	2.0	0.83
W99-1-139.0	Till	139.0	2.17	35.5	44.1	20.4	39.4	46.9	13.7	0.9	1.2	2.2	0.77
W99-1-140.0	Till	140.0	2.21	35.3	46.1	18.6	38.8	50.6	10.6	1.0	1.3	2.4	0.77

Table A4-1 Matrix grain size and carbonate analyses, core hole WEPA99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-1-141.0	Till	141.0	2.47	37.2	43.6	19.2	41.0	48.1	10.9	0.9	2.1	3.0	0.45
W99-1-142.0	Till	142.0	2.29	35.8	44.6	19.6	39.1	49.0	11.9	0.9	1.7	2.7	0.54
W99-1-143.0	Till	143.0	2.30	35.6	43.6	20.8	38.6	48.9	12.5	0.9	2.2	3.0	0.39
W99-1-144.0	Till	144.0	2.35	35.5	42.9	21.6	38.8	48.5	12.7	0.9	1.9	2.8	0.50
W99-1-145.0	Till	145.0	2.12	36.1	42.1	21.8	39.3	47.2	13.5	0.9	1.9	2.8	0.50
W99-1-146.0	Till	146.0	2.21	35.6	42.7	21.7	38.7	47.9	13.4	0.9	1.6	2.5	0.60
W99-1-147.0	Till	147.0	2.16	32.8	37.6	29.6	35.5	44.6	19.9	1.1	1.7	2.8	0.64
W99-1-148.0	Till	148.0	2.09	33.9	37.7	28.4	36.9	44.2	18.9	1.0	1.1	2.0	0.90
W99-1-149.0	Till	149.0	2.51	32.8	40.4	26.8	35.8	47.3	16.9	1.0	1.2	2.2	0.78
W99-1-150.0	Till	150.0	0.04	46.4	37.2	16.4	52.4	37.6	10.0	0.9	1.5	2.4	0.63
W99-1-151.0	Till	151.0	2.18	31.4	44.8	23.8	34.4	51.8	13.8	1.0	1.8	2.7	0.54
W99-1-153.0	Till	153.0	2.39	30.8	40.9	28.3	33.8	49.4	16.8	1.0	2.1	3.1	0.50
W99-1-152.0	Till	152.0	2.34	31.6	44.9	23.5	34.5	51.3	14.2	0.9	2.4	3.3	0.38
W99-1-153.4	Till	153.4	2.61	33.8	40.7	25.5	36.7	48.9	14.4	1.2	2.2	3.4	0.54
W99-1-153.6	Shale	153.6	0.06	3.1	49.5	47.4	4.0	61.3	34.7	0.8	1.2	2.0	0.64
WP99-1-155	Shale	155.0	0.10	0.7	78.6	20.7	1.1	83.1	15.8				
WP99-1-156	Shale	156.0	0.17	0.9	58.8	40.3	1.1	69.6	29.3				
WP99-1-157	Shale	157.0	0.12	1.4	64.5	34.1	1.7	70.6	27.7				
WP99-1-158	Shale	158.0	0.16	0.7	63.2	36.1	1.0	71.9	27.1				
WP99-1-159	Shale	159.0	0.10	1.2	65.8	33.0	1.6	72.0	26.4				
WP99-1-160	Shale	160.0	0.06	1.4	65.0	33.6	1.6	71.2	27.2				
WP99-1-161	Shale	161.0	0.00	0.6	82.4	17.0	0.9	86.3	12.8				
WP99-1-162	Shale	162.0	0.25	2.0	79.5	18.5	2.2	84.3	13.5				
WP99-1-163	Shale	163.0	0.00	1.2	73.3	25.5	1.5	80.1	18.4				
WP99-1-164	Shale	164.0	0.02	3.6	85.4	11.0	4.0	88.3	7.7				
WP99-1-165	Shale	165.0	0.00	2.4	84.2	13.4	2.7	88.3	9.0				
WP99-1-166	Shale	166.0	0.06	1.8	75.1	23.1	2.3	80.6	17.1				

Table A4-2: Matrix grain size and carbonate analyses, core hole WEPA99-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-2-7.5	7.5	Till	1.34	34.4	40.2	25.4	38.0	44.5	17.5	1.0	3.2	4.1	0.30
W99-2-9.5	9.5	Till	1.12	31.1	40.7	28.2	34.7	45.6	19.7	0.9	2.8	3.8	0.34
W99-2-12.0	12.0	Till	1.29	30.4	40.8	28.8	33.7	47.2	19.1	0.9	2.8	3.7	0.32
W99-2-14.0	14.0	Till	1.75	43.7	30.5	25.8	46.7	35.5	17.8	0.9	3.1	4.1	0.30
W99-2-15.0	15.0	Till	1.16	28.7	44.0	27.3	31.5	49.2	19.3	1.0	2.8	3.8	0.34
W99-2-17.0	17.0	Silt	2.07	43.1	30.7	26.2	46.0	36.3	17.7	1.1	2.7	3.8	0.39
W99-2-21.8	21.8	Till	1.88	46.6	27.9	25.5	49.4	32.7	17.9	1.0	3.2	4.1	0.30
W99-2-22.7	22.7	Till	2.09	46.9	27.2	25.9	50.0	32.2	17.8	0.8	3.6	4.4	0.22
W99-2-23.4	23.4	Till	2.07	45.1	25.2	29.7	47.9	30.4	21.7	0.9	3.5	4.4	0.27
W99-2-29.0	29.0	Till	1.87	38.9	35.1	26.0	42.0	41.2	16.8	1.0	3.5	4.5	0.27
W99-2-30.5	30.5	Till	1.45	20.4	50.4	29.2	22.6	57.3	20.1	1.1	6.8	7.9	0.18
W99-2-32.5	32.5	Till	3.60	49.8	26.2	24.0	53.1	30.4	16.5	1.3	5.6	6.9	0.24
W99-2-33.4	33.4	Till	2.72	43.2	28.3	28.5	46.4	34.7	18.9	1.2	6.2	7.4	0.21
W99-2-35.0	35.0	Till	1.55	43.5	40.5	16.0	51.5	38.0	10.5	0.8	6.8	7.5	0.12
W99-2-35.7	35.7	Till	3.39	54.7	25.0	20.3	58.0	27.6	14.4	1.3	6.3	7.5	0.21
W99-2-37.5	37.5	Till	2.48	47.1	28.0	24.9	50.5	33.4	16.1	1.2	5.6	6.8	0.23
W99-2-38.7	38.7	Till	1.99	8.0	41.6	50.4	10.9	50.6	38.5	1.0	3.5	4.5	0.29
W99-2-40.0	40.0	Silt & Clay	0.33	33.8	36.8	29.4	38.7	39.8	21.5	1.4	2.8	4.2	0.51
W99-2-41.0	41.0	Silt & Clay	1.10	37.8	26.5	35.7	40.8	33.7	25.5	0.5	1.7	2.2	0.27
W99-2-42.0	42.0	Till	0.84	41.3	29.9	28.8	44.6	37.9	17.5	1.2	3.4	4.6	0.35
W99-2-43.0	43.0	Till	0.97	48.1	26.0	25.9	51.3	32.1	16.6	1.1	2.7	3.8	0.41
W99-2-44.0	44.0	Till	1.10	43.9	30.3	25.8	47.2	36.2	16.6	1.0	2.9	4.0	0.35
W99-2-45.0	45.0	Till	1.02	48.8	27.4	23.8	52.1	31.8	16.1	1.0	3.0	4.0	0.32
W99-2-46.0	46.0	Till	1.53	52.9	23.9	23.2	56.1	29.5	14.4	0.9	2.4	3.4	0.39
W99-2-47.0	47.0	Till	3.26	49.0	25.7	25.3	52.0	32.0	16.0	1.1	2.6	3.7	0.41
W99-2-48.0	48.0	Till	0.72	47.0	28.2	24.8	50.3	34.0	15.7	0.9	2.6	3.5	0.36
W99-2-49.0	49.0	Till	1.33	44.2	26.1	29.7	47.0	34.1	18.9	0.7	3.7	4.4	0.18
W99-2-50.0	50.0	Till	1.15	41.0	31.4	27.6	44.2	37.2	18.6	0.6	1.5	2.1	0.43
W99-2-51.0	51.0	Till	0.96	43.9	28.5	27.6	46.9	34.9	18.2	0.9	2.1	3.0	0.45
W99-2-52.0	52.0	Till	0.88	43.4	30.0	26.6	46.5	36.5	17.0	0.9	2.3	3.2	0.42
W99-2-54.0	54.0	Till	0.89	27.2	35.9	36.9	29.6	46.4	24.0	0.8	2.2	3.1	0.38

Table A4-2 Matrix grain size and carbonate analyses, core hole WEPA99-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-2-55.0	55.0	Till	0.98	37.5	34.1	28.4	40.6	41.4	18.0	0.7	2.0	2.7	0.37
W99-2-56.0	56.0	Till	1.00	32.7	30.1	37.2	35.2	41.7	23.1	0.8	2.1	2.8	0.36
W99-2-57.0	57.0	Till	1.11	30.3	28.8	40.9	32.8	40.1	27.1	0.8	1.2	2.0	0.61
W99-2-58.0	58.0	Silt & Clay	0.30	11.0	38.9	50.1	12.2	57.8	30.0	0.6	2.6	3.2	0.24
W99-2-59.0	59.0	Silt & Clay	0.04	3.4	70.9	25.7	4.7	80.0	15.3	0.9	2.8	3.7	0.34
W99-2-60.0	60.0	Silt & Clay	0.16	3.8	72.6	23.6	9.6	75.2	15.2	0.7	3.4	4.1	0.21
W99-2-61.0	61.0	Silt & Clay	0.06	4.8	66.8	28.4	11.6	68.8	19.6	0.9	3.3	4.3	0.29
W99-2-62.0	62.0	Silt & Clay	0.18	5.7	63.7	30.6	8.8	70.7	20.5	1.0	2.6	3.6	0.36
W99-2-63.0	63.0	Till	1.47	40.4	35.8	23.8	44.1	40.5	15.4	1.0	2.8	3.8	0.34
W99-2-64.0	64.0	Till	1.48	40.4	34.7	24.9	43.7	40.8	15.5	0.9	3.2	4.1	0.27
W99-2-65.0	65.0	Till	1.56	44.8	29.3	25.9	48.5	34.6	16.9	0.9	2.7	3.6	0.33
W99-2-66.0	66.0	Till	1.43	44.4	34.7	20.9	47.9	38.8	13.3	0.6	2.4	3.0	0.27
W99-2-67.0	67.0	Till	1.41	44.1	33.0	22.9	47.8	38.4	13.8	0.8	2.9	3.7	0.29
W99-2-68.0	68.0	Till	1.64	45.1	31.8	23.1	48.6	37.0	14.4	0.6	2.4	3.0	0.27
W99-2-69.0	69.0	Till	1.50	45.2	29.8	25.0	47.9	34.9	17.2	1.0	2.4	3.4	0.43
W99-2-70.1	70.1	Till	1.23	44.8	32.5	22.7	48.5	37.3	14.2	1.0	2.8	3.8	0.34
W99-2-71.0	71.0	Till	1.35	44.6	30.3	25.1	48.3	35.6	16.1	1.1	2.7	3.8	0.39
W99-2-74.0	74.0	Till	1.77	46.3	34.1	19.6	49.9	38.7	11.4	0.7	2.5	3.2	0.27
W99-2-75.0	75.0	Till	1.66	46.2	30.4	23.4	49.8	35.1	15.1	0.8	2.6	3.4	0.33
W99-2-76.0	76.0	Till	1.80	50.6	29.1	20.3	54.2	32.9	12.9	1.0	2.1	3.1	0.45
W99-2-77.0	77.0	Till	1.43	45.6	31.6	22.8	49.1	35.9	15.0	1.0	2.8	3.8	0.34
W99-2-78.0	78.0	Till	1.66	46.3	32.2	21.5	49.8	36.4	13.8	1.0	2.8	3.8	0.34
W99-2-79.0	79.0	Till	1.33	46.7	31.8	21.5	50.3	35.9	13.8	0.9	3.2	4.1	0.29
W99-2-80.0	80.0	Till	1.39	46.2	36.2	17.6	49.7	39.4	10.9	0.9	2.9	3.8	0.30
W99-2-81.0	81.0	Till	1.21	45.6	35.9	18.5	49.1	38.9	12.0	1.0	2.5	3.4	0.39
W99-2-82.0	82.0	Till	1.25	45.5	33.5	21.0	49.1	37.9	13.0	1.0	2.5	3.4	0.39
W99-2-83.0	83.0	Till	1.23	46.0	34.5	19.5	49.6	39.0	11.4	1.0	2.6	3.6	0.36
W99-2-84.0	84.0	Till	1.31	45.4	34.9	19.7	48.7	39.6	11.7	0.8	2.6	3.4	0.29
W99-2-85.0	85.0	Till	1.35	46.0	34.3	19.7	49.3	39.0	11.7	0.9	2.5	3.4	0.37
W99-2-86.0	86.0	Till	1.47	43.6	34.1	22.3	46.6	39.1	14.3	0.9	2.2	3.1	0.40
W99-2-87.0	87.0	Till	1.50	39.2	36.0	24.8	42.1	42.8	15.1	1.0	2.8	3.8	0.36

Table A4-2 Matrix grain size and carbonate analyses, core hole WEPA99-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-2-88.0	88.0	Till	1.27	39.2	34.8	26.0	42.0	42.0	16.0	1.1	2.3	3.4	0.48
W99-2-92.7	92.7	Till	1.75	43.9	35.1	21.0	47.1	40.1	12.8	0.9	2.2	3.1	0.40
W99-2-93.1	93.1	Till	1.64	43.9	34.7	21.4	47.1	39.4	13.5	0.9	2.4	3.2	0.37
W99-2-94.0	94.0	Till	1.96	41.6	35.3	23.1	44.5	42.1	13.4	1.0	2.1	3.1	0.45
W99-2-95.0	95.0	Till	1.55	39.0	33.3	27.7	42.0	41.0	17.0	1.0	2.2	3.2	0.44
W99-2-96.0	96.0	Till	1.82	43.0	35.1	21.9	46.3	40.5	13.2	0.8	2.1	2.9	0.36
W99-2-97.0	97.0	Till	1.43	39.3	37.4	23.3	42.2	43.4	14.4	1.3	2.1	3.4	0.63
W99-2-98.0	98.0	Till	1.43	39.3	33.2	27.5	42.1	41.1	16.8	1.3	2.8	4.1	0.47
W99-2-99.0	99.0	Till	1.57	39.9	32.2	27.9	42.8	40.3	16.9	1.1	2.7	3.8	0.41
W99-2-100.0	100.0	Till	1.52	44.2	32.6	23.2	46.9	38.8	14.3	0.9	2.6	3.6	0.36
W99-2-101.0	101.0	Till	1.33	41.6	33.4	25.0	44.4	41.5	14.1	1.0	2.2	3.2	0.44
W99-2-102.0	102.0	Till	1.37	37.8	36.6	25.6	40.4	45.0	14.6	0.9	2.6	3.6	0.36
W99-2-103.0	103.0	Till	1.54	37.9	35.3	26.8	40.5	44.5	15.0	0.9	2.6	3.6	0.34
W99-2-104.0	104.0	Till	1.62	37.2	32.3	30.5	39.8	41.1	19.1	1.2	1.8	3.0	0.69
W99-2-105.0	105.0	Till	1.29	38.4	33.7	27.9	41.1	42.5	16.4	1.0	2.0	3.0	0.49
W99-2-106.0	106.0	Till	1.46	36.0	41.4	22.6	38.4	49.0	12.6	1.0	2.0	3.0	0.50
W99-2-107.1	107.1	Till	1.18	35.4	38.1	26.5	37.9	46.2	15.9	1.0	1.7	2.7	0.61
W99-2-108.0	108.0	Till	1.28	37.2	40.1	22.7	39.8	47.5	12.7	0.9	1.6	2.5	0.60
W99-2-109.0	109.0	Till	1.52	38.6	41.2	20.2	41.1	47.0	11.9	0.9	1.7	2.7	0.54
W99-2-110.1	110.1	Till	3.39	1.7	76.8	21.5	27.9	58.9	13.2	0.9	1.8	2.7	0.51
W99-2-111.0	111.0	Till	1.48	35.5	43.4	21.1	37.4	49.2	13.4	0.8	1.7	2.5	0.46
W99-2-112.0	112.0	Till	1.28	33.0	37.3	29.7	36.0	44.8	19.2	1.0	2.0	3.0	0.50
W99-2-113.5	113.5	Till	1.06	31.5	37.2	31.3	34.4	45.1	20.5	1.1	2.5	3.6	0.44
W99-2-114.3	114.3	Till	1.20	33.6	38.8	27.6	36.8	45.8	17.4	1.1	2.5	3.6	0.44
W99-2-115.0	115.0	Till	1.44	36.6	37.9	25.5	39.7	45.0	15.3	0.9	2.8	3.7	0.34
W99-2-116.0	116.0	Till	1.40	35.0	36.7	28.3	38.1	42.7	19.2	1.1	2.6	3.7	0.41
W99-2-117.0	117.0	Till	1.23	40.1	30.6	29.3	43.1	38.5	18.4	1.1	3.0	4.1	0.37
W99-2-118.0	118.0	Till	1.62	39.3	31.7	29.0	42.3	39.6	18.1	0.9	2.4	3.4	0.39
W99-2-119.0	119.0	Till	1.42	38.3	31.2	30.5	41.3	38.6	20.1	1.2	2.9	4.1	0.40
W99-2-120.0	120.0	Till	1.33	40.0	29.6	30.4	43.1	35.6	21.3	1.2	2.9	4.1	0.40
W99-2-121.0	121.0	Till	1.25	37.8	32.3	29.9	40.7	39.8	19.5	1.1	3.0	4.1	0.38

Table A4-2 Matrix grain size and carbonate analyses, core hole WEPA99-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-2-122.0	122.0	Till	1.33	39.6	32.0	28.4	42.5	39.6	17.9	0.7	2.3	3.0	0.31
W99-2-123.0	123.0	Till	1.37	34.4	34.4	31.2	37.5	41.6	20.9	1.0	3.1	4.1	0.31
W99-2-124.0	124.0	Till	0.76	31.0	31.7	37.3	33.1	41.7	25.2	1.3	4.0	5.3	0.32
W99-2-125.0	125.0	Till	0.70	29.2	30.7	40.1	32.7	37.5	29.8	1.2	3.9	5.1	0.32
W99-2-127.0	127.0	Till	0.70	30.5	33.5	36.0	33.9	41.4	24.7	1.2	3.9	5.1	0.32
W99-2-128.0	128.0	Till	0.88	29.9	35.6	34.5	33.6	43.6	22.8	1.0	3.8	4.7	0.26
W99-2-129.0	129.0	Till	0.68	28.2	32.5	39.3	31.8	40.5	27.7	1.0	3.5	4.5	0.29
W99-2-130.0	130.0	Till	0.54	23.9	32.7	43.4	27.1	43.7	29.2	1.5	3.2	4.7	0.47
W99-2-131.0	131.0	Till	0.45	23.4	24.7	51.9	26.3	38.0	35.7	1.2	3.8	5.0	0.32
W99-2-132.0	132.0	Till	0.70	30.2	31.2	38.6	33.4	39.4	27.2	1.2	4.0	5.2	0.30
W99-2-133.0	133.0	Till	0.54	25.2	34.4	40.4	28.9	42.6	28.5	1.2	3.6	4.9	0.34
W99-2-134.2	134.2	Till	0.76	36.6	27.6	35.8	39.9	35.8	24.3	1.1	3.4	4.5	0.33
W99-2-135.0	135.0	Till	0.49	31.8	29.4	38.8	35.3	37.4	27.3	1.4	3.8	5.2	0.36
W99-2-136.0	136.0	Till	0.12	51.9	20.5	27.6	55.5	25.3	19.2	1.4	6.8	8.2	0.21
W99-2-137.0	137.0	Till	0.00	6.6	54.0	39.4	9.3	69.8	20.9	1.5	8.2	9.8	0.20
W99-2-138.0	138.0	Silt & Clay	0.04	50.2	17.7	32.1	53.8	24.4	21.8	1.3	6.3	7.6	0.21
W99-2-139.0	139.0	Silt & Clay	0.00	4.7	69.4	25.9	10.3	71.6	18.1	1.1	4.9	6.0	0.23
W99-2-140.0	140.0	Silt	0.02	3.2	67.9	28.9	6.9	74.3	18.8	1.2	5.0	6.2	0.25
W99-2-141.0	141.0	Silt	0.04	35.0	35.6	29.4	41.0	37.4	21.6	1.0	4.8	5.9	0.22
W99-2-142.0	142.0	Silt	0.02	53.1	20.8	26.1	56.6	24.8	18.6	1.1	4.8	5.9	0.22
W99-2-143.0	143.0	Silt	0.02	48.8	25.1	26.1	54.6	26.8	18.6	1.3	4.6	5.9	0.27
W99-2-144.0	144.0	Silt	0.00	11.7	59.9	28.4	21.0	59.3	19.7	1.3	4.8	6.1	0.26
W99-2-145.0	145.0	Silt	0.12	48.6	14.6	36.8	49.7	24.5	25.8	1.5	5.8	7.3	0.27
W99-2-146.0	146.0	Silt	0.00	44.7	27.0	28.3	52.1	27.7	20.2	1.3	5.0	6.2	0.26
W99-2-148.1	148.1	Silt & Clay	0.00	1.9	66.2	31.9	5.9	71.6	22.5	1.2	4.6	5.8	0.26
W99-2-149.0	149.0	Till & Clay	0.00	4.3	57.7	38.0	7.6	66.8	25.6	1.0	4.1	5.1	0.24
W99-2-149.9	149.9	Till & Clay	0.00	1.0	58.2	40.8	2.7	69.2	28.1	1.2	4.7	5.9	0.25
W99-2-151.0	151.0	Till & Clay	0.59	24.7	32.9	42.4	27.9	42.6	29.5	1.3	4.4	5.7	0.28
W99-2-152.0	152.0	Till & Clay	0.08	3.3	51.3	45.4	5.4	62.6	32.0	2.0	6.3	8.4	0.33
W99-2-153.0	153.0	Till & Clay	0.86	19.7	39.9	40.4	22.6	49.8	27.6	1.2	4.5	5.7	0.27
W99-2-154.0	154.0	Till & Clay	0.53	24.1	38.0	37.9	28.6	44.3	27.1	1.3	4.4	5.7	0.28

Table A4-2 Matrix grain size and carbonate analyses, core hole WEPA99-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W99-2-155.0	155.0	Till & Clay	0.04	11.3	45.7	43.0	14.3	58.7	27.0	2.0	5.5	7.5	0.37
W99-2-156.0	156.0	Till	0.90	34.1	33.5	32.4	37.8	40.0	22.2	1.0	2.8	3.8	0.34
W99-2-157.0	157.0	Till	1.03	35.4	34.6	30.0	38.9	41.8	19.3	0.8	3.0	3.7	0.26
W99-2-158.0	158.0	Till	0.76	31.3	32.4	36.3	34.9	39.9	25.2	1.0	3.5	4.5	0.27
W99-2-159.0	159.0	Mudstone	0.00	0.0	6.7	93.3	0.1	17.8	82.1	1.1	2.6	3.8	0.43
W99-2-160.0	160.0	Mudstone	0.00	0.2	19.6	80.2	0.6	35.9	63.5	1.6	3.7	5.4	0.44

Table A4-3: Matrix grain size and carbonate analyses, core hole WR99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
WR99-1-23.4	Till	23.40	1.08	31.3	50.1	18.6	35.3	54.2	10.5	0.7	2.4	3.1	0.31
WR99-1-26.0	Till	26.00	2.42	44.7	37.8	17.5	48.1	42.8	9.1	0.7	2.4	3.1	0.27
WR99-1-28.9	Till	28.90	2.73	40.9	38.3	20.8	44.4	43.0	12.6	0.7	2.2	2.9	0.34
WR99-1-30.6	Till	30.60	1.96	48.1	36.2	15.7	50.9	40.5	8.6	0.6	2.5	3.1	0.22
WR99-1-31.6	Till	31.60	2.64	42.1	41.2	16.7	45.6	44.6	9.8	0.7	1.7	2.4	0.44
WR99-1-33.0	Till	33.00	2.46	41.6	39.2	19.2	45.2	43.0	11.8	0.6	2.5	3.1	0.22
WR99-1-34.8	Till	34.80	1.86	30.4	45.5	24.1	33.4	51.4	15.2	0.7	1.5	2.2	0.47
WR99-1-35.9	Till	35.90	1.66	33.0	42.1	24.9	36.3	48.8	14.9	0.7	2.2	2.9	0.34
WR99-1-36.6	Till	36.60	2.07	32.8	42.4	24.8	35.9	48.7	15.4	0.6	1.6	2.2	0.36
WR99-1-37.7	Till	37.70	1.88	39.1	36.2	24.7	42.6	42.6	14.8	0.7	1.9	2.7	0.38
WR99-1-38.6	Till	38.60	2.17	33.9	46.8	19.3	37.1	50.4	12.5	0.7	1.9	2.5	0.35
WR99-1-39.9	Till	39.90	1.77	34.6	43.3	22.1	37.9	47.7	14.4	0.4	1.5	1.9	0.26
WR99-1-40.9	Till	40.90	1.96	29.4	45.6	25.0	32.3	50.7	17.0	0.6	1.8	2.5	0.36
WR99-1-41.8	Silt & Clay	41.80	0.00	0.4	71.8	27.8	0.9	82.5	16.6	0.6	5.0	5.5	0.12
WR99-1-43.0	Silt & Clay	43.00	0.02	0.7	71.9	27.4	1.1	83.3	15.6	0.3	5.5	5.8	0.07
WR99-1-43.9	Silt & Clay	43.90	0.00	0.9	71.8	27.3	1.3	83.9	14.8	0.9	4.2	5.1	0.22
WR99-1-45.0	Silt & Clay	45.00	0.29	6.6	60.5	32.9	7.9	72.4	19.7	0.9	4.4	5.4	0.21
WR99-1-46.0	Silt & Clay	46.00	0.00	0.4	56.0	43.6	1.6	73.5	24.9	0.7	3.3	3.9	0.20
WR99-1-46.5	Silt & Clay	46.50	0.33	9.0	56.2	34.8	10.8	68.9	20.3	0.7	2.2	2.9	0.29
WR99-1-47.5	Till	47.50	2.05	38.5	40.3	21.2	41.9	44.9	13.2	0.7	1.3	2.0	0.49
WR99-1-48.6	Till	48.60	2.24	38.4	44.5	17.1	41.7	47.4	10.9	0.7	1.7	2.3	0.39
WR99-1-49.8	Till	49.80	2.13	39.4	39.6	21.0	42.8	43.6	13.6	0.7	1.4	2.2	0.50
WR99-1-51.0	Till	51.00	2.26	39.2	41.5	19.3	42.6	44.2	13.2	0.6	1.8	2.5	0.35
WR99-1-52.3	Till	52.30	2.12	39.5	41.3	19.2	43.0	44.6	12.4	0.6	1.7	2.3	0.39
WR99-1-53.2	Till	53.20	2.41	40.7	34.2	25.1	44.2	40.1	15.7	0.9	2.0	2.9	0.47
WR99-1-54.3	Till	54.30	2.31	39.9	41.1	19.0	43.4	45.0	11.6	0.6	1.4	2.0	0.45
WR99-1-58.2	Till	58.20	2.10	39.7	41.2	19.1	43.2	45.2	11.6	0.9	1.5	2.4	0.60
WR99-1-59.0	Till	59.00	1.95	44.0	36.7	19.3	47.7	40.5	11.8	0.7	1.6	2.4	0.44
WR99-1-60.0	Till	60.00	2.47	45.6	35.3	19.1	49.4	38.4	12.2	0.7	1.5	2.2	0.49
WR99-1-61.0	Till	61.00	2.29	45.7	32.1	22.2	49.3	36.4	14.3	0.7	1.8	2.5	0.38
WR99-1-62.0	Till	62.00	2.50	45.3	38.4	16.3	48.8	41.4	9.8	0.6	1.7	2.3	0.36

Table A4-3 Matrix grain size and carbonate analyses, core hole WR99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
WR99-1-63.0	Till	63.00	2.14	44.7	37.3	18.0	48.3	40.8	10.9				
WR99-1-65.4	Till	65.40	2.12	46.7	33.5	19.8	49.9	38.0	12.1	0.7	2.0	2.7	0.34
WR99-1-66.4	Till	66.40	1.82	45.2	34.3	20.5	48.7	38.9	12.4	0.6	1.9	2.5	0.32
WR99-1-68.0	Till	68.00	2.15	41.4	39.3	19.3	44.9	42.8	12.3	0.6	2.3	2.9	0.27
WR99-1-69.5	Till	69.50	1.52	40.1	36.5	23.4	43.4	43.3	13.3	0.6	2.3	2.8	0.26
WR99-1-71.2	Till	71.20	1.37	41.4	37.8	20.8	44.6	43.3	12.1	0.7	2.8	3.5	0.24
WR99-1-72.5	Till	72.50	1.62	42.2	34.6	23.2	45.7	40.8	13.5	0.7	2.4	3.0	0.27
WR99-1-73.6	Till	73.60	1.67	51.0	25.9	23.1	51.3	35.5	13.2	0.7	2.0	2.7	0.32
WR99-1-74.5	Till	74.50	2.01	44.8	32.9	22.3	47.8	39.4	12.8	0.9	2.3	3.2	0.40
WR99-1-80.6	Till & Clay	80.60	0.02	5.4	60.4	34.2	7.7	68.8	23.5	0.8	3.5	4.3	0.22
WR99-1-85.0	Sand	85.00	0.43	26.8	66.0	7.2	33.6	63.0	3.4	1.0	3.1	4.1	0.34
WR99-1-86.0	Clay	86.00	0.00	0.3	92.3	7.4	0.5	95.5	3.6	5.5	3.8	9.4	1.46
WR99-1-86.5	Sand	86.50	0.02	5.3	80.9	13.8	8.0	83.6	8.4	0.7	0.6	1.3	1.15
WR99-1-88.2	Silt	88.20	0.00	8.3	77.1	14.6	9.4	81.5	9.1	1.1	3.6	4.7	0.30
WR99-1-89.5	Sand	89.50	1.37	57.5	28.9	13.6	60.1	32.0	7.9	0.8	2.8	3.5	0.28
WR99-1-91.5	Sand	91.50	1.77	57.9	31.9	10.2	60.5	33.9	5.6	0.9	2.0	2.9	0.47
WR99-1-93.0	Till	93.00	1.20	42.0	40.5	17.5	45.1	43.6	11.3	1.0	3.1	4.1	0.31
WR99-1-94.0	Till	94.00	1.07	33.7	48.7	17.6	36.4	52.2	11.4	0.7	2.2	2.9	0.32
WR99-1-95.0	Till	95.00	1.35	40.2	40.4	19.4	43.2	45.3	11.5	0.7	1.4	2.1	0.46
WR99-1-96.0	Silt	96.00	0.92	28.5	51.9	19.6	31.0	56.2	12.8	0.7	1.7	2.4	0.39
WR99-1-97.2	Silt	97.20	0.00	2.7	82.2	15.1	5.6	86.0	8.4	0.7	2.7	3.4	0.27
WR99-1-98.0	Silt	98.00	0.00	1.6	82.2	16.2	5.5	86.0	8.5	1.0	2.8	3.8	0.34
WR99-1-99.0	Clay	99.00	0.06	5.4	52.2	42.4	6.9	64.4	28.7	0.7	2.7	3.4	0.24
WR99-1-100.0	Clay	100.0	0.00	0.7	75.9	23.4	0.8	85.0	14.2	0.7	2.9	3.6	0.24
WR99-1-101.8	Clay	101.8	0.04	0.6	72.6	26.8	0.7	81.1	18.2	0.7	1.2	1.8	0.56
WR99-1-104.2	Clay	104.2	0.00	0.4	38.1	61.5	0.7	62.2	37.1	0.7	0.6	1.3	1.03
WR99-1-106.5	Clay	106.5	0.04	1.5	69.9	28.6	1.8	82.3	15.9	0.7	1.7	2.3	0.42
WR99-1-108.5	Clay	108.50	0.08	1.7	51.8	46.5	2.2	68.6	29.2	0.8	1.6	2.4	0.48
WR99-1-110.0	Clay	110.00	0.04	1.6	52.0	46.4	2.0	68.9	29.1	0.6	2.5	3.1	0.25
WR99-1-112.0	Clay	112.00	0.06	2.2	55.7	42.1	2.6	68.2	29.2	0.6	1.0	1.6	0.60
WR99-1-114.2	Silt & Clay	114.20	0.00	2.3	77.8	19.9	3.0	85.0	12.0	0.8	6.8	7.6	0.12

Table A4-3 Matrix grain size and carbonate analyses, core hole WR99-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
WR99-1-115.4	Silt & Clay	115.40	0.02	2.0	78.8	19.2	2.7	86.5	10.8	0.9	3.3	4.3	0.29
WR99-1-116.5	Silt & Clay	116.50	0.04	3.7	72.2	24.1	5.3	80.0	14.7	0.8	2.9	3.7	0.29
WR99-1-118.0	Silt	118.00	0.19	7.7	62.7	29.6	9.3	74.1	16.6	0.9	3.0	3.9	0.32
WR99-1-120.5	Silt	120.50	0.08	2.4	87.6	10.0	5.1	89.9	5.0	1.3	3.7	5.0	0.35
WR99-1-122.0	Silt	122.00	0.04	16.2	69.4	14.4	23.6	68.2	8.2	0.6	3.1	3.7	0.21
WR99-1-137.0	Sand	137.00	0.06	27.5	60.2	12.3	37.9	55.4	6.7	0.5	2.4	3.0	0.23
WR99-1-139.0	Sand	139.00	0.14	17.4	67.2	15.4	26.4	63.9	9.7	0.7	2.6	3.3	0.27
WR99-1-145.0	Clay	145.00	0.12	1.8	76.6	21.6	3.0	85.7	11.3	0.9	2.3	3.2	0.42
WR99-1-146.0	Clay	146.00	0.08	1.4	76.4	22.2	2.3	84.3	13.4	0.6	2.0	2.7	0.30
WR99-1-149.2	Sand	149.20	2.29	28.0	46.5	25.5	28.8	55.6	15.6	1.0	3.4	4.4	0.29
WR99-1-152.0	Sand & Gravel	152.00	1.48	79.5	12.4	8.1	83.1	12.1	4.8	0.9	1.9	2.9	0.50

Table A4-4: Matrix grain size and carbonate analyses, core hole WEPA00-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-1-2.9	Till	2.90	1.21	42.3	35.4	22.3	45.2	39.2	15.6	1.8	9.8	11.6	0.18
W00-1-4.25	Till	4.25	1.09	35.6	39.4	25.0	37.2	44.6	18.2	1.9	10.8	12.7	0.19
W00-1-6.0	Till	6.00	0.72	32.0	44.8	23.2	35.3	46.8	17.9	1.9	11.1	13.0	0.17
W00-1-7.0	Till	7.00	0.91	34.6	39.3	26.1	36.8	46.0	17.2	1.9	10.2	12.1	0.18
W00-1-9.3	Till	9.30	0.84	41.5	37.1	21.4	44.4	42.1	13.5	1.9	10.9	12.8	0.18
W00-1-10.35	Till	10.35	1.11	46.3	34.5	19.2	48.4	39.0	12.6	1.8	9.6	11.4	0.19
W00-1-12.0	Till	12.00	0.99	39.0	43.5	17.5	42.4	45.6	12.0	1.9	10.7	12.6	0.19
W00-1-13.4	Till	13.40	1.44	41.1	34.6	24.3	43.6	41.0	15.4	1.9	11.6	13.5	0.17
W00-1-14.65	Till	14.65	1.48	45.7	35.3	19.0	48.2	39.6	12.2	1.9	10.0	11.9	0.19
W00-1-22.95	Till	22.95	1.69	56.8	18.2	25.0	57.9	22.6	19.5	1.0	3.3	4.4	0.30
W00-1-24.45	Till	24.45	1.38	46.8	40.5	12.7	49.3	43.3	7.4	1.2	3.6	4.8	0.32
W00-1-25.5	Till	25.50	1.32	45.0	43.5	11.5	47.8	44.4	7.8	1.4	4.1	5.4	0.33
W00-1-27.3	Till	27.30	1.34	40.0	46.9	13.1	42.5	49.2	8.3	1.2	3.6	4.8	0.32
W00-1-28.5	Till	28.50	1.19	42.9	38.9	18.2	45.6	42.2	12.2	1.2	3.9	5.1	0.29
W00-1-29.5	Till	29.50	1.42	49.5	34.1	16.4	52.5	35.7	11.8	1.0	3.9	4.9	0.27
W00-1-32.2	Till	32.20	0.86	27.0	60.4	12.6	28.5	62.2	9.3	1.0	4.4	5.3	0.22
W00-1-34.0	Till	34.00	0.86	27.6	60.3	12.1	29.1	61.7	9.2	1.1	4.6	5.7	0.23
W00-1-34.9	Till	34.90	0.94	32.6	53.2	14.2	34.4	54.9	10.7	1.0	3.9	4.8	0.25
W00-1-45.4	Till	45.40	1.15	50.2	38.7	11.1	53.0	38.9	8.1	0.8	3.3	4.1	0.26
W00-1-46.4	Till	46.40	0.99	46.8	35.7	17.5	52.7	35.4	11.9	1.0	3.5	4.4	0.28
W00-1-82.05	Till	82.05	1.64	47.4	33.8	18.8	50.5	37.2	12.3	1.0	3.3	4.2	0.29
W00-1-83.1	Till	83.10	1.57	41.0	36.8	22.2	44.1	40.6	15.3	0.9	3.1	4.1	0.30
W00-1-84.1	Till	84.10	1.05	40.1	39.1	20.8	43.2	42.2	14.6	0.8	3.5	4.2	0.22
W00-1-85.2	Till	85.20	1.37	42.0	35.1	22.9	45.0	39.9	15.1	0.9	3.7	4.6	0.26
W00-1-86.2	Till	86.20	1.48	43.0	36.3	20.7	46.1	42.9	11.0	0.7	3.2	3.9	0.21
W00-1-87.2	Till	87.20	1.80	46.0	33.9	20.1	49.6	39.4	11.0	0.9	3.1	4.1	0.30
W00-1-89.4	Till	89.40	1.56	41.7	30.4	27.9	44.7	38.4	16.9	0.7	3.4	4.1	0.20
W00-1-90.4	Till	90.40	1.87	44.9	35.4	19.7	48.6	40.6	10.8	1.1	3.7	4.8	0.29
W00-1-91.4	Till	91.40	1.71	45.2	34.7	20.1	48.5	39.8	11.7	0.8	4.0	4.8	0.19
W00-1-92.35	Till	92.35	1.68	45.4	32.8	21.8	48.7	38.5	12.8	1.1	3.9	5.0	0.27
W00-1-93.4	Till	93.40	1.95	47.5	27.8	24.7	50.9	34.8	14.3	0.8	3.7	4.5	0.21

Table A4-4 Matrix grain size and carbonate analyses, core hole WEPA00-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-1-95.1	Till	95.10	0.39	10.8	64.5	24.7	11.7	74.0	14.3	0.8	4.9	5.7	0.16
W00-1-96.0	Till	96.00	1.23	28.5	46.4	25.1	31.3	54.6	14.1	1.0	4.4	5.3	0.22
W00-1-96.9	Till	96.90	1.75	46.1	32.8	21.1	49.4	38.6	12.0	1.0	3.4	4.3	0.29
W00-1-98.05	Till	98.05	1.83	45.1	31.2	23.7	48.7	37.3	14.0	0.7	3.9	4.6	0.19
W00-1-99.0	Till	99.00	1.52	46.8	34.9	18.3	49.9	38.1	12.0	1.0	3.5	4.5	0.27
W00-1-100.0	Till	100.00	1.87	45.5	34.0	20.5	49.2	37.8	13.0	1.0	3.8	4.8	0.27
W00-1-101.0	Till	101.00	1.72	43.2	36.4	20.4	46.7	39.8	13.5	0.8	4.0	4.8	0.19
W00-1-102.0	Till	102.00	1.72	45.0	35.2	19.8	48.1	39.7	12.2	1.0	3.5	4.6	0.30
W00-1-104.6	Till	104.60	2.09	45.8	33.6	20.6	49.2	37.7	13.1	0.8	3.9	4.7	0.20
W00-1-105.7	Till	105.70	1.77	47.1	31.0	21.9	50.2	35.3	14.5	0.8	4.1	4.9	0.19
W00-1-106.7	Till	106.70	1.93	45.4	34.2	20.4	49.1	37.5	13.4	1.0	3.7	4.7	0.26
W00-1-107.7	Till	107.70	1.58	43.2	37.4	19.4	46.2	42.2	11.6	0.9	3.6	4.5	0.24
W00-1-108.7	Till	108.70	1.64	44.2	36.4	19.4	47.7	40.2	12.1	1.0	3.5	4.5	0.28
W00-1-110.9	Till	110.90	1.73	42.8	37.8	19.4	46.0	41.9	12.1	1.0	4.4	5.4	0.22
W00-1-115.4	Till	115.40	1.93	49.0	31.3	19.7	51.7	36.1	12.2	0.8	2.2	3.0	0.39
W00-1-117.3	Till	117.30	1.56	55.5	26.9	17.6	58.1	31.6	10.3	0.8	1.2	2.0	0.64
W00-1-120.05	Till	120.05	2.36	50.7	34.5	14.8	53.6	37.2	9.2	1.0	1.2	2.2	0.78
W00-1-120.95	Till	120.95	1.93	51.8	32.0	16.2	54.7	35.4	9.9	0.8	1.1	2.0	0.74
W00-1-121.9	Till	121.90	2.44	50.7	33.1	16.2	53.4	36.7	9.9	1.0	2.1	3.1	0.45
W00-1-123.7	Till	123.70	4.59	58.2	25.3	16.5	60.7	29.5	9.8	1.2	4.5	5.7	0.26
W00-1-124.6	Till	124.60	3.73	53.1	28.0	18.9	55.9	32.6	11.5	1.3	4.6	5.8	0.28
W00-1-125.55	Till	125.55	3.71	57.9	27.2	14.9	60.6	30.7	8.7	1.3	4.5	5.8	0.28
W00-1-127.0	Sand	127.00	4.81	58.6	30.8	10.6	61.1	32.6	6.3	1.0	3.8	4.7	0.26
W00-1-153.0	Till	153.00	1.83	25.9	56.4	17.7	29.9	58.8	11.3	1.0	1.4	2.4	0.70
W00-1-154.0	Till	154.00	2.95	35.8	49.3	14.9	39.2	51.7	9.1	0.9	1.7	2.5	0.51
W00-1-155.0	Till	155.00	1.70	25.8	53.0	21.2	29.8	58.3	11.9	1.0	1.6	2.5	0.62
W00-1-156.0	Till	156.00	2.26	29.6	59.1	11.3	33.7	59.8	6.5	0.9	0.9	1.7	0.99
W00-1-157.35	Till	157.35	2.50	28.8	57.0	14.2	31.8	59.1	9.1	0.9	1.4	2.2	0.63
W00-1-158.4	Till	158.40	2.46	35.7	53.3	11.0	39.1	54.1	6.8	0.8	1.5	2.2	0.53
W00-1-159.3	Till	159.30	2.36	29.9	55.8	14.3	33.2	59.1	7.7	0.7	1.0	1.7	0.66
W00-1-160.2	Till	160.20	3.20	31.8	52.1	16.1	35.3	54.3	10.4	0.7	1.5	2.2	0.47

Table A4-4 Matrix grain size and carbonate analyses, core hole WEPA00-1

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-1-162.2	Till	162.20	3.16	35.3	53.4	11.3	38.8	54.7	6.5	0.7	1.8	2.5	0.39
W00-1-164.35	Till	164.35	3.02	33.3	53.4	13.3	37.2	53.9	8.9	1.0	2.5	3.5	0.39
W00-1-165.4	Till	165.40	2.70	35.7	48.5	15.8	39.1	50.7	10.2	1.1	1.7	2.7	0.65
W00-1-166.4	Till	166.40	2.16	39.1	45.1	15.8	39.9	50.4	9.7	1.0	1.8	2.7	0.54
W00-1-167.6	Till	167.60	1.98	26.2	56.5	17.3	29.5	60.5	10.0	1.2	2.3	3.6	0.52
W00-1-168.9	Till	168.90	1.98	29.6	54.9	15.5	33.0	57.9	9.1	1.2	2.9	4.1	0.42
W00-1-169.9	Till	169.90	2.75	33.8	50.0	16.2	36.9	52.5	10.6	1.4	2.6	3.9	0.53
W00-1-171.0	Till	171.00	2.56	36.2	48.0	15.8	39.7	49.9	10.4	1.2	2.0	3.2	0.60
W00-1-172.0	Till	172.00	3.04	34.8	47.8	17.4	38.1	49.7	12.2	1.4	2.1	3.4	0.66
W00-1-173.0	Till	173.00	3.25	37.0	45.3	17.7	40.3	47.3	12.4	1.7	2.0	3.7	0.84

Table A4-5: Matrix grain size and carbonate analyses, core hole WEPA00-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-2-5.7	Till	5.70	1.25	47.4	30.9	21.7	50.2	33.9	15.9	2.0	9.5	11.6	0.21
W00-2-8.6	Till	8.60	1.07	40.5	34.4	25.1	43.7	38.1	18.2	2.0	9.3	11.3	0.21
W00-2-9.5	Till	9.50	1.36	37.2	38.0	24.8	39.9	42.2	17.9	2.0	9.3	11.3	0.22
W00-2-13.2	Till	13.20	1.19	36.6	35.1	28.3	39.7	40.1	20.2	2.5	10.0	12.5	0.26
W00-2-14.2	Till	14.20	1.29	37.0	35.2	27.8	39.6	40.3	20.1	2.2	10.2	12.3	0.21
W00-2-15.2	Till	15.20	1.47	39.4	32.9	27.7	42.6	37.4	20.0	1.9	10.4	12.3	0.18
W00-2-15.6	Till	15.60	1.44	37.4	36.0	26.6	40.1	41.8	18.1	2.0	10.3	12.3	0.19
W00-2-16.75	Till	16.75	1.77	44.0	36.9	19.1	47.5	41.3	11.2	2.2	9.0	11.1	0.24
W00-2-18.3	Till	18.30	1.07	48.7	28.8	22.5	51.6	34.9	13.5	2.8	10.5	13.2	0.27
W00-2-19.6	Till	19.60	1.58	46.6	33.0	20.4	50.0	37.3	12.7	2.8	9.5	12.3	0.30
W00-2-20.6	Till	20.60	1.15	47.9	30.2	21.9	50.8	36.2	13.0	2.5	10.1	12.6	0.25
W00-2-21.6	Till	21.60	1.07	47.6	30.6	21.8	51.1	35.8	13.1	2.1	10.1	12.2	0.21
W00-2-22.8	Till	22.80	0.70	37.8	33.9	28.3	40.5	42.7	16.8	2.2	11.2	13.4	0.20
W00-2-25.9	Till	25.90	1.01	40.9	31.4	27.7	44.1	39.7	16.2	2.1	10.6	12.7	0.21
W00-2-26.9	Till	26.90	1.16	38.6	31.9	29.5	41.6	40.7	17.7	2.3	10.8	13.1	0.22
W00-2-27.9	Till	27.90	1.34	38.3	31.9	29.8	42.1	39.6	18.3	1.9	11.0	12.9	0.17
W00-2-29.0	Till	29.00	1.27	38.8	29.9	31.3	41.5	39.7	18.8	2.3	11.0	13.3	0.21
W00-2-30.1	Till	30.10	1.08	37.6	29.2	33.2	40.8	38.4	20.8	2.3	11.8	14.1	0.21
W00-2-31.4	Till	31.40	1.06	37.4	36.6	26.0	39.9	43.1	17.0	2.3	10.9	13.2	0.22
W00-2-32.3	Till	32.30	1.27	37.8	38.6	23.6	41.1	43.1	15.8	1.5	9.7	11.3	0.16
W00-2-46.7	Silt & Clay	46.70	0.00	7.3	73.6	19.1	8.1	80.7	11.2	1.0	6.2	7.2	0.17
W00-2-87.9	Till	87.90	0.96	31.5	51.1	17.4	35.6	53.6	10.8	1.4	8.8	10.2	0.16
W00-2-89.1	Till	89.10	0.88	32.6	51.1	16.3	37.7	52.1	10.2	1.3	9.3	10.7	0.14
W00-2-90.1	Till	90.10	1.19	32.6	45.8	21.6	36.5	49.7	13.8	1.3	8.7	10.1	0.15
W00-2-91.1	Till	91.10	0.94	32.9	45.6	21.5	37.6	48.1	14.3	1.6	9.0	10.6	0.18
W00-2-92.15	Till	92.15	1.03	32.2	48.4	19.4	36.8	50.4	12.8	1.7	9.4	11.1	0.18
W00-2-93.2	Till	93.20	1.21	32.9	49.3	17.8	37.6	51.4	11.0	1.4	9.8	11.2	0.15
W00-2-93.9	Till	93.90	0.41	29.3	51.9	18.8	35.6	53.4	11.0	1.8	7.6	9.5	0.25
W00-2-95.2	Till	95.20	2.31	41.9	40.7	17.4	45.3	43.9	10.8	2.1	4.9	7.0	0.44
W00-2-96.3	Till	96.30	1.97	36.6	48.1	15.3	40.2	50.6	9.2	1.6	5.0	6.6	0.33
W00-2-97.3	Till	97.30	2.23	39.9	44.9	15.2	43.3	48.2	8.5	1.8	4.9	6.7	0.37

Table A4-5 Matrix grain size and carbonate analyses, core hole WEPA00-2

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-2-98.3	Till	98.30	2.70	39.5	43.7	16.8	42.3	47.0	10.7	2.6	4.8	7.3	0.54
W00-2-99.3	Till	99.30	2.22	42.3	43.5	14.2	45.6	46.2	8.2	2.7	5.1	7.8	0.55
W00-2-100.3	Till	100.30	2.18	43.9	39.9	16.2	46.7	43.9	9.4	3.2	4.8	8.0	0.65
W00-2-101.3	Till	101.30	2.13	42.3	43.6	14.1	45.9	46.2	7.9	1.6	6.4	8.0	0.27
W00-2-102.3	Till	102.30	2.32	43.3	40.6	16.1	46.3	44.2	9.5	1.8	5.3	7.1	0.35
W00-2-103.3	Till	103.30	1.93	41.9	42.0	16.1	45.4	44.7	9.9	1.8	4.9	6.7	0.36
W00-2-104.45	Till	104.45	2.13	40.4	41.3	18.3	43.4	45.9	10.7	1.2	5.5	6.7	0.23
W00-2-105.5	Till	105.50	2.01	41.7	41.1	17.2	45.6	44.9	9.5	1.9	5.2	7.1	0.38
W00-2-107.7	Till	107.70	2.39	34.4	47.3	18.3	37.4	51.1	11.5	1.9	4.5	6.4	0.42
W00-2-108.7	Till	108.70	2.13	36.7	45.2	18.1	41.5	47.9	10.6	2.0	5.5	7.4	0.37
W00-2-109.6	Till	109.60	2.03	37.2	46.7	16.1	41.1	49.1	9.8	2.0	5.5	7.6	0.37
W00-2-111.45	Silt & Clay	111.45	0.04	1.2	57.7	41.1	2.2	73.3	24.5	2.4	10.8	13.2	0.23

Table A4-6: Matrix grain size and carbonate analyses, core hole WEPA00-3

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-3-1.3	Till	1.3	1.02	42.0	33.8	24.2	44.7	37.9	17.4	1.9	9.3	11.2	0.21
W00-3-4.0	Till	4.0	1.01	66.0	19.8	14.2	69.1	22.3	8.6	2.0	9.4	11.4	0.21
W00-3-5.0	Till	5.0	1.26	49.1	30.3	20.6	51.9	32.0	16.1	2.0	9.6	11.6	0.21
W00-3-6.5	Till	6.5	1.39	40.4	37.0	22.6	42.8	40.9	16.3	2.0	11.3	13.3	0.18
W00-3-7.6	Till	7.6	1.29	41.7	36.5	21.8	43.9	41.0	15.1	1.9	9.6	11.6	0.20
W00-3-8.75	Till	8.75	1.29	41.2	38.2	20.6	43.9	41.8	14.3	2.1	11.1	13.2	0.19
W00-3-17.5	Till	17.5	0.92	40.2	36.7	23.1	42.5	41.4	16.1	2.5	9.9	12.4	0.25
W00-3-18.5	Till	18.5	1.43	43.1	32.1	24.8	45.8	38.3	15.9	2.0	11.0	13.0	0.18
W00-3-19.5	Till	19.5	1.27	31.7	35.2	33.1	34.2	41.9	23.9	1.9	9.2	11.1	0.21
W00-3-20.5	Till	20.5	1.25	42.6	31.1	26.3	45.2	38.2	16.6	1.9	9.7	11.6	0.20
WOO-3-22.25	Till	22.25	1.23	37.2	27.5	35.3	40.3	30.5	29.2	1.5	8.4	10.0	0.18
W00-3-23.5	Till	23.5	1.29	36.6	26.3	37.1	39.3	31.0	29.7	1.6	8.9	10.5	0.18
W00-3-26.7	Till	26.7	1.59	46.6	31.4	22.0	50.0	37.2	12.8	1.6	9.4	11.0	0.17
W00-3-27.3	Till	27.3	1.19	42.7	34.3	23.0	46.2	38.6	15.2	1.5	8.5	10.1	0.18
W00-3-28.5	Till	28.5	1.23	45.5	34.1	20.4	48.8	37.8	13.4	2.0	10.1	12.1	0.20
W00-3-29.5	Till	29.5	1.54	44.1	34.1	21.8	47.0	38.8	14.2	2.0	10.4	12.5	0.19
W00-3-30.5	Till	30.5	1.16	40.7	36.7	22.6	43.9	42.6	13.5	2.1	9.1	11.2	0.23
W00-3-32.2	Till	32.2	1.51	41.7	34.9	23.4	44.4	41.3	14.3	1.8	10.2	12.0	0.17
W00-3-33.35	Till	33.35	1.00	38.4	39.5	22.1	41.2	44.9	13.9	2.1	11.4	13.4	0.18
W00-3-34.3	Till	34.3	0.80	33.0	36.5	30.5	36.2	44.8	19.0	2.1	12.1	14.1	0.17
W00-3-35.55	Till	35.55	1.15	40.3	34.4	25.3	43.3	39.9	16.8	2.2	12.3	14.5	0.18
W00-3-36.65	Till	36.65	1.07	41.1	34.5	24.4	43.8	41.4	14.8	2.1	10.9	13.1	0.21
W00-3-38.0	Till	38.0	1.15	39.9	34.3	25.8	43.0	39.2	17.8	2.0	10.7	12.7	0.19
W00-3-39.8	Till	39.8	0.84	30.9	33.2	35.9	33.1	39.9	27.0	1.5	8.7	10.2	0.18
W00-3-41.2	Till	41.20	1.19	39.3	38.3	22.4	42.3	42.9	14.8	1.7	9.1	10.7	0.18
W00-3-43.2	Till	43.2	1.23	39.0	32.9	28.1	42.1	41.2	16.7	1.7	9.2	10.9	0.19
W00-3-44.2	Till	44.2	1.35	41.6	34.8	23.6	44.3	41.2	14.5	1.9	9.9	11.8	0.20
W00-3-45.2	Till	45.2	1.41	41.3	36.3	22.4	44.1	41.1	14.8	2.1	10.8	12.8	0.20
W00-3-46.25	Till	46.25	1.43	41.9	32.7	25.4	44.5	39.2	16.3	2.0	10.3	12.3	0.20
W00-3-47.3	Till	47.30	1.88	41.9	31.2	26.9	44.8	38.6	16.6	1.6	10.6	12.1	0.16
W00-3-48.3	Till	48.3	1.29	42.3	32.9	24.8	44.9	39.1	16.0	1.9	10.4	12.3	0.19

Table A4-6 Matrix grain size and carbonate analyses, core hole WEPA00-3

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
												Total	Calcite/Dolomite
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Carbonates	Ratio
W00-3-49.3	Till	49.3	1.31	41.7	34.6	23.7	44.7	39.9	15.4	2.1	10.6	12.7	0.21
W00-3-50.5	Till	50.5	1.50	42.0	33.7	24.3	44.6	41.3	14.1	2.1	9.4	11.5	0.22
W00-3-51.5	Till	51.5	1.29	41.8	33.6	24.6	44.3	40.5	15.2	2.1	10.3	12.4	0.20
W00-3-52.5	Till	52.5	1.19	41.4	36.6	22.0	44.4	42.0	13.6	1.9	10.2	12.1	0.19
WOO-3-53.5	Till	53.5	1.31	39.4	34.4	26.2	42.0	41.3	16.7	1.5	9.8	11.4	0.16
W00-3-54.5	Till	54.5	1.60	43.1	34.8	22.1	46.4	38.5	15.1	1.7	9.4	11.2	0.19
W00-3-55.5	Till	55.5	1.13	31.5	31.7	36.8	33.7	42.0	24.3	1.8	8.7	10.5	0.21
W00-3-56.6	Till	56.6	0.91	24.4	23.1	52.5	26.5	36.6	36.9	1.4	8.2	9.5	0.18
W00-3-57.6	Till	57.6	0.56	22.4	26.6	51.0	24.7	37.9	37.4	1.2	8.3	9.5	0.15
W00-3-58.6	Till	58.6	0.52	20.2	25.4	54.4	22.0	39.4	38.6	1.5	9.0	10.4	0.16
W00-3-59.6	Till	59.6	1.03	36.1	28.1	35.8	38.6	35.7	25.7	1.5	8.5	10.1	0.18
W00-3-60.6	Till	60.6	0.70	20.3	24.3	55.4	22.4	36.2	41.4	1.4	8.5	9.9	0.17
W00-3-62.0	Till	62.0	1.37	41.7	27.8	30.5	44.4	34.9	20.7	1.5	9.2	10.7	0.17
W00-3-63.0	Till	63.0	1.61	41.5	28.8	29.7	44.5	34.6	20.9	1.4	10.0	11.4	0.14
W00-3-64.1	Till	64.1	0.99	31.0	27.8	41.2	33.4	35.9	30.7	1.5	9.0	10.5	0.17
W00-3-65.45	Till	65.45	0.82	29.2	27.7	43.1	31.7	37.0	31.3	1.1	7.9	9.0	0.16
W00-3-66.5	Till	66.5	0.84	35.8	29.6	34.6	38.6	37.2	24.2	1.5	8.6	10.1	0.18
W00-3-68.0	Till	68.0	0.92	27.3	26.5	46.2	29.6	38.5	31.9	1.5	8.9	10.5	0.17
W00-3-68.9	Till	68.9	0.76	17.2	33.3	49.5	19.2	43.3	37.5	1.4	8.3	9.7	0.18
W00-3-73.3	Till	73.3	1.39	37.2	30.6	32.2	39.8	38.6	21.6	1.8	9.3	11.0	0.19
W00-3-77.05	Till & Clay	77.05	1.61	47.3	32.8	19.9	50.8	38.0	11.2	1.8	10.0	11.7	0.18
W00-3-77.85	Till	77.85	2.31	51.6	24.2	24.2	54.8	28.0	17.2	1.1	2.4	3.4	0.44
W00-3-78.35	Till	78.35	1.99	50.1	26.5	23.4	53.8	31.0	15.2	1.2	2.9	4.2	0.43
W00-3-78.85	Till	78.85	2.32	50.9	25.8	23.3	54.1	29.5	16.4	0.7	1.9	2.6	0.37
W00-3-79.85	Till	79.85	2.19	48.8	35.3	15.9	52.5	38.6	8.9	0.9	4.2	5.1	0.20
W00-3-80.85	Till	80.85	2.01	49.9	34.5	15.6	53.3	39.5	7.2	0.7	3.2	4.0	0.23
W00-3-82.55	Till	82.55	51.44	51.4	33.1	15.5	54.4	37.1	8.5	1.0	3.7	4.7	0.26
W00-3-83.6	Till	83.6	2.01	47.7	35.4	16.9	51.0	38.6	10.4	1.0	4.4	5.4	0.22
W00-3-84.6	Till	84.6	1.74	47.1	32.8	20.1	49.9	40.9	9.2	0.7	3.8	4.5	0.20
W00-3-92.0	Till	92.0	1.29	46.7	35.6	17.7	50.3	41.6	8.1	1.3	4.2	5.5	0.32
W00-3-93.0	Till	93.0	1.88	45.8	36.5	17.7	49.1	42.7	8.2	1.1	3.8	5.0	0.30

Table A4-6 Matrix grain size and carbonate analyses, core hole WEPA00-3

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-3-93.9	Till	93.9	1.34	45.0	37.0	18.0	48.2	42.0	9.8	1.4	3.6	5.0	0.40
W00-3-109.75	Till	109.75	1.74	46.9	38.3	14.8	50.6	43.3	6.1	1.0	4.1	5.1	0.25
W00-3-110.7	Till	110.7	1.51	40.9	43.2	15.9	43.7	50.2	6.1	1.1	3.9	5.0	0.28
W00-3-111.75	Till	111.75	1.72	44.2	42.5	13.3	48.2	46.4	5.4	1.1	4.9	6.0	0.22
W00-3-112.8	Till	112.8	1.27	43.0	38.4	18.6	45.9	44.8	9.3	1.1	0.7	1.9	1.56
W00-3-113.85	Till	113.85	1.52	47.6	34.9	17.5	50.3	40.0	9.7	1.3	2.9	4.3	0.45
W00-3-114.9	Till	114.9	1.81	47.3	31.0	21.7	50.4	39.0	10.6	1.3	2.8	4.1	0.48
W00-3-115.95	Till	115.95	1.43	45.1	33.4	21.5	48.4	41.3	10.3	1.5	3.2	4.7	0.46
W00-3-117.05	Till	117.05	1.29	46.6	32.3	21.1	50.0	40.8	9.2	1.4	3.4	4.8	0.42
W00-3-118.05	Till	118.05	1.74	48.7	31.2	20.1	51.7	38.3	10.0	1.3	3.4	4.8	0.39
W00-3-119.05	Till	119.05	1.79	46.2	32.0	21.8	49.5	38.4	12.1	1.4	3.2	4.6	0.44
W00-3-120.1	Till	120.1	1.65	41.0	42.4	16.6	44.0	47.3	8.7	1.3	3.1	4.5	0.42
W00-3-121.0	Till	121.0	3.07	51.5	36.4	12.1	54.8	39.5	5.7	1.3	3.8	5.1	0.35
W00-3-125.5	Till	125.5	1.52	47.7	37.7	14.6	52.3	39.8	7.9	1.0	1.9	2.9	0.51
W00-3-127.7	Till	127.7	1.47	51.1	37.3	11.6	56.3	37.3	6.4	1.0	2.3	3.3	0.44
W00-3-129.05	Till	129.05	2.33	44.5	38.7	16.8	48.3	43.0	8.7	0.7	1.5	2.2	0.47
W00-3-131.95	Till	131.95	2.30	45.1	40.3	14.6	49.4	43.9	6.7	1.0	1.9	2.9	0.50
W00-3-133.0	Till	133.0	2.09	48.0	37.4	14.6	51.6	41.7	6.7	1.0	1.9	2.9	0.50
W00-3-134.25	Till	134.25	1.91	45.4	37.9	16.7	49.1	42.2	8.7	0.7	1.6	2.4	0.45
W00-3-135.3	Till	135.3	2.12	42.5	44.0	13.5	45.6	47.8	6.6	1.5	2.6	4.0	0.57
W00-3-136.25	Till	136.25	2.51	36.9	47.6	15.5	40.7	50.7	8.6	1.0	2.6	3.6	0.40
W00-3-138.2	Till	138.2	2.95	43.6	45.0	11.4	47.7	47.8	4.5	1.0	2.3	3.3	0.42
W00-3-139.2	Till	139.2	4.67	50.6	35.4	14.0	54.0	39.4	6.6	0.8	2.1	2.9	0.37
W00-3-140.2	Till	140.2	3.01	45.2	40.9	13.9	48.8	44.7	6.5	0.7	2.2	2.9	0.31
W00-3-141.65	Till	141.65	4.30	45.4	41.1	13.5	48.8	44.7	6.5	0.8	2.2	3.1	0.38
W00-3-143.1	Till	143.1	3.23	46.1	40.9	13.0	49.4	44.1	6.5	1.2	4.8	5.9	0.24
W00-3-144.2	Till	144.2	3.74	48.8	38.6	12.6	52.2	39.9	7.9	1.4	5.4	6.8	0.27
W00-3-145.15	Till	145.15	1.98	33.3	51.5	15.2	37.5	54.9	7.6	1.3	1.8	3.0	0.71
W00-3-147.1	Till	147.1	2.21	31.4	53.5	15.1	34.9	57.6	7.5	1.2	2.1	3.2	0.56
W00-3-148.0	Till	148.0	1.98	35.7	47.9	16.4	39.5	51.3	9.2	1.4	1.9	3.2	0.74
W00-3-149.3	Till	149.3	2.86	39.2	45.7	15.1	43.0	49.5	7.5	1.3	2.0	3.4	0.65

Table A4-6 Matrix grain size and carbonate analyses, core hole WEPA00-3

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-3-151.0	Till	151.0	2.53	33.8	47.7	18.5	37.6	49.9	12.5	1.3	2.1	3.4	0.64
W00-3-152.15	Till	152.15	2.38	42.2	40.7	17.1	45.7	44.8	9.5	1.9	2.3	4.2	0.83

Table A4-7: Matrix grain size and carbonate analyses, core hole WEPA00-4

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63µm)	Silt (<63µm)	Clay (<4µm)	Sand (>50µm)	Silt (<50µm)	Clay (<2µm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-4-10.10	Till	10.10	1.78	41.8	41.1	17.1	45.7	44.8	9.5	0.8	2.4	3.1	0.32
W00-4-11.5	Till	11.5	1.80	43.6	28.9	27.5	47.3	35.3	17.4	1.0	3.2	4.2	0.32
W00-4-12.2	Till	12.2	1.97	54.4	26.1	19.5	57.7	29.3	13.0	1.3	3.1	4.4	0.43
W00-4-13.1	Till	13.1	1.64	42.9	27.6	29.5	46.7	33.9	19.4	1.3	2.7	4.1	0.48
W00-4-16.1	Till	16.1	0.76	26.3	28.3	45.4	29.1	40.6	30.3	1.4	3.6	4.9	0.39
W00-4-17.1	Till	17.1	1.13	39.7	29.8	30.5	42.7	38.6	18.7	1.7	6.5	8.2	0.27
W00-4-23.1	Till	23.1	2.47	45.2	37.0	17.8	48.4	41.9	9.7	1.4	3.8	5.2	0.37
W00-4-34.0	Till	34.0	1.92	46.9	36.9	16.2	49.6	42.1	8.3	0.9	4.7	5.6	0.20
W00-4-34.9	Till	34.9	0.74	27.3	47.4	25.3	29.9	54.5	15.6	1.2	2.7	3.9	0.45
W00-4-40.0	Sand & Clay	40.0	2.39	42.3	30.4	27.3	45.4	36.3	18.3	1.7	4.7	6.4	0.37
W00-4-41.0	Till	41.0	2.41	34.9	40.9	24.2	37.8	47.3	14.9	1.7	4.9	6.5	0.34
W00-4-41.7	Till	41.7	1.53	40.1	41.6	18.3	44.1	44.7	11.2	1.3	4.3	5.6	0.31
W00-4-43.20	Till	43.20	1.76	40.0	40.1	19.9	43.7	44.1	12.2	1.4	4.2	5.6	0.34
W00-4-44.05	Till	44.05	1.19	26.9	45.3	27.8	29.3	54.0	16.7	1.6	4.2	5.8	0.38
W00-4-52.80	Till	52.80	1.29	35.5	44.5	20.0	38.9	49.8	11.3	0.7	2.0	2.7	0.34
W00-4-54.05	Till	54.05	0.96	24.8	52.9	22.3	27.6	58.0	14.4	0.8	1.8	2.5	0.43
W00-4-57.9	Till	57.9	0.54	32.9	37.4	29.7	35.7	45.7	18.6	0.9	2.2	3.1	0.40
W00-4-58.45	Till	58.45	0.76	27.9	44.3	27.8	30.9	50.4	18.7	1.0	2.4	3.4	0.39
W00-4-59.4	Till	59.4	1.41	35.7	48.4	15.9	39.1	51.4	9.5	1.0	2.6	3.6	0.36
W00-4-60.4	Till	60.4	1.33	36.8	41.0	22.2	40.2	45.9	13.9	1.0	1.9	2.9	0.49
W00-4-61.9	Till	61.9	1.50	36.7	45.3	18.0	40.3	50.9	8.8	0.8	1.9	2.7	0.40
W00-4-63.1	Till	63.1	1.19	35.4	45.9	18.7	38.7	50.0	11.3	0.9	1.6	2.4	0.56
W00-4-64.1	Till	64.1	1.19	35.3	46.2	18.5	38.7	50.8	10.5	1.0	2.3	3.3	0.41
W00-4-70.3	Clay	70.3	1.41	34.5	44.9	20.6	37.7	50.5	11.8	0.8	1.7	2.5	0.50
W00-4-74.5	Till	74.5	1.49	43.9	35.4	20.7	48.5	38.9	12.6	1.1	1.7	2.7	0.65
W00-4-75.5	Till	75.5	1.68	44.2	35.3	20.5	48.5	39.8	11.7	1.0	1.7	2.7	0.54
W00-4-76.70	Till	76.70	1.39	43.4	38.0	18.6	48.0	41.0	11.0	0.5	1.5	2.0	0.30
W00-4-77.70	Till	77.70	1.62	42.5	39.1	18.4	46.8	42.3	10.9	0.9	1.8	2.7	0.48
W00-4-78.7	Till	78.7	1.38	43.6	41.8	14.6	48.2	42.8	9.0	0.8	2.1	2.8	0.37
W00-4-80.0	Till	80.0	2.03	45.3	36.2	18.5	49.4	39.6	11.0	1.0	2.3	3.2	0.42
W00-4-81.10	Till	81.10	1.97	37.1	28.8	34.1	41.2	32.0	26.8	1.1	2.7	3.8	0.39

Table A4-7 Matrix grain size and carbonate analyses, core hole WEPA00-4

Sample #	Material	Depth	Sand (1-2mm)	Sand (>63μm)	Silt (<63μm)	Clay (<4μm)	Sand (>50μm)	Silt (<50μm)	Clay (<2μm)	Weight percent of carbonates (%)			
		m	% wt	% wt	% wt	% wt	% wt	% wt	% wt	Calcite	Dolomite	Total Carbonates	Calcite/Dolomite Ratio
W00-4-82.10	Till	82.10	2.37	37.2	30.2	32.6	40.7	32.8	26.5	1.2	2.5	3.7	0.46
W00-4-83.0	Till	83.0	1.72	43.9	39.5	16.6	48.4	41.9	9.7	0.9	2.3	3.3	0.40
W00-4-84.1	Till	84.1	1.45	44.6	35.1	20.3	49.0	39.6	11.4	0.9	1.8	2.7	0.48
W00-4-85.95	Till	85.95	1.53	44.6	37.3	18.1	49.2	40.3	10.5	0.9	2.2	3.1	0.40
W00-4-87.70	Till	87.70	1.35	42.6	40.3	17.1	47.2	43.3	9.5	0.7	2.0	2.7	0.37
W00-4-89.50	Till	89.50	1.74	43.7	37.8	18.5	48.1	40.9	11.0	0.7	2.1	2.8	0.35

Appendix 5. Alberta Geological Survey Water-Well Construction Details and Water-Level Information

Alberta Geological Survey water-well construction details

Tabular monthly water level elevations

Hydrographs of water level elevations, November 2000 to December 2001

Well Name:	**WEPA 00-1-WT**
Location (DLS):	06-33-074-09W4Mer
Latitude	55.4514162 °
Longitude	111.3298313 °
Surveyed Ground Level:	666.83 m

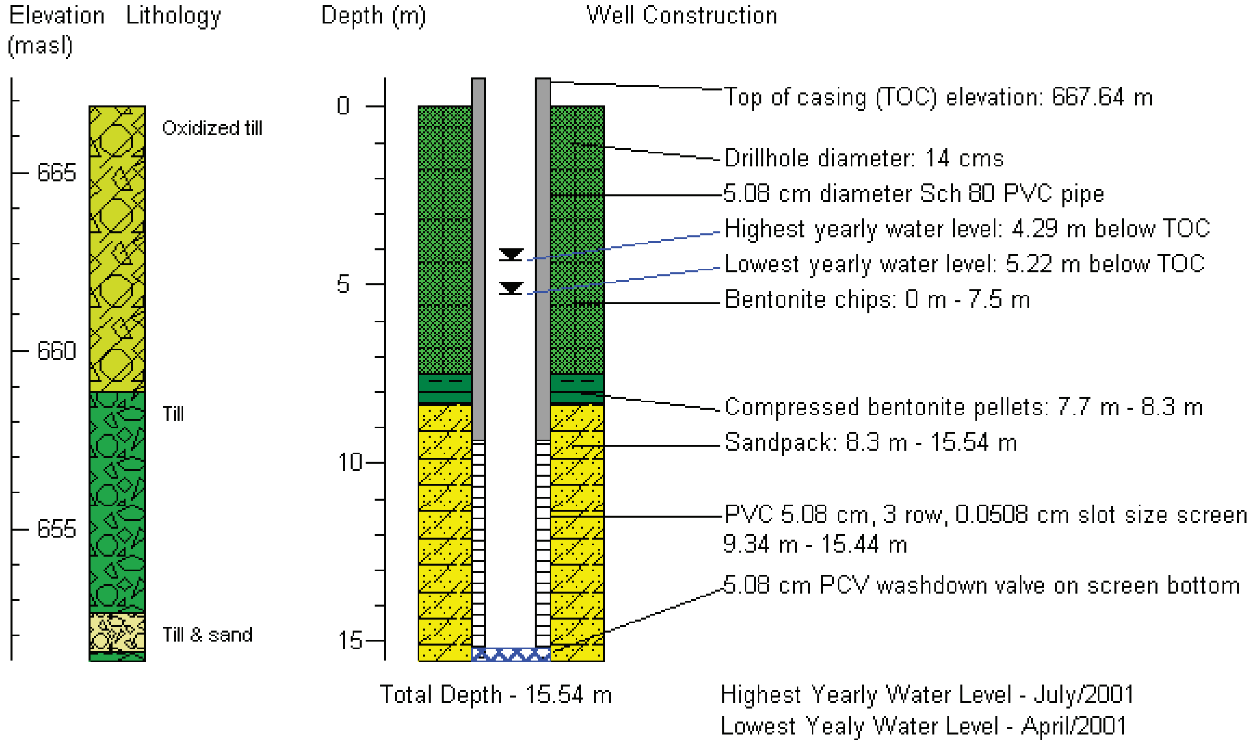


Figure A5-1: Water-table well construction details: WEPA 00-1-WT

Well Name: **WEPA 00-1-41**

Location (DLS): 06-33-074-09W4Mer

Latitude: 55.4513766 °

Longitude 111.3298244 °

Surveyed Ground Level: 667.01 m

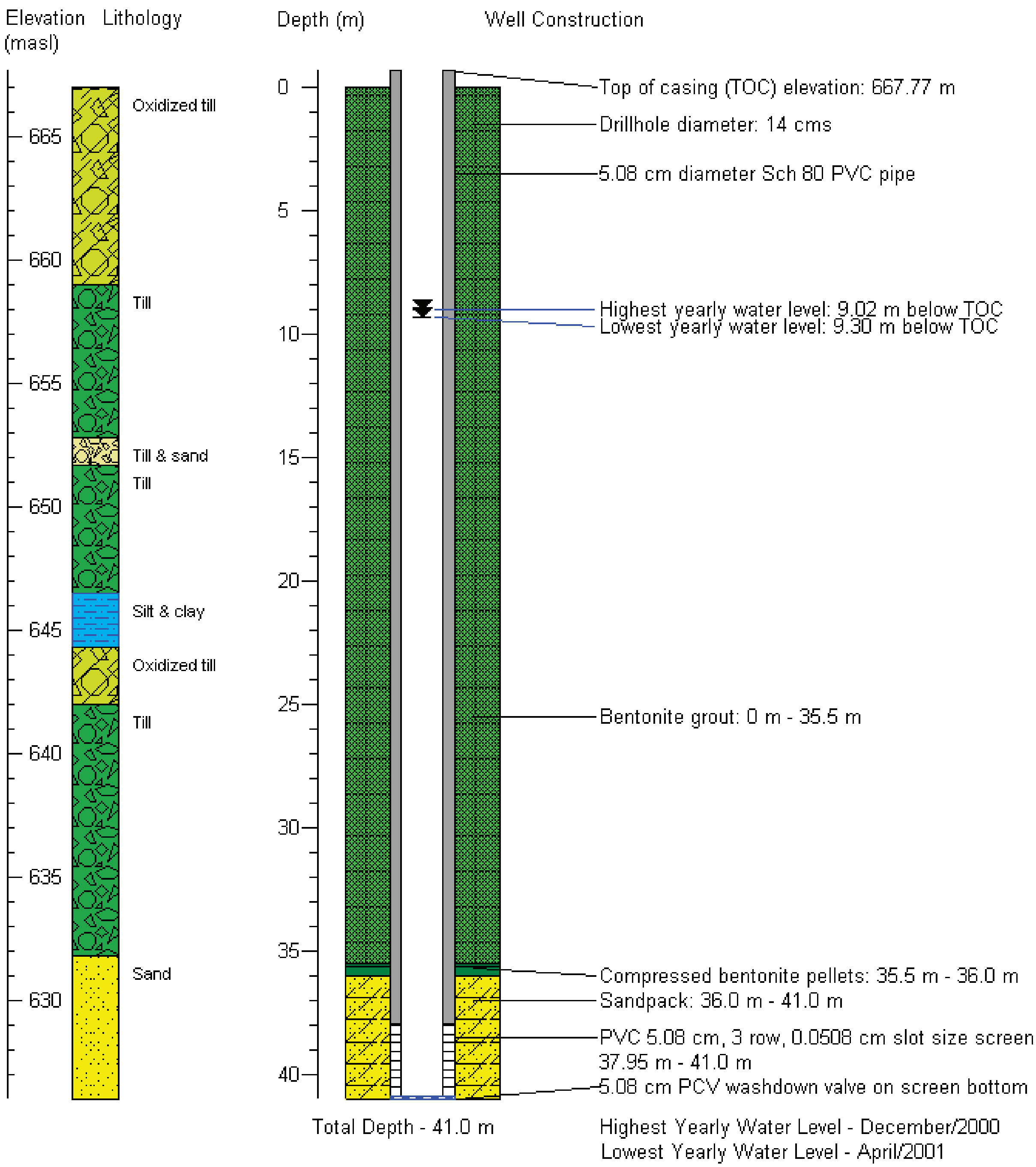


Figure A5-2: Piezometer construction details: WEPA 00-1-41

Well Name: **WEPA 00-1-76**

Location (DLS): 06-33-074-09W4Mer

Latitude: 55.4513830 °

Longitude 111.3299586 °

Surveyed Ground Level: 666.99 m

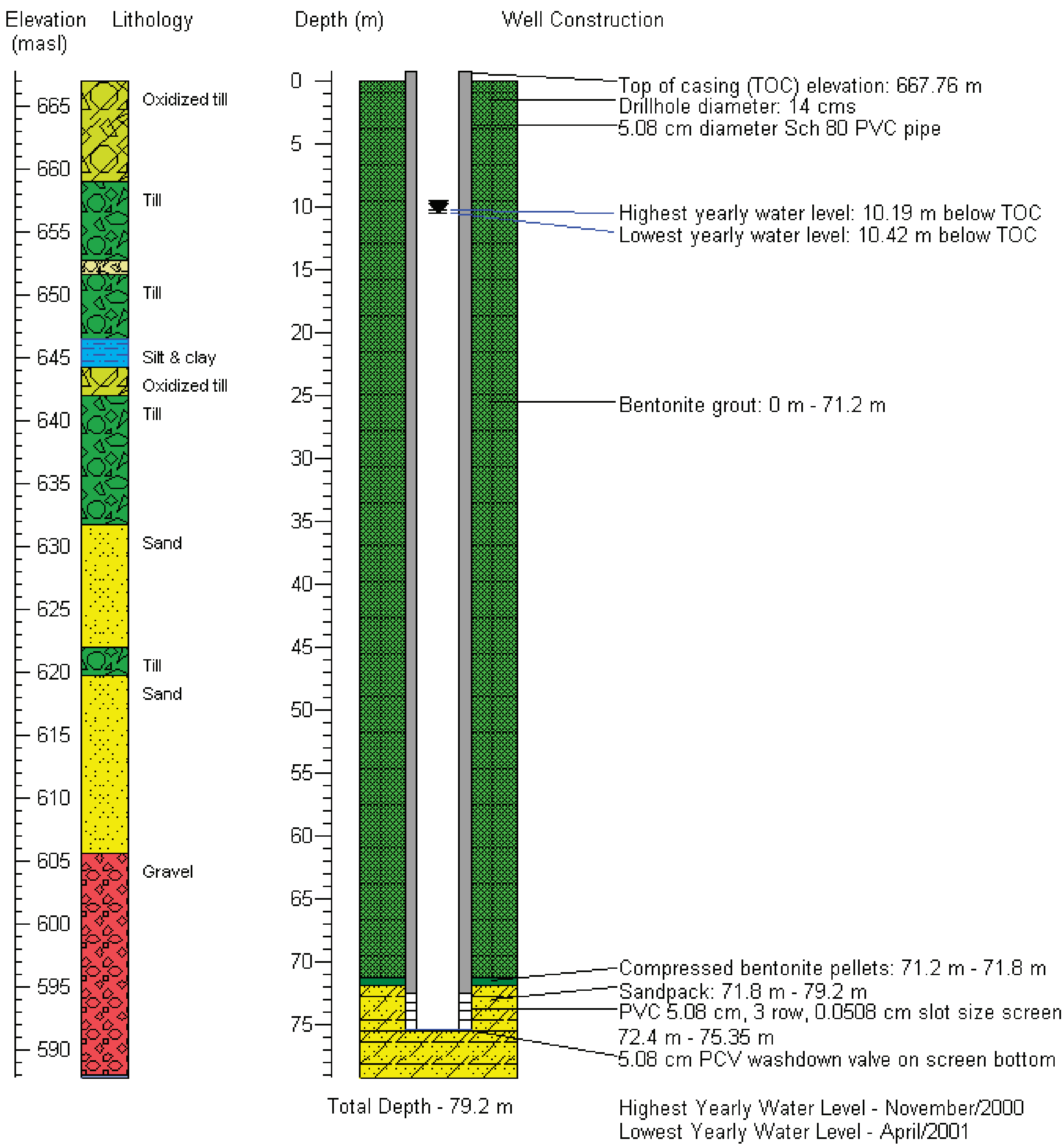


Figure A5-3: Piezometer construction details: WEPA 00-1-76

Well Name: **WEPA 00-1-120**

Location (DLS): 06-33-074-09W4Mer

Latitude: 55.4513762 °

Longitude 111.3298897 °

Surveyed Ground Level: 666.92 m

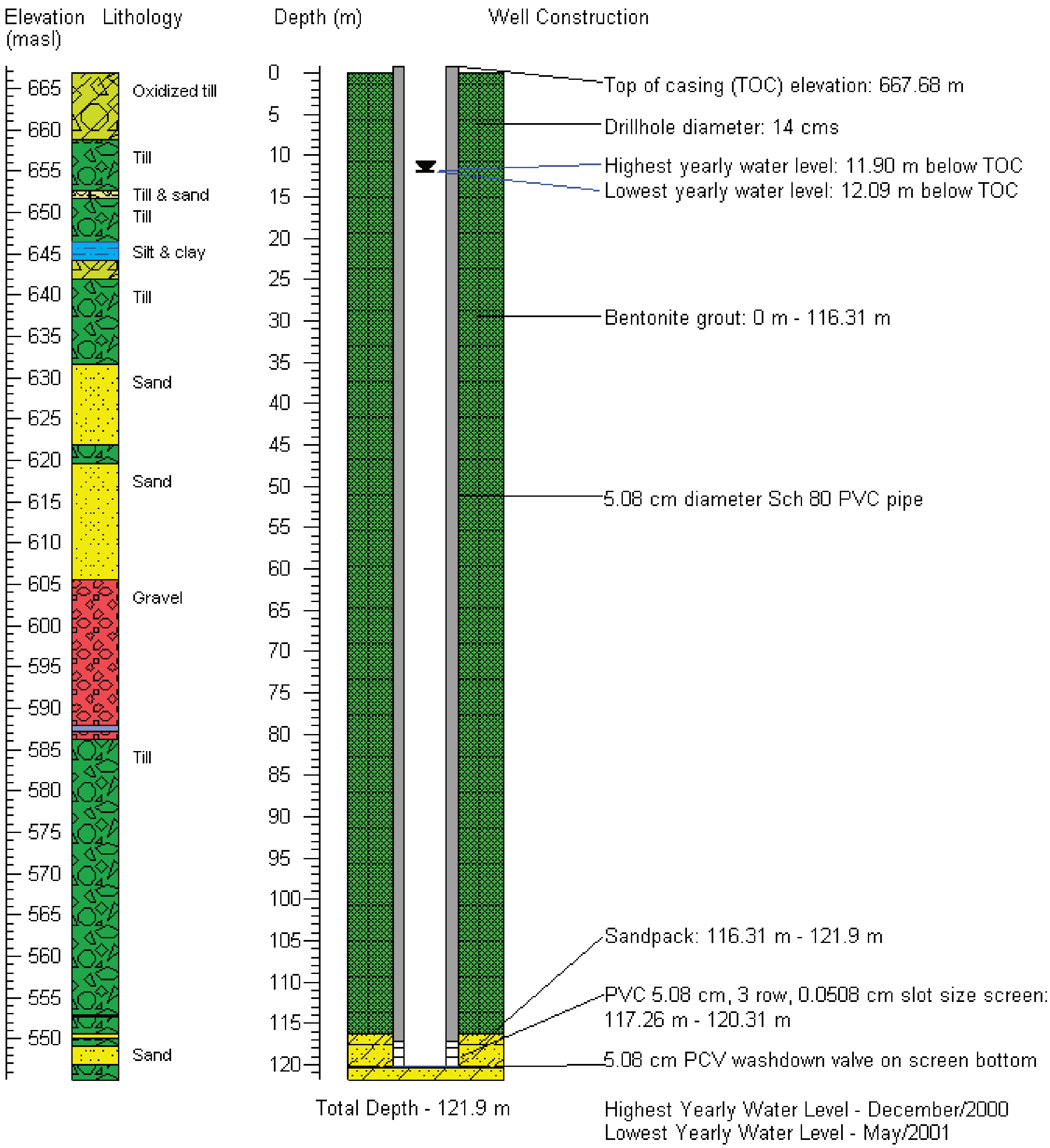


Figure A5-4: Piezometer construction details: WEPA 00-1-120

Well Name: WEPA 00-3-17

Location (DLS): 16-04-075-05W4Mer

Latitude: 55.4730401 °

Longitude 110.7072983 °

Surveyed Ground Level: 648.17 m

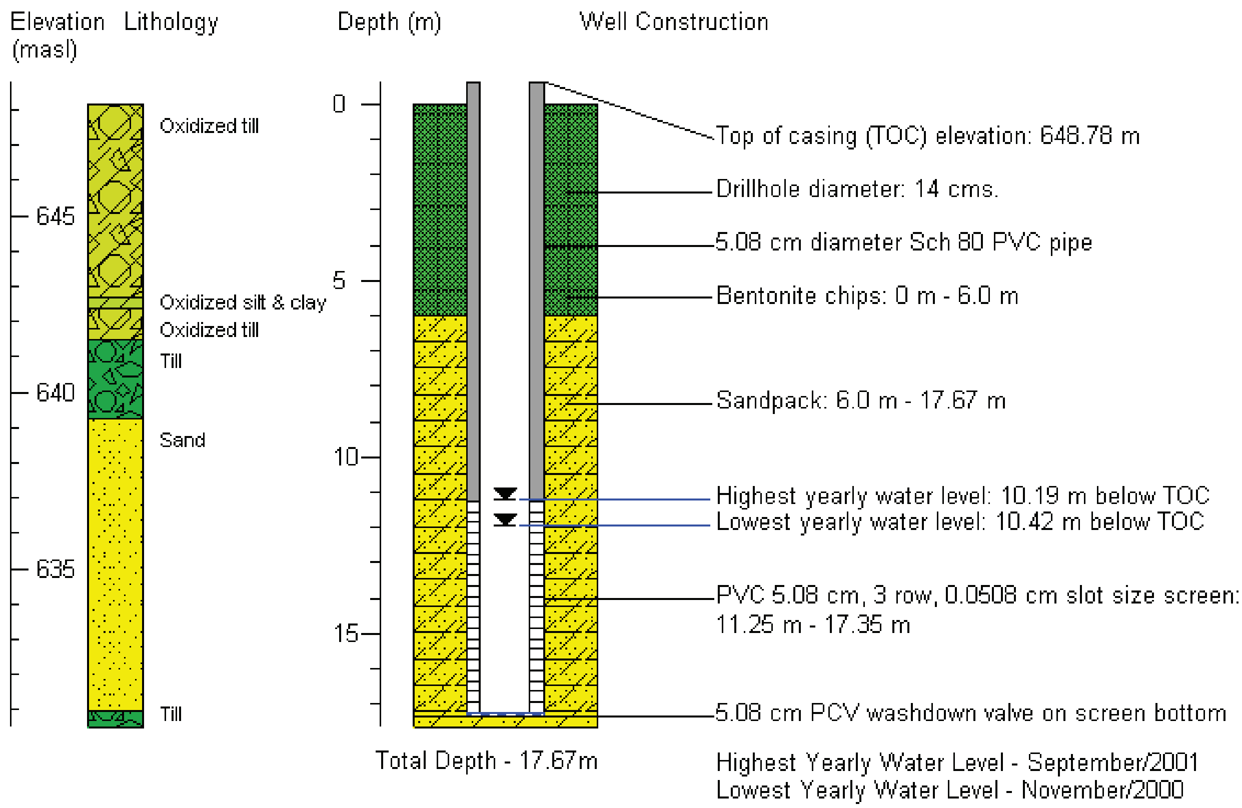


Figure A5-5: Water-table well construction details: WEPA 00-3-17 (WT).

Well Name: **WEPA 00-3-79**

Location (DLS): 16-04-075-05W4Mer

Latitude: 55.4730068 °

Longitude 110.7073184 °

Surveyed Ground Level: 648.26 m

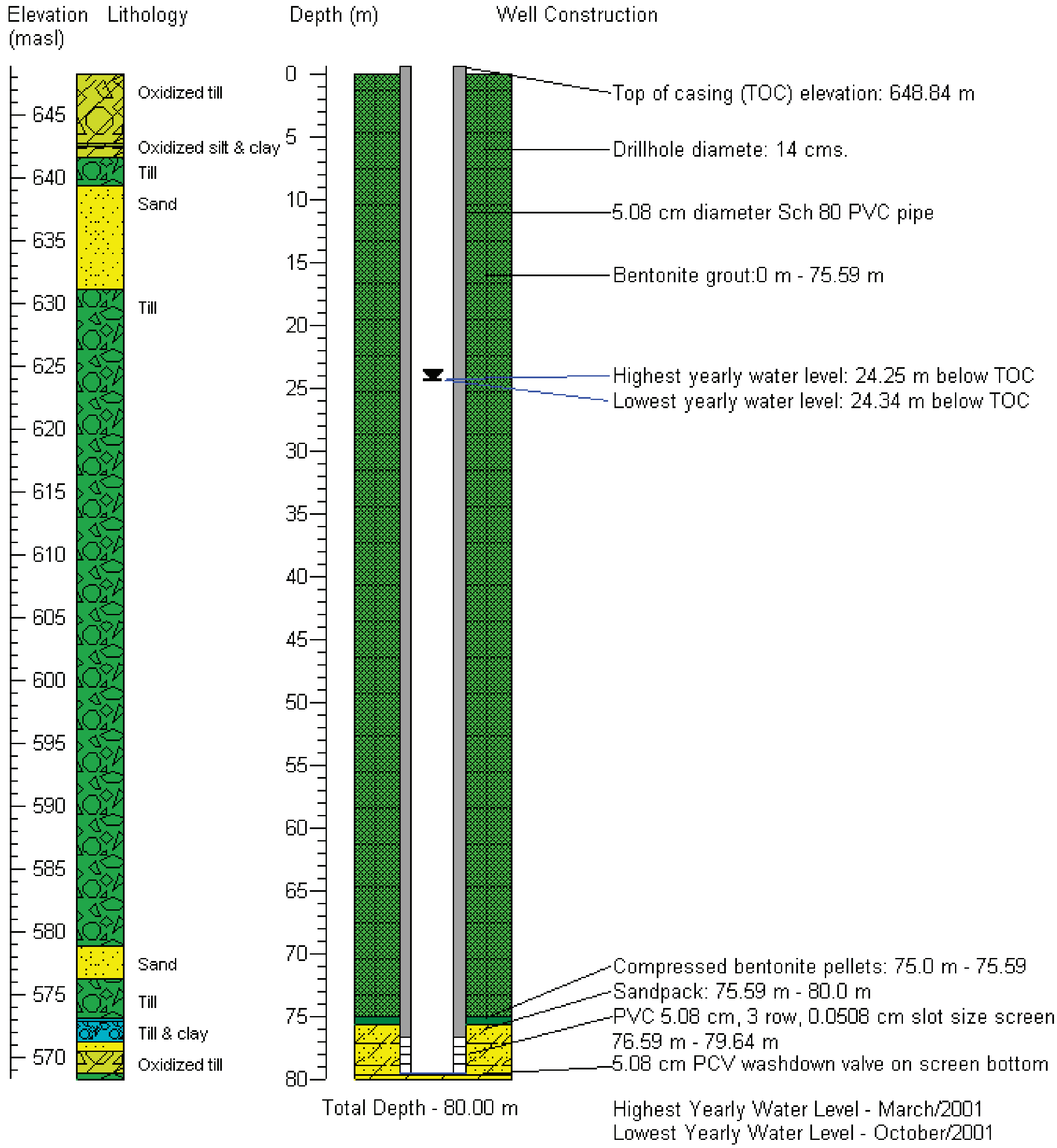


Figure A5-6: Piezometer construction details: WEPA 00-3-79

Well Name:	**WEPA 00-3-158**
Location (DLS):	16-04-075-05W4Mer
Latitude:	55.4729752 °
Longitude	110.7073340 °
Surveyed Ground Level:	648.20 m

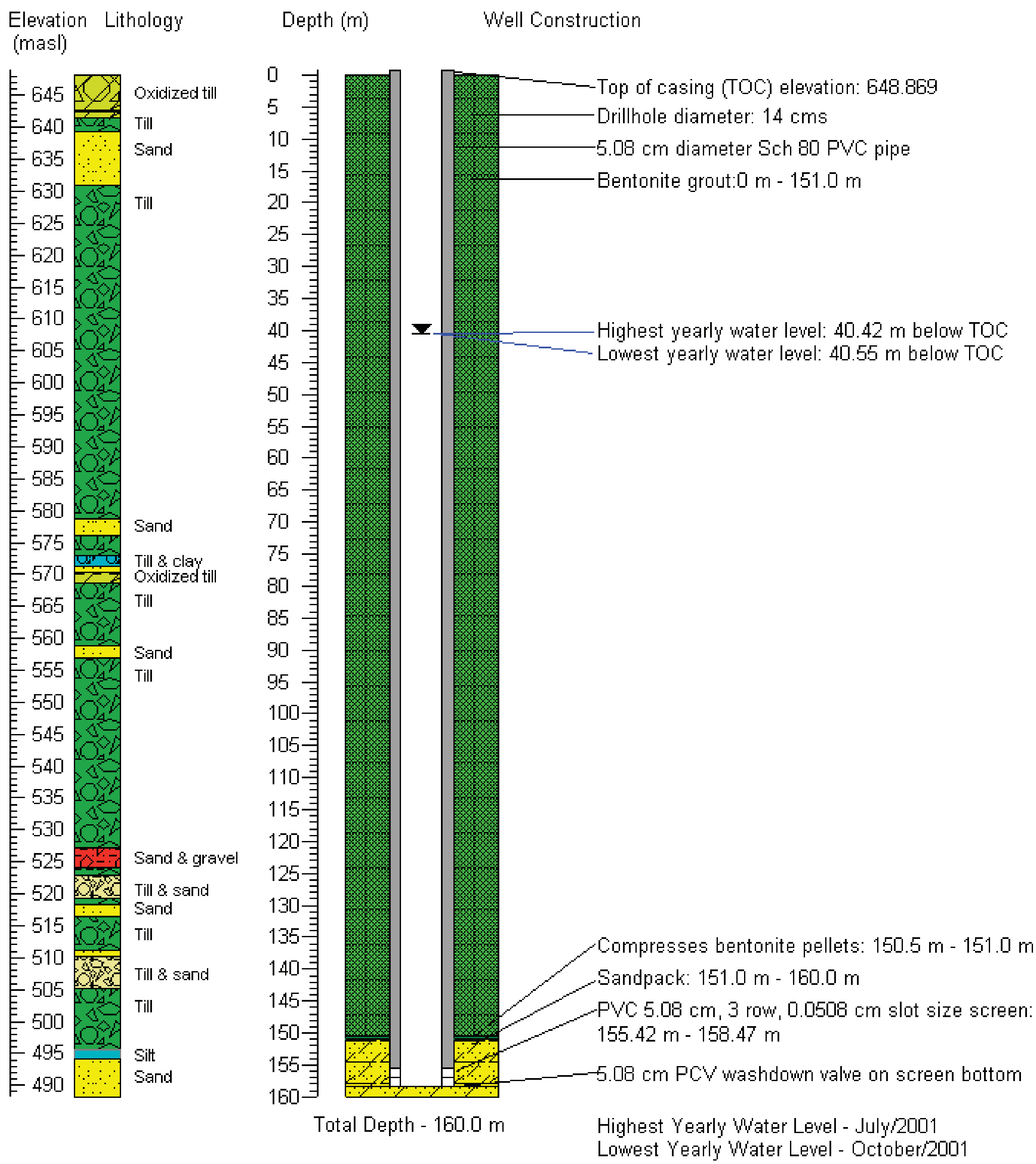


Figure A5-7: Piezometer construction details: WEPA 00-3-158

Well Name: **WR99-1-WT**
Location (DLS): 07-36-77-15W4M
Latitude: 55.7143976 °
Longitude 112.1878725 °
Surveyed Ground Level: 663.15 m

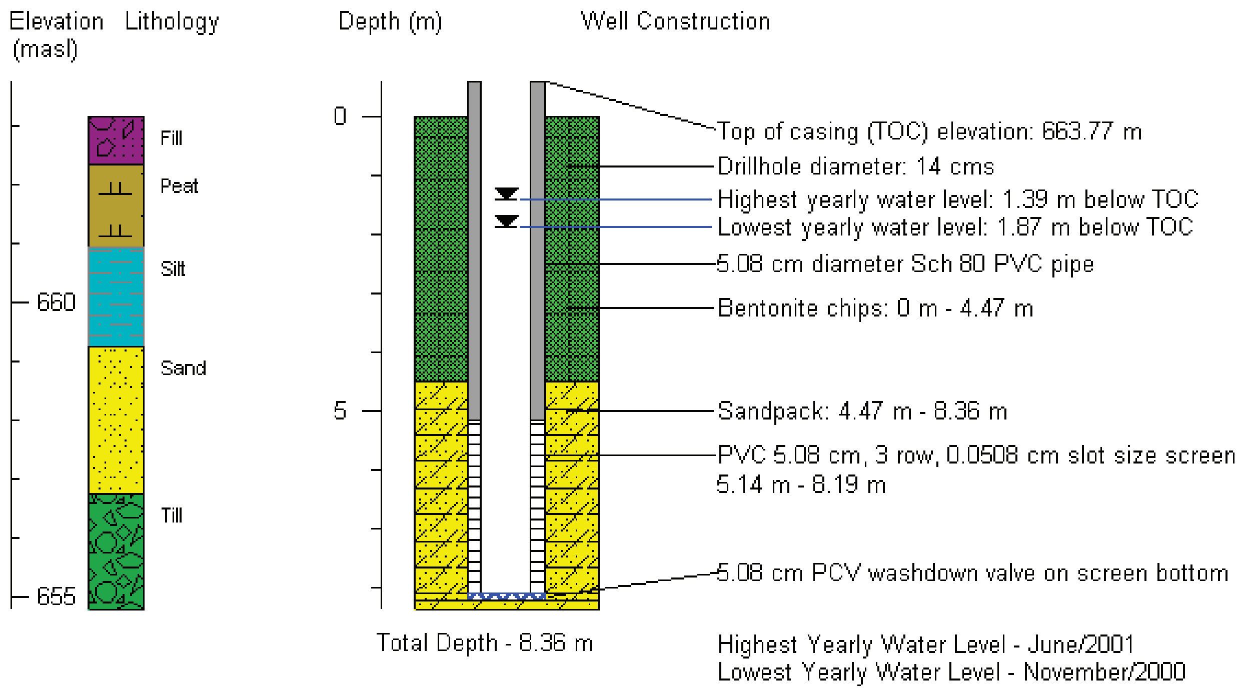


Figure A5-8: Water-table well construction details: WR99-1-WT

Well Name: **WR99-1-230**

Location (DLS): 07-36-77-15W4M

Latitude: 55.7143794 °

Longitude 112.1879148 °

Surveyed Ground Level: 663.07 m

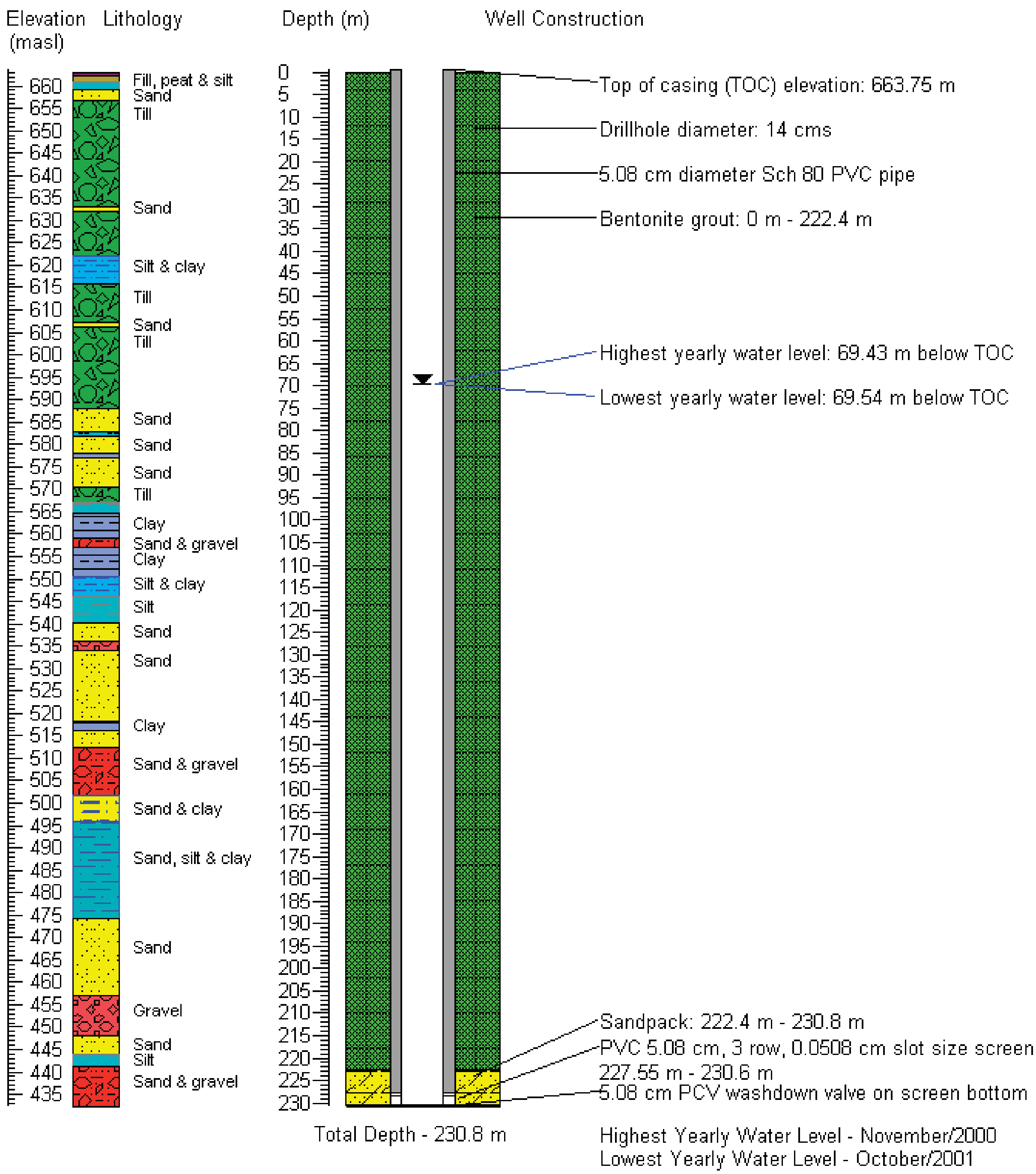


Figure A5-9: Piezometer construction details: WR99-1-230

Table A5-1: Monthly Water level Elevations in metres above sea level (masl) and vertical hydraulic gradients for AGS well installations, November 2000 - December 2001.

Date	WEPA 00-1-15(WT)	WEPA 00-1-41	WEPA 00-1-76	WEPA 00-1-120	WEPA 00-3-17(WT)	WEPA 00-3-79	WEPA 00-3-158	WR 99-1-8(WT)	WR 99-1-230
05-Nov-00	662.934	658.748	657.567	655.738					
09-Nov-00							608.339		
10-Nov-00					636.851	620.4	608.349		
16-Nov-00									593.608
17-Nov-00								661.226	
21-Nov-00	662.944	658.748	657.567	655.748	637.031	624.55	608.399	661.526	593.648
06-Dec-00	662.894	658.748	657.577	655.778	637.061	624.55	608.409		
07-Dec-00								661.406	593.608
05-Feb-01	662.664	658.608	657.467	655.698	636.991	624.55	608.389		
07-Feb-01								661.286	593.588
19-Mar-01	662.504	658.543	657.407	655.658	636.951	624.59	608.419	661.246	593.628
24-Apr-01	662.424	658.468	657.337	655.588	636.916	624.56	608.359		
25-Apr-01								661.476*	593.608
07-May-01	662.434	658.478	657.347	655.588					
10-May-01					636.901	624.56	608.369		
22-May-01	662.454	658.498	657.367	655.608					
23-May-01					636.911	624.5	608.379	661.626*	593.618
21-Jun-01	662.614	658.608	657.437	655.638	637.011	624.52	608.389	661.706	593.628
25-Jul-01	663.354	658.718	657.517	655.698	637.181	624.53	608.449	661.536	593.598
27-Aug-01	663.114	658.698	657.517	655.688	637.391	624.5	608.419	661.436	593.578
25-Sep-01	662.914	658.668	657.497	655.688	637.581	624.52	608.389	661.416	593.578
25-Oct-01	662.784	658.638	657.467	655.648	637.511	624.5	608.319	661.466	593.538
26-Nov-01	662.684	658.618	657.457	655.658	637.561	624.5	608.299	661.366	593.508

Interval	Vertical Gradient (m/m)	Interval	Vertical Gradient (m/m)		
WEPA 00-1-15 to WEPA 00-1-41	0.16	WEPA 00-3-17 to WEPA 00-3-79	0.21	Note:	* denotes a frozen waterlevel.
WEPA 00-1-41 to WEPA 00-1-76	0.03	WEPA 00-3-79 to WEPA 00-1-158	0.20		(WT) denotes a water table well.
WEPA 00-1-76 to WEPA 00-1-120	0.04	WR 99-1-8 to WR 99-1-230	0.30		

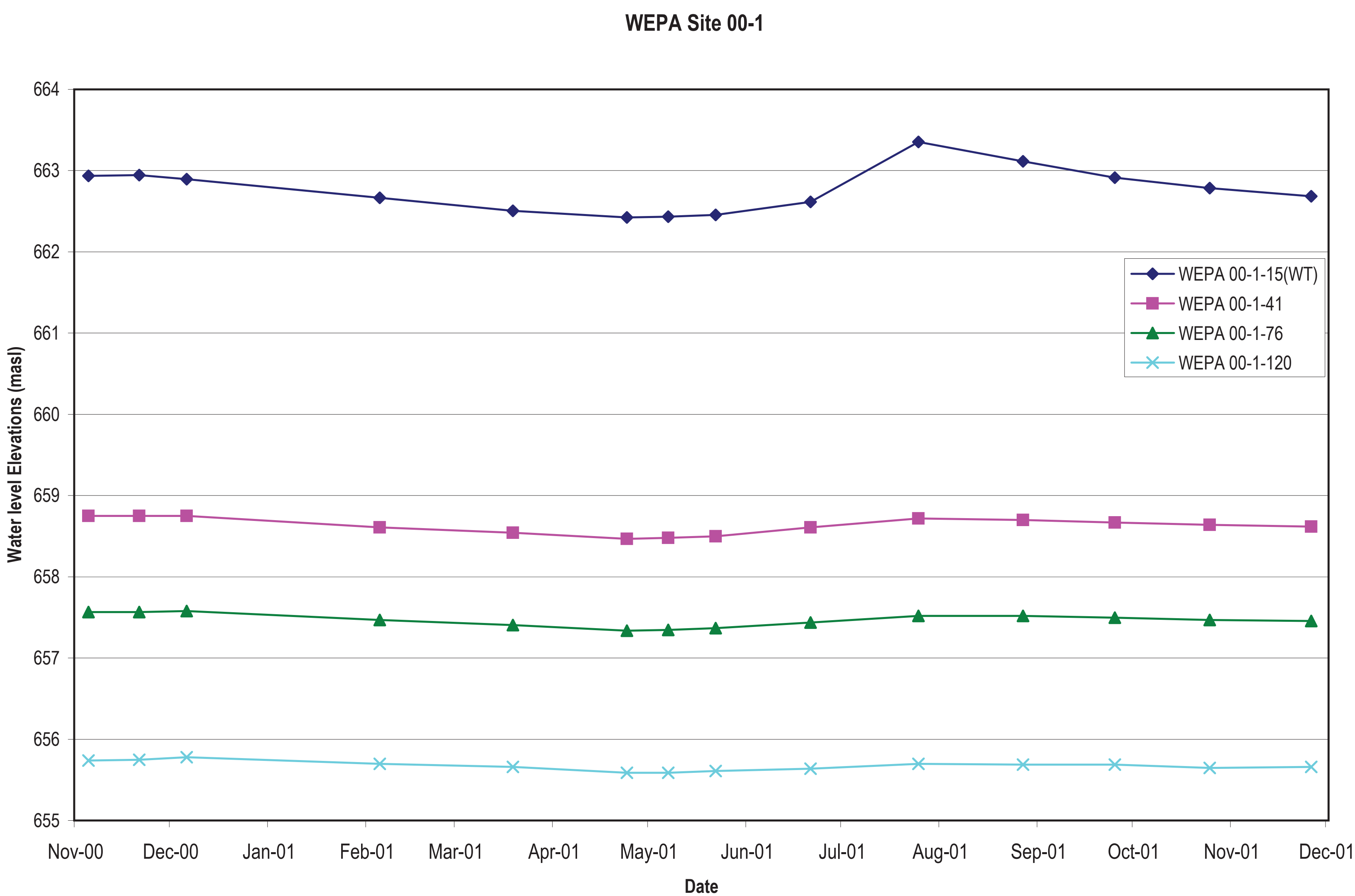


Figure A5-10: Hydrographs of monthly water levels for site WEPA 00-1.

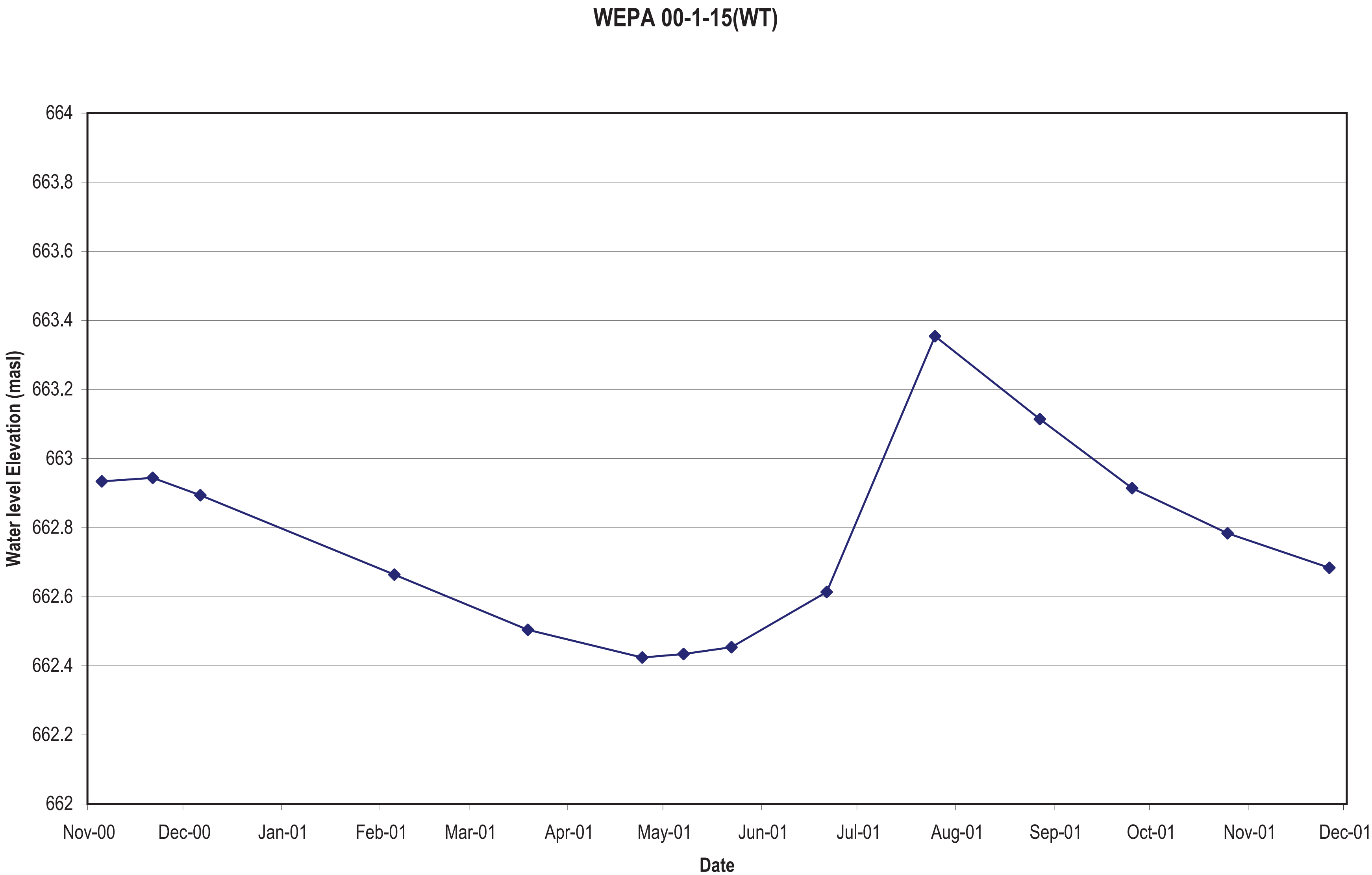


Figure A5-11: Hydrograph of monthly water levels for water table well WEPA 00-1-15(WT).

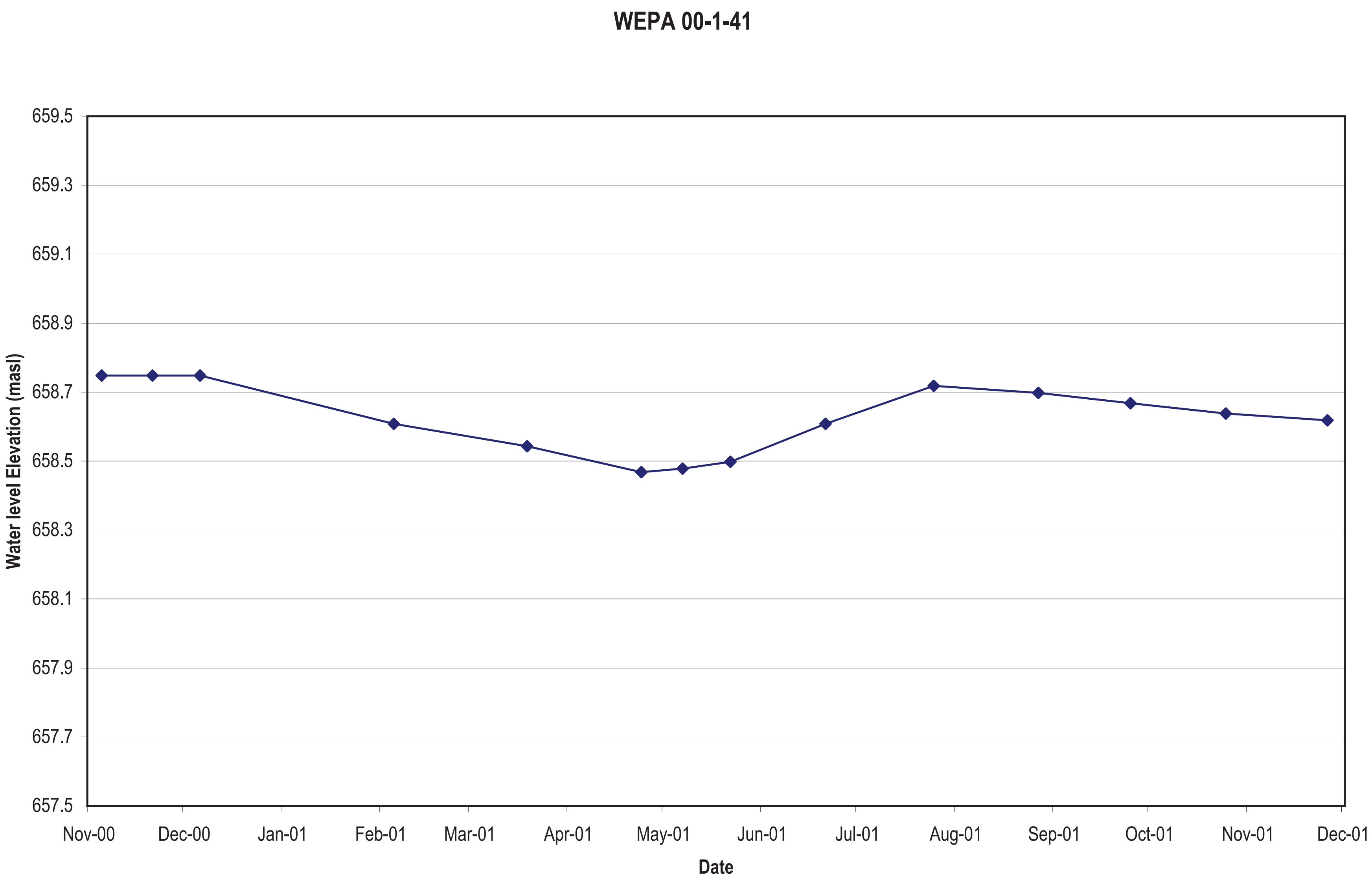


Figure A5-12: Hydrograph of monthly water levels for piezometer WEPA 00-1-41.

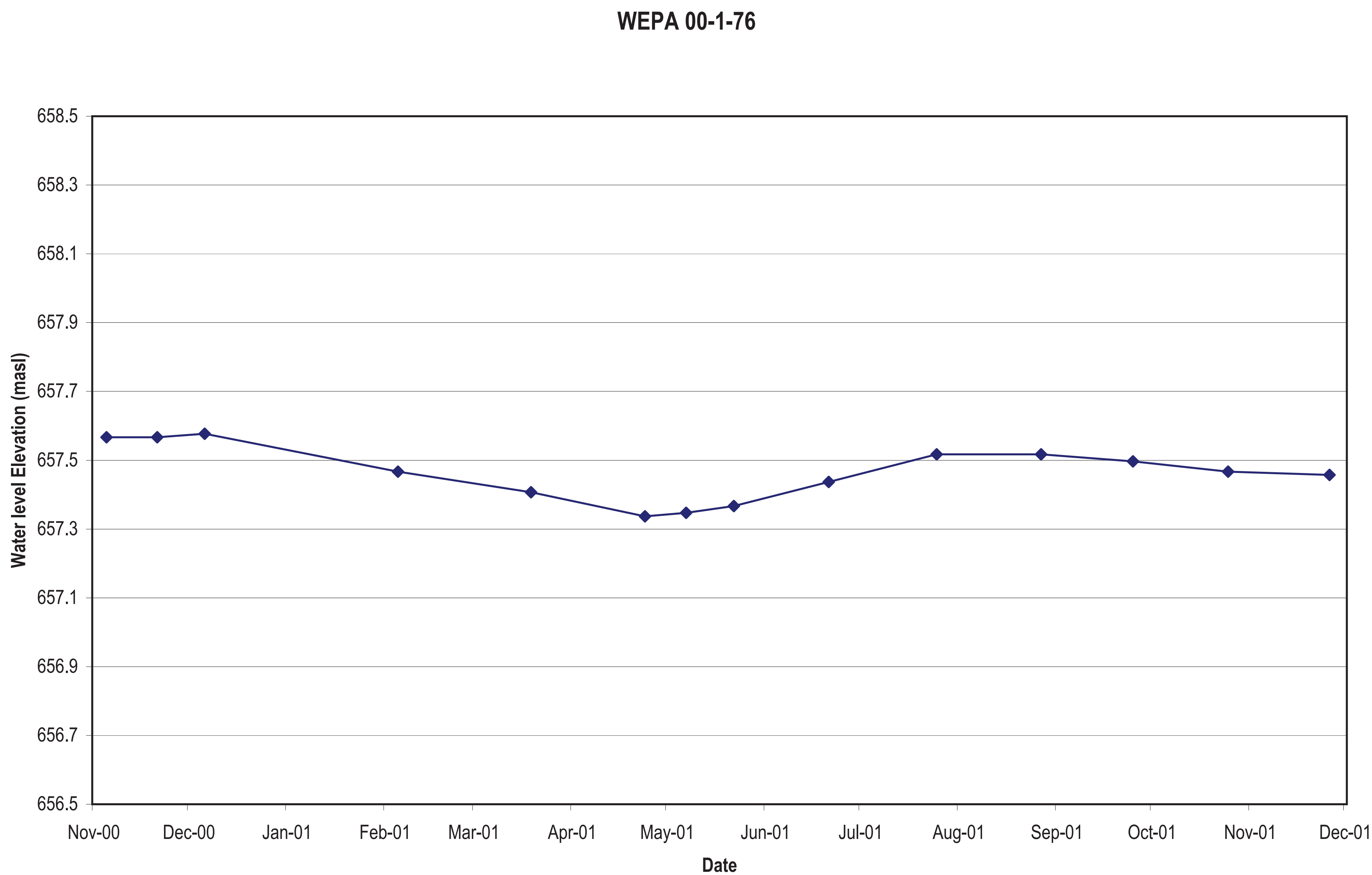
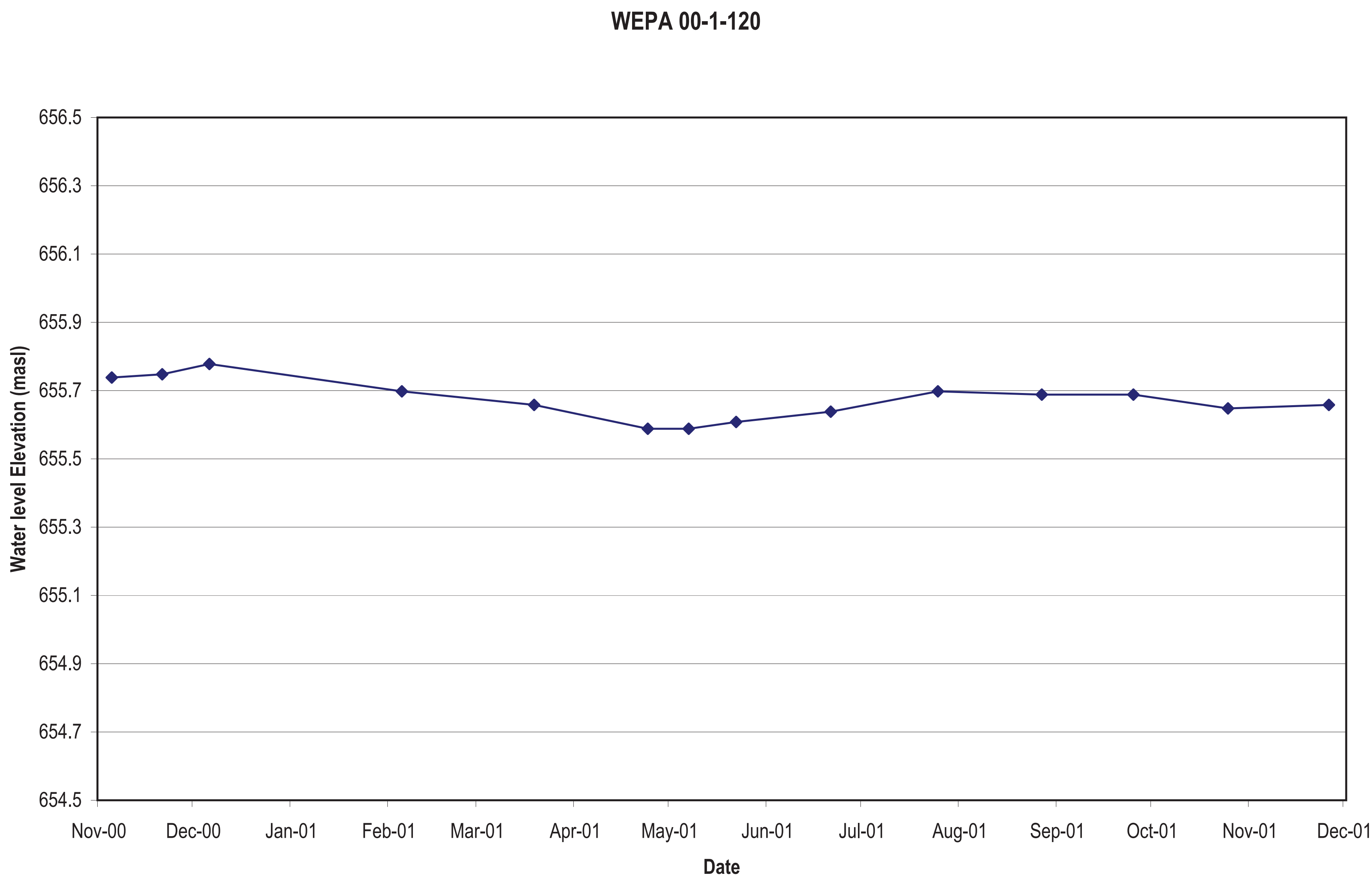


Figure A5-13: Hydrograph of monthly water levels for piezometer 00-1-76.



FigureA5-14: Hydrograph of monthly water levels for piezometer 00-1-120.

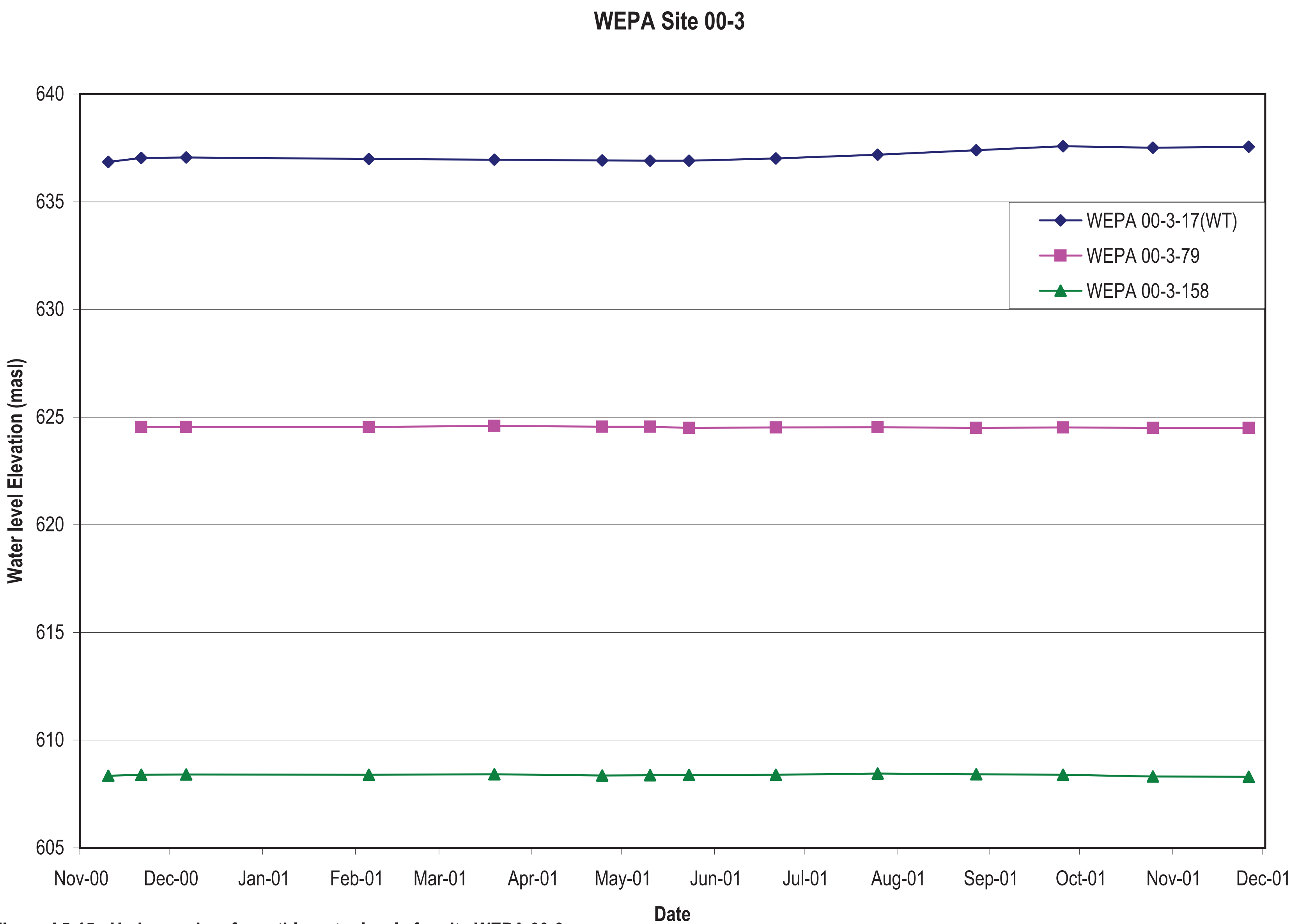


Figure A5-15: Hydrographs of monthly water levels for site WEPA 00-3.

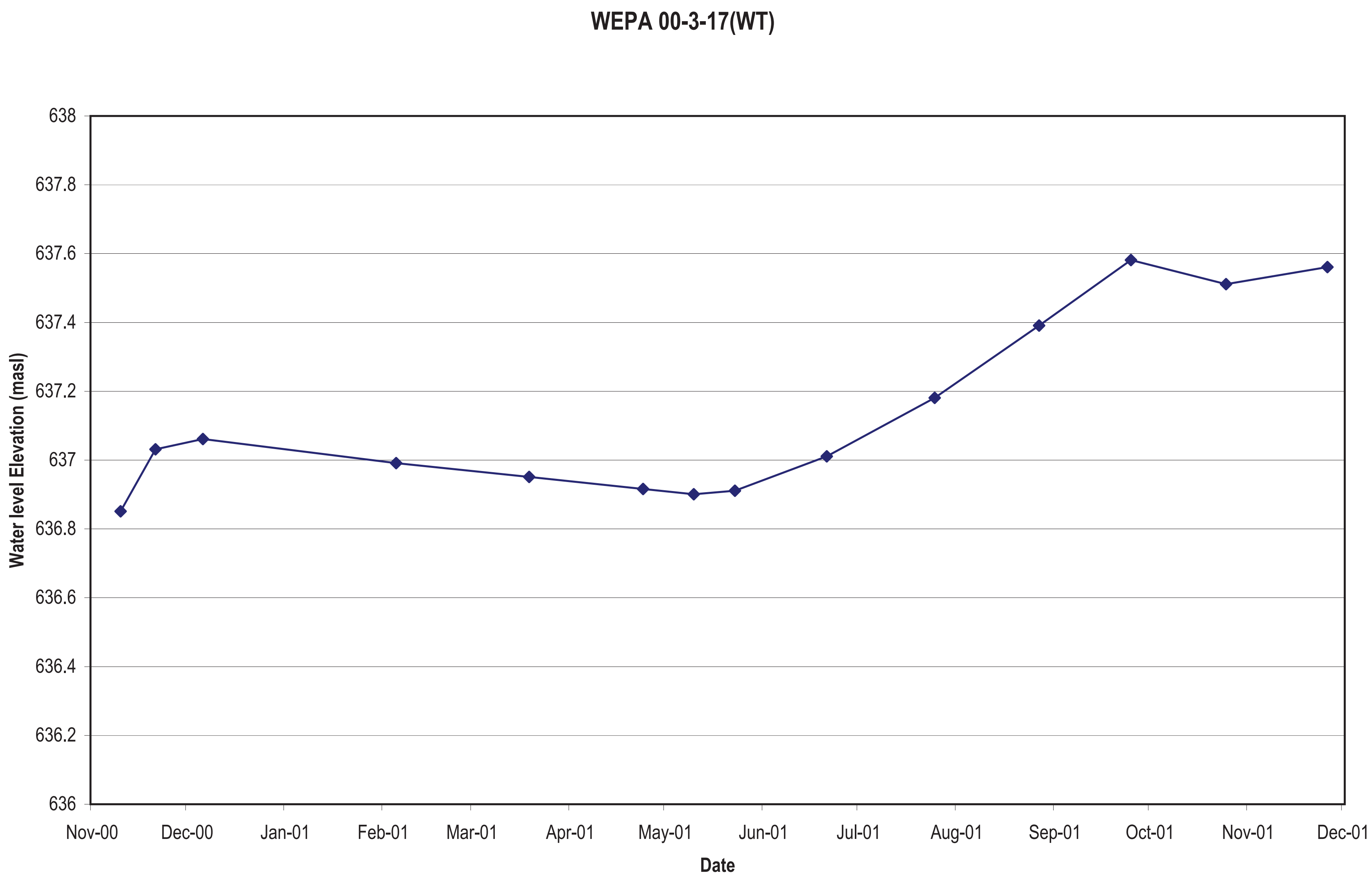


Figure A5-16: Hydrograph of monthly water levels for water table well WEPA 00-3-17(WT).

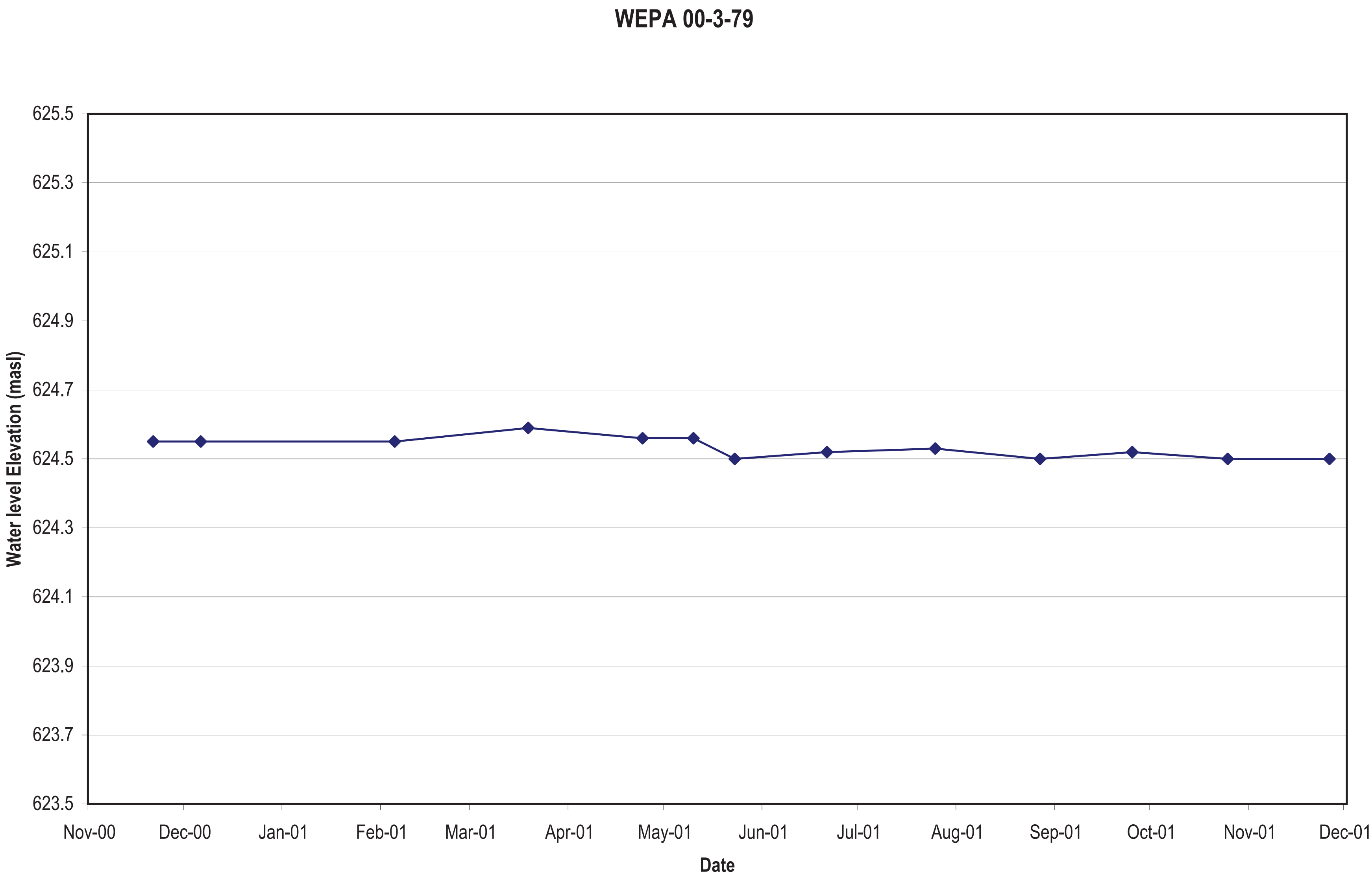


Figure A5-17: Hydrograph of monthly water levels for piezometer WEPA 00-3-79.

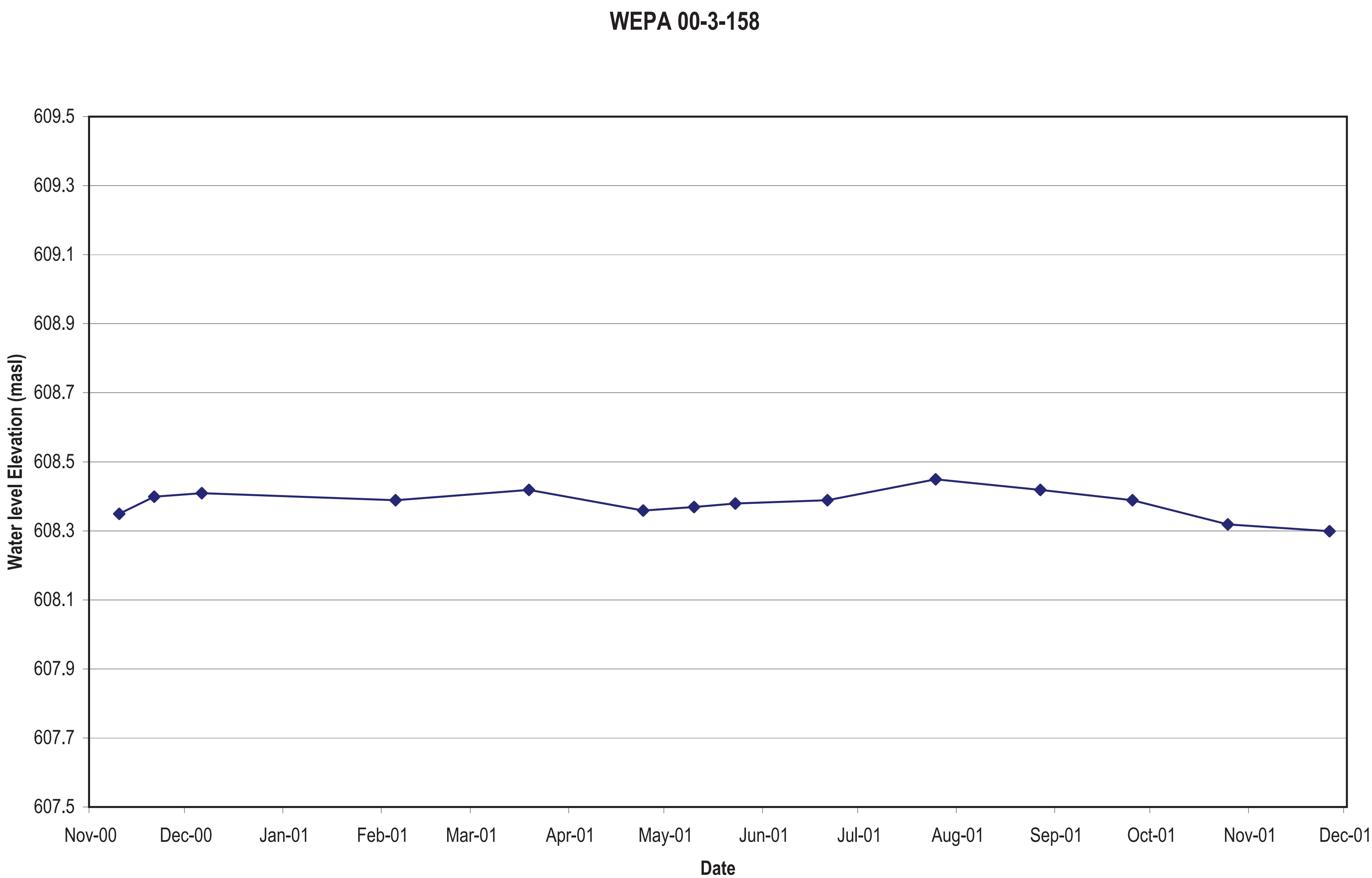


Figure A5-18: Hydrograph of monthly water levels for piezometer WEPA 00-3-158.

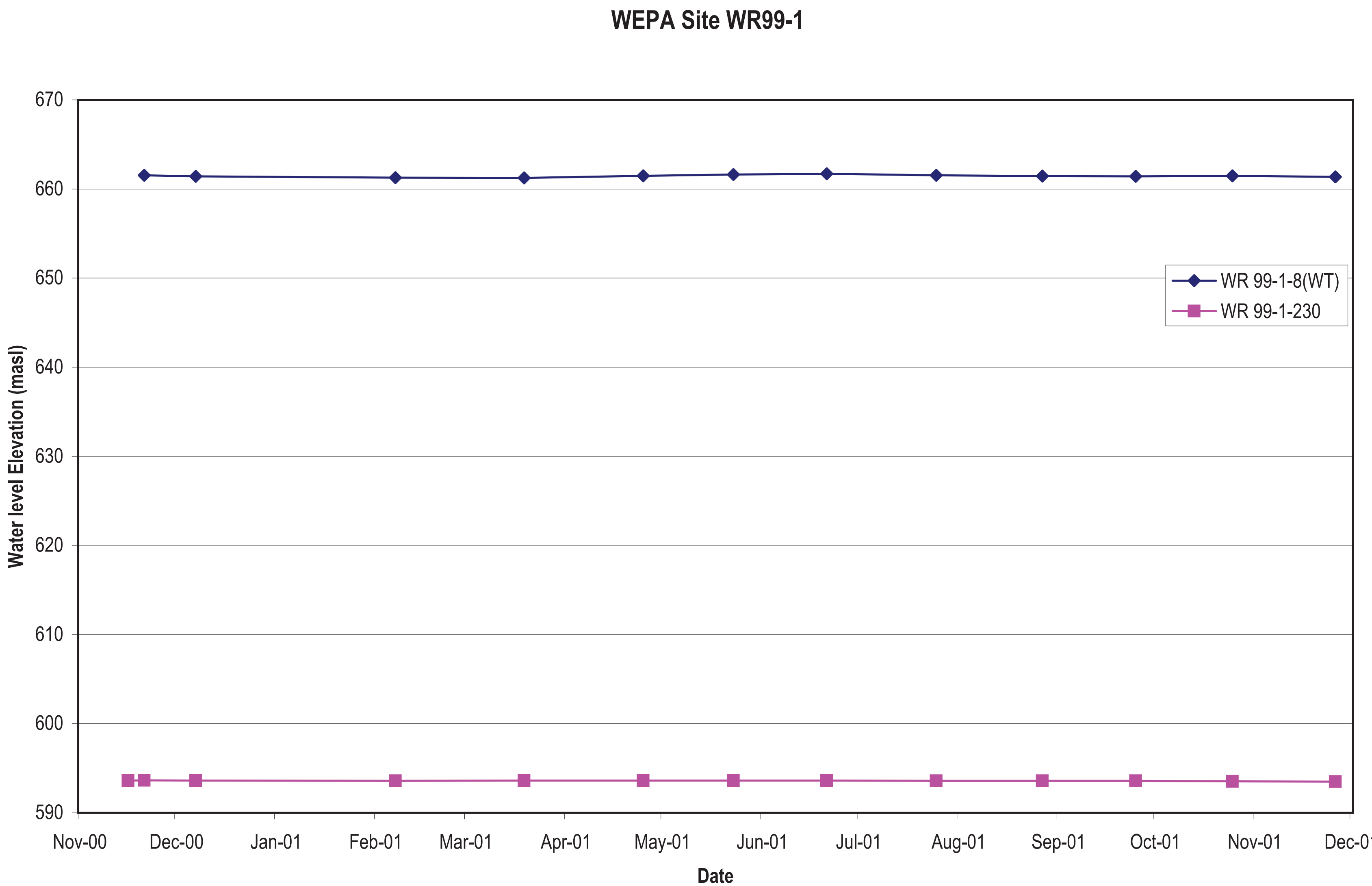


Figure A5-19: Hydrographs of monthly water levels for site WR99-1.

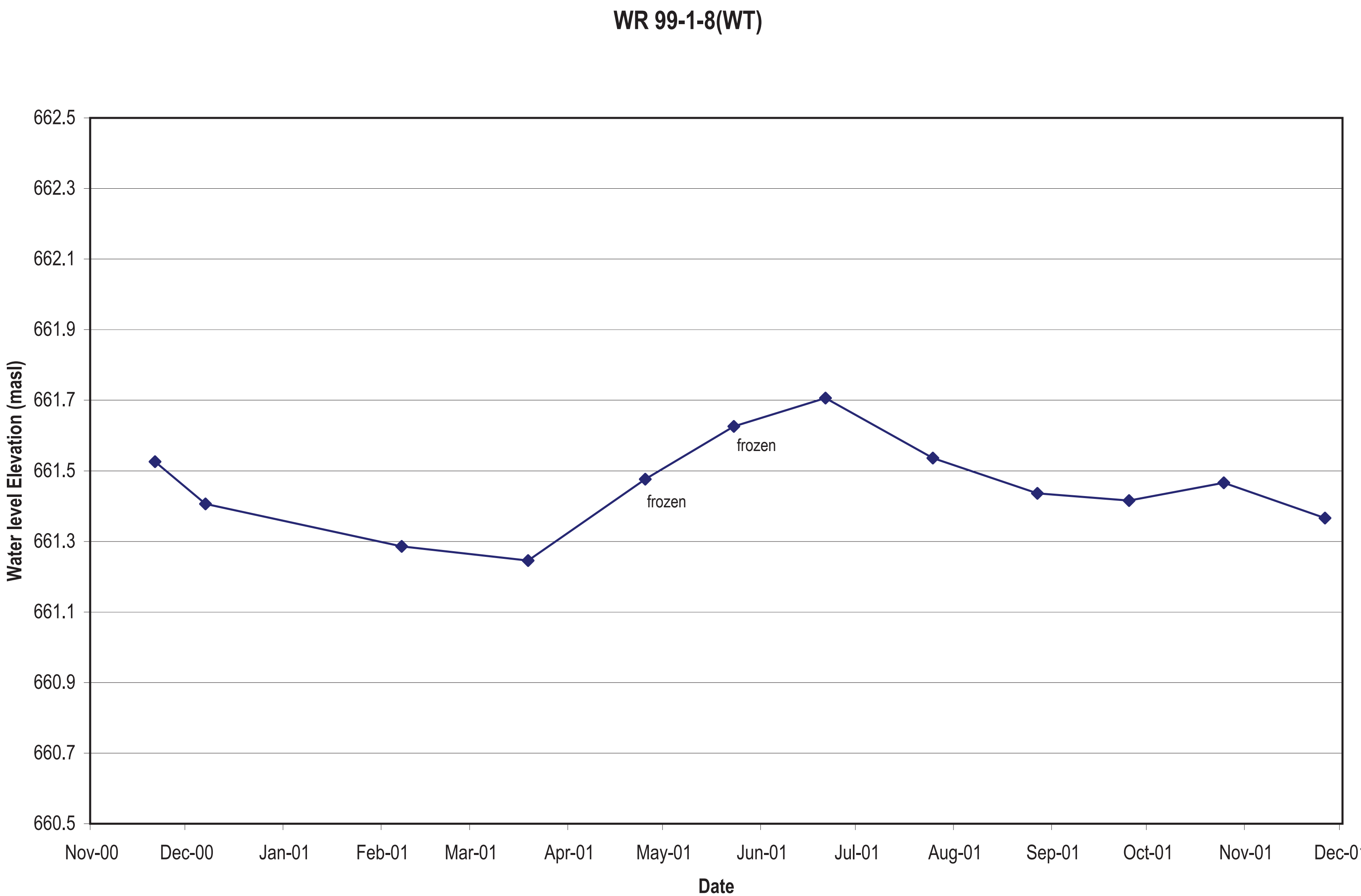


Figure A5-20: Hydrograph of monthly water levels for water table well WR99-1-8(WT).

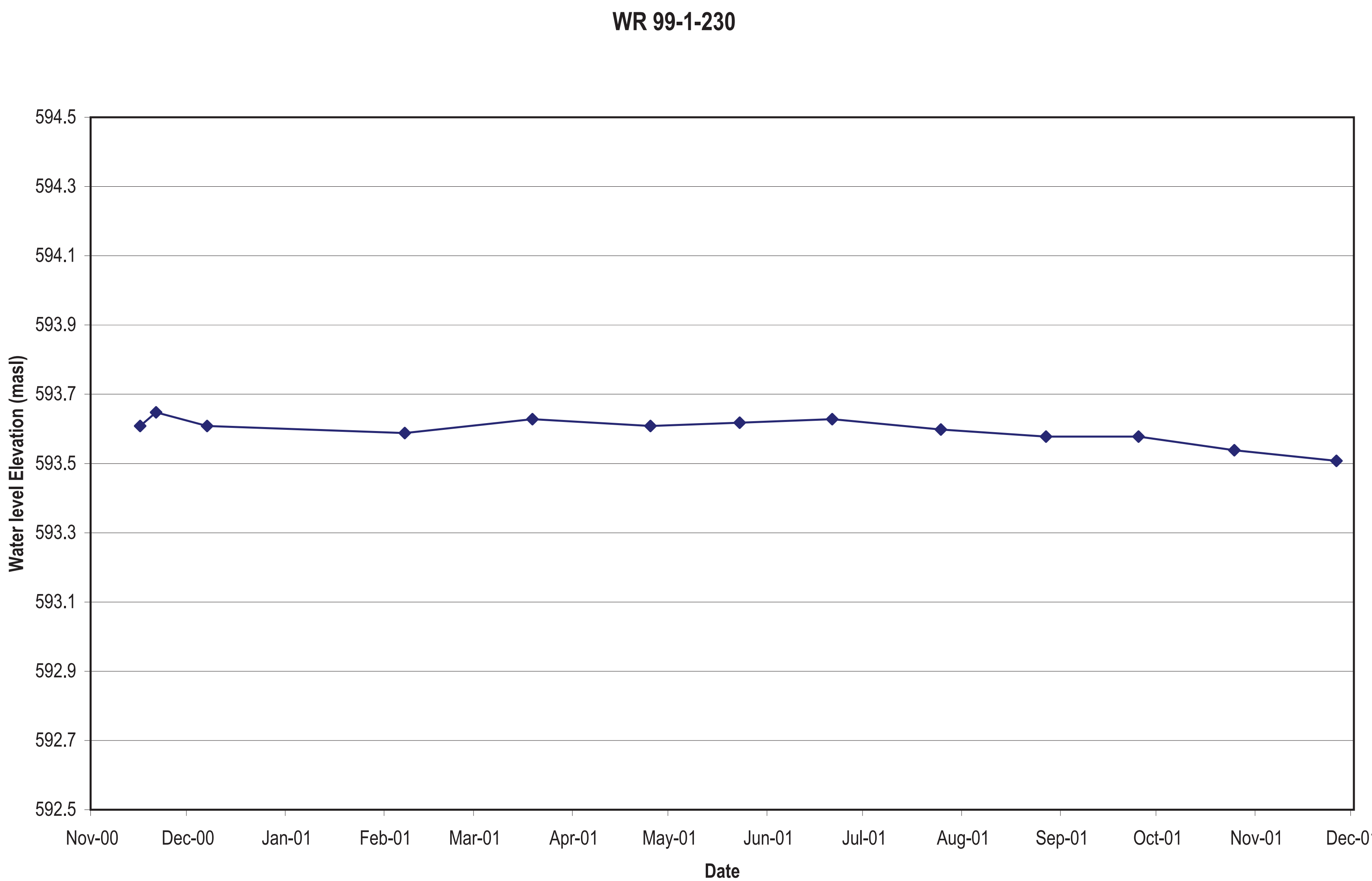


Figure A5-21: Hydrograph of monthly water levels for piezometer WR99-1-230.

Appendix 6: Field Determination, Sampling and Sample Processing Protocols for Groundwater, Formation water and Surface water.

This appendix contains links to

Geonote* 2002-09, Sampling of Surface Water and Spring Water in the Athabasca oil Sands (In Situ) Area, Alberta, 1999-2001 — A Compilation of Protocols and Methods

Geonote* 2002-10, Sampling of Groundwater from Wells in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 — A Compilation of Protocols and Methods

Geonote* 2002-11, Sampling of Formation Water from Wells in the Athabasca Oil Sands (In Situ) Area, Alberta, 1999-2001 — A Compilation of Protocols and Methods

*Geonote is an AGS publication designed to release protocols or methods, data, or preliminary interpretations of data

Appendix 7. Summaries of Groundwater Chemistry, Groundwater Isotope, and Groundwater Radiocarbon Analyses

Figures A7-1 to A75 Quaternary, Empress, Upper Mannville, Lower Mannville and Devonian Formation Chemistry Summaries

Tables A7-6 to A7-10 Quaternary, Empress, Upper Mannville, Lower Mannville and Devonian Formation Isotope Summaries

Table A7-11 Radiocarbon Analysis Summary

Table A7-1: Quaternary formation chemistry summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (masl)	Formation	Well Name
1	09-24-085-09W4	56.386505	111.275414	482994.9	6249132.0	763.5	Quaternary	ARC # 10-47
2	16-02-087-09W4	56.520851	111.309494	480958.0	6264094.3	429.8	Quaternary	ARC # 11-33
3	07-36-077-15W4	55.714398	112.187874	425371.4	6174932.8	662.5	Quaternary	AGS WR 99-1-8
4	06-33-074-09W4	55.451416	111.329831	479138.6	6145075.9	666.8	Quaternary	AGS WEPA 00-1-15
5	06-33-074-09W4	55.451377	111.329824	479139.0	6145071.6	667.1	Quaternary	AGS WEPA 00-1-41
6	06-33-074-09W4	55.451383	111.329959	479130.8	6145072.1	667.0	Quaternary	AGS WEPA 00-1-76
7	06-33-074-09W4	55.451376	111.329890	479135.2	6145071.6	666.9	Quaternary	AGS WEPA 00-1-120
8	15-04-075-05W4	55.473040	110.707298	518502.7	6147472.0	648.2	Quaternary	AGS WEPA 00-3-17
9	15-04-075-05W4	55.473007	110.707318	518501.3	6147468.2	648.3	Quaternary	AGS WEPA 00-3-79
10	15-04-075-05W4	55.472975	110.707334	518500.4	6147164.8	648.2	Quaternary	AGS WEPA 00-3-158
11	16-35-071-14W4	55.198740	112.503240	404319.5	6117937.9	566.9	Quaternary	SUNCOR OFFICE DOMESTIC WELL
12	10-10-070-17W4	55.051690	112.499700	404193.4	6101571.2	566.9	Quaternary	R. SEREDIAK FARM DOMESTIC WELL
13	04-24-071-17W4	55.156830	112.488420	405163.5	6113254.6	548.6	Quaternary	G. BIGELOW FARM DOMESTIC WELL
14	16-22-071-17W4	55.169970	112.520300	403164.0	6114760.6	562.4	Quaternary	R. LACUSTA FARM DOMESTIC WELL
15	10-36-076-15W4	55.631550	112.188850	425152.1	6165714.3	569.4	Quaternary	RIO ALTO E. DUNCAN COMP. STATION DOMESTIC WELL
16	11-10-084-10W4	56.271950	111.500430	469009.1	6236460.1	652.0	Quaternary	NORTHSTAR GAS COMP. STATION DOMESTIC WELL
17	07-09-082-12W4	56.093130	111.814650	449314.9	6216743.6	742.2	Quaternary	ALTA GAS CAS COMP. STATION DOMESTIC WELL
18	05-22-070-04W4	55.073460	110.537650	529521.6	6103063.6	672.2	Quaternary	AEC FOSTER CREEK PW1
19	05-22-070-04W4	55.073460	110.537650	529521.6	6103063.6	672.3	Quaternary	AEC FOSTER CREEK PW2
20	16-31-076-07W4	55.628840	111.079810	494974.8	6164774.8	571.2	Quaternary	CONKLIN SCHOOL DOMESTIC WELL
21	04-35-071-10W4	55.187780	111.437420	472149.6	6115774.8	662.9	Quaternary	RIO ALTO CLYDE LAKE COMP. STATION DOMESTIC WELL
22	14-26-069-12W4	55.007050	111.727860	453448.5	6095818.1	585.2	Quaternary	
23	13-17-070-17W4	55.065766	112.494221	404576.8	6103129.9	560.8	Quaternary	
24	15-24-070-17W4	55.080280	112.454887	407122.3	6104692.0	570.0	Quaternary	
25	14-34-077-15W4	55.719738	112.244484	421825.8	6175589.5	617.2	Quaternary	
26	07-03-070-17W4	55.029363	112.506931	403678.3	6099096.8	557.8	Quaternary	GORDON LEGARE DOMESTIC WELL
27	14-03-070-17W4	55.036685	112.513280	403289.7	6099920.6	560.8	Quaternary	WILLIAM COCHRANE DOMESTIC WELL
28	02-25-070-17W4	55.083872	112.456115	407052.3	6105093.4	570.0	Quaternary	O. ST.JEAN DOMESTIC WELL
29	02-03-084-11W4	56.248077	111.648768	459797.8	6233879.7	641.9	Quaternary	PETRO-CANADA HANGINSTONE PRODUCTION WELL

Table A7-1: Quaternary formation chemistry summary.

				Field Parameters									Laboratory Parameter	
Key	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date	Field Temp (°C)	Field pH	Field Cond (mS/cm)	Field ORP (mV)	Standard half cell potential at field T (mV)	Field Eh (mV)	Field DO (mg/L)	Field P-Alk (mg/L)	Field T-Alk (mg/L)	Laboratory pH	Laboratory Cond (mS/cm)
1	11.3	12.8	July 11, 1979	7.0	7.20								7.70	800.0
2	7.0	8.5	August 3, 2000	6.4	9.02	1513	-271	257	-14	0.8	<2	830	8.85	2170.0
3	5.1	8.2	June 22, 2001	6.4	7.07	402	-71	257	186	0.3	<2	348	7.24	566.0
4	9.3	15.4	May 9, 2001	6.3	6.81	651	127	257	384	0.8	<2	666	7.09	1020.0
5	37.9	41.0	May 8, 2001	6.2	7.44	349	-155	257	102	0.0	<2	370	7.55	551.0
6	72.4	75.4	May 8, 2001	7.0	7.48	424	-152	256	104	0.1	<2		7.74	645.0
7	117.3	120.3	May 9, 2001	5.6	7.48	382	-154	257	103	0.1	<2	412	7.65	601.0
8	11.2	17.3	May 11, 2001	6.6	7.08	506	69	257	326	0.2	<2	474	7.50	770.0
9	76.6	79.6	May 11, 2001	8.3	7.17	1100	-49	255	206	0.1	<2	676	7.46	1540.0
10	155.4	158.5	May 10, 2001	7.1	7.67	594	-136	256	120	0.0	<2	522	8.14	896.0
11	39.0	48.2	July 11, 2000	8.3	7.13	778	-141	255	114	2.0	<2	418	7.31	1050.0
12	42.7	45.7	July 12, 2000	10.4	7.44	912	-59	254	195	1.9	<2	480	7.60	1160.0
13	24.4	30.5	July 12, 2000	6.8	7.18	655	-190	256	67	1.2	<2	436	7.32	875.0
14	28.0	29.6	July 13, 2000	7.2	7.15	610	-152	256	104	0.2	<2	410	7.22	848.0
15	64.9	69.5	July 13, 2000	6.4	7.28	346	-145	257	111	2.8	<2	236	7.19	467.0
16	18.0	20.4	July 18, 2000	6.5	7.28	391	-124	257	132	0.1	<2	286	7.32	559.0
17	56.1	59.1	July 18, 2000	6.5	7.43	413	-170	257	86	0.1	<2	298	7.37	596.0
18	61.0	70.7	July 24, 2000	7.6	7.40	542	-174	256	82	0.1	<2	500	7.62	735.0
19	66.9	73.0	July 24, 2000	6.9	7.36	557	-148	256	108	0.2	<2	510	7.63	765.0
20	26.5	72.7	July 26, 2000	7.2	7.29	427	-157	256	99	0.2	<10	1200	7.58	603.0
21	65.5	67.1	July 27, 2000	8.3	7.36	818	-105	255	150	0.2	<2	540	7.54	1140.0
22	54.9	46.4	March 21, 1989										7.50	690.0
23	33.5	35.0	September 26, 1991										7.66	990.0
24	23.8	29.9	September 13, 1990										7.55	912.0
25	110.0	116.4	August 24, 1983										8.40	660.0
26	16.8	22.9	September 8, 1992										7.44	882.0
27	12.2	12.5	August 12, 1988										7.60	875.0
28	9.7	10.1	September 13, 1990										7.50	675.0
29	15.8	27.4	November 20, 1990										7.33	378.0

Table A7-1: Quaternary formation chemistry summary.

	s														
Key	Laboratory P-Alkalinity (mg $CaCO_3$/L)	Laboratory Total Alkalinity (mg $CaCO^3$/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	Cl by NAA (μg/mL)	Br by NAA (μg/mL)	I by NAA (μg/mL)	SO_4 (mg/L)	Hardness (mg/L $CaCO_3$)	TDS (mg/L)
1			77.0	30.00	61.0	2.5	346	0	78.0				36.60		596
2	84	867	6.0	3.45	557.0	2.5	852	101	126.0				226.00	291.00	1440
3	<5	322	105.0	19.30	4.8	2.4	393	<6	9.4	10.50	0.02	0.01	7.84	341.00	342
4	<5	601	168.0	50.60	4.3	1.3	732	<6	<0.5	0.93	0.05	0.01	6.87	628.00	591
5	<5	311	82.0	24.40	11.7	3.6	379	<6	<0.5	1.31	0.01	<0.01	5.11	305.00	313
6	<5	313	74.4	20.20	48.0	9.9	381	<6	11.0	12.80	0.01	<0.01	30.20	269.00	381
7	<5	336	81.5	24.50	24.2	5.1	410	<6	5.0	1.83	0.01	<0.01	6.08	304.00	348
8	<5	398	104.0	38.40	20.2	2.8	485	<6	15.9	18.70	0.03	<0.01	28.00	418.00	448
9	<5	662	101.0	48.50	167.0	5.8	807	<6	82.7	88.00	0.36	0.46	138.00	452.00	941
10	<5	453	32.9	11.20	182.0	4.7	552	<6	5.4	6.87	0.06	0.03	54.20	128.00	562
11			125.0	40.30	75.7	4.8	529	<6	15.3	15.10	0.08	0.02	188.00	479.00	710
12			72.5	26.80	202.0	4.7	656	<6	34.2	44.60	0.17	0.03	108.00	291.00	771
13			120.0	36.50	41.6	4.5	537	<6	3.6	3.38	0.03	0.01	103.00	449.00	573
14	<5	424	125.0	35.50	23.7	4.4	517	<6	4.4	2.25	0.02	0.00	101.00	457.00	547
15	<5	260	68.6	18.90	11.6	3.2	317	<6	1.2	0.28	0.01	<0.01	21.50	249.00	281
16	<5	294	75.3	19.00	26.3	4.2	359	<6	0.9	0.63	<0.02	0.01	20.50	266.00	323
17	<5	316	76.2	18.90	34.2	6.6	385	<6	0.8	0.18	<0.04	<0.01	21.00	268.00	347
18	<5	428	85.5	25.00	66.0	4.6	521	<6	3.2	2.94	0.04	0.03	19.80	316.00	461
19	<5	454	85.5	25.30	74.5	5.0	554	<6	2.8	3.39	0.05	0.03	18.40	318.00	484
20	<5	353	84.0	26.90	24.6	4.0	431	<6	<0.5	0.72	<0.04	0.01	8.26	320.00	360
21	<5	529	112.0	42.40	120.0	10.6	645	<6	4.8	4.33	<0.05	0.04	178.00	453.00	785
22			68.0	24.00	69.0	3.0	460		6.0				24.00		440
23		468	78.0	24.00	123.0	5.1	571		8.0				80.00		600
24		439	121.0	38.00	38.0	4.8	535		1.0				95.00		561
25		385	63.0	18.00	85.0	5.5	459	5	<2				34.00		439
26		439	139.0	32.00	10.0	3.4	535		0.8				62.00		511
27		401	109.0	34.00	52.0	3.2	489		12.0				65.00		516
28		372	95.0	32.00	6.0	2.6	453		1.0				12.00		372
29		172	55.0	11.00	7.0		210		16.0				2.00		231

Table A7-1: Quaternary formation chemistry summary.

Key	Charge Balance Error (%)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)	Propionic acid (mg/L)	As (mg/L)	Al (mg/L)	Sb (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)
1	2.2																	
2	-1.4	<0.2	<0.3	<0.1	221.0	<0.01	0.031	<0.005	0.0227	<0.0005	<0.007	3.700	<0.0005	<0.0008	0.0025	0.111	0.007	<0.002
3	1.6					<0.01	0.031	<0.005	0.2830	<0.0005	<0.007	0.060	<0.0005	<0.0008	0.0033	0.002	0.051	0.005
4	2.5					<0.01	<0.008	<0.005	0.1570	<0.0005	<0.007	0.037	<0.0005	<0.0008	0.0010	<0.001	0.094	<0.002
5	2.9					<0.01	<0.008	<0.005	0.1720	<0.0005	0.008	0.088	<0.0005	<0.0008	0.0007	0.002	0.056	<0.002
6	3.6					<0.01	0.011	<0.005	0.1750	<0.0005	<0.007	0.116	<0.0005	<0.0008	0.0017	0.002	0.048	<0.002
7	2.0					<0.01	0.010	<0.005	0.2440	<0.0005	<0.007	0.158	<0.0005	<0.0008	<0.0007	0.002	0.057	<0.002
8	1.7					<0.01	<0.008	<0.005	0.1610	<0.0005	0.007	0.066	<0.0005	<0.0008	0.0009	0.002	0.071	<0.002
9	-5.7					<0.01	0.012	<0.005	0.0301	<0.0005	<0.007	0.330	<0.0005	<0.0008	0.0024	0.001	0.081	<0.002
10	1.3					0.030	0.012	<0.005	0.0718	<0.0005	<0.007	0.487	<0.0005	<0.0008	0.0017	0.004	0.024	<0.002
11	-0.2	<0.2	<0.3	<0.1	0.5	<0.01	0.081	<0.005	0.0468	<0.0005	0.112	0.405	<0.0005	<0.0008	0.0012	0.004	6.900	<0.002
12	2.7	<0.2	<0.3	<0.1	157.0	<0.01	0.039	<0.005	0.0785	<0.0005	0.019	0.517	<0.0005	<0.0008	0.0018	0.005	0.531	<0.002
13	-0.6	0.3	<0.3	0.4	176.0	<0.01	0.052	<0.005	0.0965	<0.0005	<0.007	0.214	0.0010	<0.0008	0.0009	0.004	7.800	<0.002
14	-1.9	0.4	<0.3	0.6	155.0	<0.01	0.057	<0.005	0.0880	<0.0005	<0.007	0.208	0.0009	<0.0008	0.0008	0.004	7.330	<0.002
15	-1.0	0.2	<0.3	0.2	105.0	0.010	0.033	<0.005	0.0826	<0.0005	<0.007	0.099	0.0013	<0.0008	0.0007	0.004	11.200	<0.002
16	1.8	<0.2	<0.3	<0.1	107.0	<0.001	0.008	<0.005	0.0731	<0.0005	<0.007	0.186	<0.0005	<0.0008	0.0018	0.002	0.761	<0.002
17	1.8	0.3	<0.3	0.3	113.0	0.020	0.030	<0.005	0.1750	<0.0005	<0.007	0.308	<0.0005	<0.0008	0.0014	0.002	4.200	<0.002
18	1.5					<0.01	0.017	<0.005	0.0800	<0.0005	<0.007	0.168	<0.0005	<0.0008	0.0011	0.005	0.014	<0.002
19	0.9	0.2	<0.3	0.4	147.0	<0.01	0.017	<0.005	0.0965	<0.0005	<0.007	0.176	<0.0005	<0.0008	<0.0007	0.004	0.019	<0.002
20	2.3	0.2	<0.3	0.2	126.0	<0.01	0.038	<0.005	0.1400	<0.0005	<0.007	0.122	<0.0005	<0.0008	0.0007	0.004	0.019	<0.002
21	0.5	<0.2	<0.3	0.2	163.0	0.020	0.028	<0.005	0.0251	<0.0005	<0.007	0.209	<0.0005	<0.0008	0.0015	0.003	0.027	<0.002
22	1.4																	
23	0.4																0.160	
24	0.8																4.480	
25	1.2																2.400	
26	0.0																5.310	
27	4.3																0.760	
28	0.0																4.190	
29	0.2																3.930	

Table A7-1: Quaternary formation chemistry summary.

Key	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)	SiO2 (mg/L)	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
1										19.0								
2	0.081	0.005	<0.0001	<0.001	0.073	0.64	<0.004	2.920	27.7		59.5	<0.001	0.2740	75.300	<0.004	<0.0004	<0.001	0.0017
3	0.023	1.300	<0.0001	<0.001	0.004	<0.03	<0.004	8.510	42.7		91.5	0.001	0.4120	2.610	<0.004	<0.0004	<0.001	0.0055
4	0.020	0.025	<0.0001	<0.001	0.003	<0.03	<0.004	10.700	20.7		44.3	<0.001	0.1570	2.290	<0.004	<0.0004	0.001	0.0011
5	0.032	0.377	<0.0001	<0.001	<0.001	<0.03	<0.004	11.000	18.1		38.8	<0.001	0.3900	1.700	<0.004	<0.0004	<0.001	0.0010
6	0.034	0.791	<0.0001	0.010	<0.001	<0.03	<0.004	9.340	17.1		36.6	<0.001	0.4070	10.100	<0.004	<0.0004	<0.001	0.0009
7	0.040	0.121	<0.0001	<0.001	<0.001	<0.03	0.004	11.800	18.9		40.5	<0.001	0.5540	2.030	<0.004	<0.0004	<0.001	0.0006
8	0.030	0.091	<0.0001	0.001	<0.001	<0.03	<0.004	11.700	17.0		38.9	<0.001	0.2690	9.330	<0.004	<0.0004	0.004	0.0017
9	0.062	0.077	<0.0001	0.002	<0.001	0.11	<0.004	11.000	17.8		38.1	<0.001	0.6030	46.000	<0.004	<0.0004	0.002	0.0008
10	0.048	0.127	<0.0001	0.034	0.002	0.39	<0.004	14.900	21.4		45.7	<0.001	0.3140	18.100	<0.004	0.0009	<0.001	0.0006
11	0.094	0.367	<0.0001	<0.001	<0.001	0.49	<0.004	8.480	41.6		89.0	<0.001	0.9200	62.700	<0.004	<0.0004	0.003	0.0139
12	0.080	0.047	<0.0001	<0.001	0.004	0.25	<0.004	7.570	36.3		77.5	<0.001	0.7910	36.100	<0.004	<0.0004	0.003	0.0651
13	0.060	0.266	<0.0001	<0.001	<0.001	0.59	<0.004	9.720	47.6		102.0	<0.001	0.7470	34.500	<0.004	<0.0004	0.002	0.0032
14	0.066	0.138	<0.0001	<0.001	<0.001	0.58	<0.004	10.900	53.5		114.5	<0.001	0.9000	33.500	<0.004	<0.0004	0.002	0.0044
15	0.033	0.576	<0.0001	0.003	<0.001	0.76	<0.004	10.100	48.9		104.5	<0.001	0.3700	7.160	<0.004	<0.0004	<0.001	0.0048
16	0.045	0.266	<0.0001	0.006	0.004	0.25	<0.004	9.920	13.6		29.0	<0.001	0.4890	6.840	<0.004	<0.0004	0.002	0.0180
17	0.049	0.259	<0.0001	0.015	<0.001	0.47	<0.004	10.300	46.1		98.5	<0.001	0.7490	6.990	<0.004	<0.0004	<0.001	0.0163
18	0.050	0.149	<0.0001	0.003	0.005	0.06	<0.004	12.900	21.2		45.3	0.001	0.5140	6.620	<0.004	<0.0004	<0.001	0.0049
19	0.053	0.134	<0.0001	0.003	<0.001	0.05	<0.004	12.800	20.8		44.5	<0.001	0.5470	6.130	<0.004	<0.0004	<0.001	0.0027
20	0.029	0.194	<0.0001	<0.001	<0.001	0.04	<0.004	11.300	20.7		44.1	0.001	0.4120	2.750	<0.004	<0.0004	<0.001	0.0041
21	0.064	0.794	<0.0001	0.005	<0.001	0.03	<0.004	9.280	19.2		41.1	0.001	0.5940	59.300	<0.004	<0.0004	0.001	0.0176
22										10.0								
23										14.9								
24										17.0								
25																		
26										17.2								
27										18.0								
28										17.5								
29																		

Table A7-1: Quaternary formation chemistry summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (masl)	Formation	Well Name
30	NW-19-086-18W4	56.468058	112.830515	387226.0	6259677.2	529.0	Quaternary	NOVA BUFFALO CREEK COMP. STATION NW-19-86-18
31	NW-15-089-09W4	56.722509	111.354662	478295.1	6286553.6	246.0	Quaternary	A FRAME CONTRACTING NW-15-89-9
32	09-24-085-09W4	56.386505	111.275414	482994.9	6249132.0	764.1	Quaternary	ARC # 10-165

Table A7-1: Quaternary formation chemistry summary.

				Field Parameters									Laboratory Parameter	
Key	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date	Field Temp (^oC)	Field pH	Field Cond (mS/cm)	Field ORP (mV)	Standard half cell potential at field T (mV)	Field Eh (mV)	Field DO (mg/L)	Field P-Alk (mg/L)	Field T-Alk (mg/L)	Laboratory pH	Laboratory Cond (mS/cm)
30	49.7	51.2	January 27, 1987										8.70	1670.0
31	32.0	3.5	August 9, 1989										7.68	784.0
32	34.9	36.4	August 4, 2000	5.1	8.09	297	-168	258	90	0.1	<2	310	7.91	440.0

Table A7-1: Quaternary formation chemistry summary.

	s															
Key	Laboratory P-Alkalinity (mg $CaCO_3$/L)	Laboratory Total Alkalinity (mg $CaCO^3$/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	Cl by NAA (µg/mL)	Br by NAA (µg/mL)	I by NAA (µg/mL)	SO_4 (mg/L)	Hardness (mg/L $CaCO_3$)	TDS (mg/L)
30		844	<1	<1	415.0	1.8	944	42	58.0				<5		988
31		310	79.0	22.00	58.0	3.1	378		46.0				48.00		443
32	<5	239	68.8	13.60	9.8	25.5	291	<6	<0.5	1.84	<0.012	<0.01	17.50	228.00	278

Table A7-1: Quaternary formation chemistry summary.

Key	Charge Balance Error (%)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)	Propionic acid (mg/L)	As (mg/L)	Al (mg/L)	Sb (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)
30	2.8																0.100	
31	-0.8																0.770	
32	4.5	<0.2	<0.3	<0.1	95.2	<0.01	0.044	<0.005	0.1260	<0.0005	<0.007	0.073	<0.0005	<0.0008	<0.0007	0.008	0.013	<0.002

Table A7-1: Quaternary formation chemistry summary.

Key	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)	SiO2 (mg/L)	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
30										6.4								
31										10.0								
32	0.054	0.282	<0.0001	0.002	0.006	<0.03	<0.004	11.300	10.4	22.2		<0.001	0.6940	5.840	<0.004	<0.0004	<0.001	0.0039
												Note:	< denotes less than.					
													UTM zone 12, NAD 83					

Table A7-2: Empress formation chemistry summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (masl)	EUB Formation Code	Well Name
33	07-36-077-15W4	55.714379	112.187915	425369.0	6174930.7	662.4	20	AGS WR 99-1-230
34	12-01-073-06W4	55.293860	110.799660	512721.6	6127511.1	713.2	20	AEC N. PRIMROSE COMP. STATION PRODUCTION WELL
35	13-21-073-07W4	55.341278	111.031660	497991.9	6132770.0	728.8	20	RAX WS1 Kirby

Field Parameters

Key	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date	Field Temp (^oC)	Field pH	Field Cond (mS/cm)	Field ORP (mV)	Formation
33	227.5	230.6	May 24, 2001	6.0	7.72	492	-171	Quaternary
34	275.5	284.7	July 25, 2000	8.6	7.99	593	-208	Quaternary
35	290.0	300.0	April 26, 2001	7.6	7.90	689	22	Quaternary

Key	Field Eh (mV)	Field DO (mg/L)	Field P-Alk (mg/L)	Field T-Alk (mg/L)	Standard half cell potential at field T (mV)
33	86	0.1	<2	406	257
34	47	0.0	<2	480	255
35	278	2.3	<2	564	256

Table A7-2: Empress formation chemistry summary.

Laboratory Parameters

Key	Laboratory Temp (°C)	Laboratory pH	Laboratory Cond (mS/cm)	Laboratory P-Alkalinity (mg $CaCO_3$/L)	Laboratory Total Alkalinity (mg $CaCO^3$/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)
33		7.77	744.0	<5	395	64.8	18.70	98.9	5.4	482	<6	<0.5
34		8.13	787.0	<5	425	25.2	8.56	171.0	3.2	518	<6	35.1
35	18.2	8.36	832.0	<5	495	7.4	3.47	215.0	2.0	603	<6	16.5

Key	Cl by NAA (μg/mL)	Br by NAA (μg/mL)	I by NAA (μg/mL)	SO_4 (mg/L)	Hardness (mg/L $CaCO_3$)	TDS (mg/L)	Charge Balance Error (%)	Extractable Silica (mg/L)/5	SiO_2 (mg/L)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)
33	0.44	0.01	<0.01	38.10	239.00	463	2.9	7.8				
34	44.00	0.29	0.18	10.60	98.30	509	-1.1	7.6				
35	15.80	0.08	0.06	3.80	32.70	544	-1.8	15.3		<0.2	<0.3	<0.1

Key	As (mg/L)	Al (mg/L)	Sb (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)
33	0.020	<0.080	<0.005	0.0966	<0.0005	<0.007	0.360	<0.0005	<0.0008	0.0011	0.002	0.051
34	0.020	0.036	<0.005	0.1560	<0.0005	<0.007	0.333	<0.0005	<0.0008	0.0007	0.003	0.205
35	0.010	0.021	0.005	0.1360	0.0005	0.007	0.438	0.0005	0.0008	0.0024	0.003	0.133

Table A7-2: Empress formation chemistry summary.

Key	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)/5	Extractable Si (mg/L)
33	0.064	0.099	<0.0001	0.009	<0.001	0.17	<0.004	11.600	3.660	18.3
34	0.032	0.044	<0.0001	0.014	<0.001	0.65	<0.004	7.630	3.550	17.7
35	0.018	0.013	<0.0001	0.038	0.002	2.03	<0.004	7.670	7.140	35.7

Key	Propionic acid (mg/L)	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
33		39.1	<0.001	0.4970	12.700	<0.004	<0.0004	<0.001	0.0007
34		38.0	<0.001	0.3060	3.540	<0.004	<0.0004	0.002	0.0017
35	164.0	76.5	<0.001	0.1050	1.270	<0.004	0.0005	<0.001	0.0041

Key	Pb (mg/L)
33	<0.002
34	<0.002
35	<0.002

note: < denotes less than
UTM Zone 12, NAD 83

Table A7-3: Upper Mannville formation chemistry summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (masl)	Formation
36	00/04-11-067-13W4-0	54.779682	111.880104	443393.7	6070630.3	575.6	Grand Rapids
37	00/04-26-068-13W4-0	54.909420	111.882843	443399.4	6085068.7	584.6	Viking
38	00/05-26-070-16W4-0	55.089283	112.337989	414603.6	6105544.5	578.8	Grand Rapids
39	00/07-13-072-11W4-0	55.234301	111.553037	464829.5	6121004.3	650.9	Grand Rapids
40	00/06-24-077-09W4-0	55.685520	111.262275	483509.9	6171110.9	569.1	Clearwater
41	00/06-24-077-09W4-0	55.685964	111.105006	493398.2	6171134.0	553.6	Clearwater
42	00/11-26-069-11W4-0	55.005390	111.572071	463410.8	6095540.9	629.4	Viking
43	00/10-21-077-08W4-0	55.686310	111.179013	488744.9	6171182.1	562.8	Clearwater
44	00/10-33-065-03W4-0	54.670586	110.390694	539294.9	6058306.0	612.0	Grand Rapids
45	00/10-21-069-15W4-2	54.990913	112.222900	421757.2	6094464.2	546.2	Colony
46	00/07-01-067-15W4-2	54.768154	112.148811	426090.7	6069597.6	582.6	Colony
47	16-02-087-09W4	56.520851	111.309494	480958.0	6264094.3	429.2	Grand Rapids
48	07-36-085-07W4	56.411712	110.964122	502214.0	6251904.2		Grand Rapids
49	07-02-085-06W4	56.339120	110.832000	510385.8	6243836.3	483.1	Grand Rapids
50	15-05-086-07W4	56.448860	111.040080	497529.5	6256039.1	477.9	Grand Rapids

Table A7-3: Upper Mannville formation chemistry summary.

					Field Parameters			
Key	Well Name	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date	Field Temp (°C)	Field pH	Field Cond (mS/cm)	Field ORP (mV)
36	BVI LAC LA BICHE 4-11-67-13	314.0	315.0	December 12, 2000	21.4	7.77	50100	166
37	RAX TWEEDIE 4-26-68-13	249.9	252.4	January 7, 2001	21.7	7.57	48600	157
38	BVX CHARRON 5-26-70-16	290.0	291.5	January 16, 2001	22.2	7.35	37300	164
39	RAX ET AL IPIATIK 7-13-72-11	311.7	313.2	January 5, 2001	21.9	8.65	5880	132
40	AMOCO D-2 LEISMER 6-24-77-9	261.5	267.0	August 25, 2000	12.2	8.30	9790	144
41	AMOCO LEISMER 6-24-77-8	242.0	250.0	August 25, 2000	22.6	8.27	11070	134
42	RAX ET AL HEART LAKE 11-26-69-11	270.5	271.5	January 10, 2001	21.5	7.31	41100	122
43	AMOCO LEISMER 10-21-77-8	256.0	260.5	August 25, 2000	17.7	8.20	11120	120
44	TRANSWEST ET AL ETHEL LK 10-33-65-3	304.8	305.7	February 6, 2001	22.0	7.88	22200	137
45	TALISMAN CHARRON 10-21-69-15	319.7	320.4	January 5, 2001	21.8	7.52	36800	163
46	CNRL ET AL HYLO 7-1-67-15	335.0	336.0	August 24, 2000	21.1	6.98	52600	-36
47	ARC # 11-130	28.2	32.8	July 3, 2000	6.7	7.59	757	-122
48	OPTI CANADA OBSERVATION WELL	82.6	89.1	July 16, 2000	4.4	7.76	746	-223
49	RIO ALTO NEWBY COMP. STATION DOMESTIC WELL	69.8	72.8	July 19, 2000	6.3	8.97	1163	-309
50	J. MULAWKA RESIDENCE DOMESTIC WELL	48.2	49.7	July 19, 2000	8.9	9.04	784	-204

Table A7-3: Upper Mannville formation chemistry summary.

Key	Standard half cell potential at field T (mV)	Field Eh (mV)	Field DO (mg/L)	Field P-Alk (mg/L)	Field T-Alk (mg/L)
36	247	413	6.5	<2	220
37	246	403	5.6	<2	220
38	246	410	6.1	<2	238
39	246	378	5.6	<2	954
40	253	397	6.1	<2	600
41	246	380	6.6	<2	470
42	247	369	6.0	<2	236
43	249	369	6.8	<2	482
44	246	383	3.2	<2	648
45	246	409	5.7	<2	230
46	247	211	7.1	<2	177
47	256	134	0.9	<2	560
48	258	35	0.1		
49	257	-52	0.0	<2	764
50	255	51	0.1	<2	546

Table A7-3: Upper Mannville formation chemistry summary.

	Laboratory Parameters														
Key	Laboratory pH	Laboratory Cond (mS/cm)	Laboratory P Alkalinity (mg $CaCO_3$/L)	Laboratory Total Alkalinity (mg $CaCO^3$/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	Cl by NAA (μg/mL)	Br by NAA (μg/mL)	I by NAA (μg/mL)	SO_4 (mg/L)
36	7.75	42301.2	<5	144	485.0	236.00	10700.0	59.2	176	<6	16800.0	19300.00	59.30	10.50	0.60
37	7.68	38001.1	<5	119	283.0	198.00	10100.0	52.3	146	<6	16300.0	17900.00	66.60	12.40	1.79
38	7.56	30500.8	<5	169	233.0	131.00	7650.0	37.0	205	<6	11900.0	12800.00	37.60	7.66	<0.20
39	8.67	3810.0	72	988	3.4	2.12	989.0	3.9	1030	86	838.0	919.00	2.89	0.68	0.58
40	8.41	9260.0	31	598	12.0	10.60	2020.0	5.9	911	<6	2710.0	2940.00	9.54	1.93	<0.20
41	8.40	8440.0	27	436	11.0	8.44	1800.0	5.2	465	33	2590.0	3010.00	8.18	1.78	0.49
42	7.51	32900.1	<5	172	210.0	142.00	8680.0	33.3	209	<6	13100.0	14600.00	51.00	10.60	1.72
43	8.36	9310.0	13	484	12.0	10.60	2040.0	6.3	558	16	2900.0	3280.00	10.80	2.13	<0.20
44	8.00	18300.3	<5	628	48.6	40.90	4300.0	20.2	765	<6	6490.0	6610.00	21.20	3.79	0.85
45	7.56	30700.3	<5	129	264.0	127.00	7790.0	39.0	158	<6	11900.0	12900.00	39.20	7.90	6.10
46	7.59	46801.1	<5	103	528.0	249.00	10700.0	45.0	125	<6	18000.0	19500.00	60.10	10.10	5.40
47	7.79	1100.0	<5	497	46.4	16.40	210.0	3.0	606	<6	73.5	77.10	<0.06	<0.01	31.20
48	7.72	1110.0	<5	599	77.0	33.70	137.0	8.2	730	<6	2.7	3.14	<0.05	0.01	80.60
49	8.72	1690.0	47	819	2.3	1.08	457.0	1.8	885	56	98.8	87.90	0.27	0.13	3.72
50	8.81	1100.0	58	587	1.0	0.43	294.0	1.2	573	70	2.5	0.67	<0.05	<0.01	40.20

Table A7-3: Upper Mannville formation chemistry summary.

Key	Hardness (mg/L $CaCO_3$)	TDS (mg/L)	Charge Balance Error (%)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)	Propionic acid (mg/L)	As (mg/L)	Al (mg/L)	Sb (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	B (mg/L)	Cd (mg/L)
36	2180.00	28400	3.4	<4	<6	<2	141.0	<0.10	0.160	<0.050	20.6000	<0.0050	0.073	8.660	0.0054
37	1520.00	27000	1.0	<0.2	<0.3	<0.1	<0.3	<0.01	<0.008	<0.005	19.7000	<0.0005	<0.007	3.060	0.0072
38	1120.00	20000	2.5	<4	<6	<2	146.0	<0.10	<0.080	<0.050	12.7000	<0.0050	<0.070	9.350	<0.0050
39	17.20	2430	0.1	<0.2	<0.3	0.2	146.0	0.020	0.013	<0.005	0.1620	<0.0005	<0.007	7.270	<0.0005
40	74.00	5120	-1.0	<0.2	<0.3	<0.1	113.0	<0.10	<0.080	<0.050	0.7630	<0.0050	<0.070	5.520	<0.0050
41	61.00	4680	-1.3	<0.2	<0.3	<0.1	79.0	<0.10	<0.080	<0.050	0.4950	<0.0050	<0.070	5.600	<0.0050
42	1110.00	22300	3.6	<0.2	<0.3	<0.1	<0.3	<0.01	<0.008	<0.005	12.0000	<0.0005	<0.007	3.840	<0.0005
43	74.00	5250	-0.6	<0.2	<0.3	<0.1	73.5	<0.10	<0.080	<0.050	0.7360	<0.0050	<0.070	5.770	<0.0050
44	289.00	11300	-0.6	<1	<2	<0.5	289.0	<0.01	<0.008	<0.005	2.5100	<0.0005	0.015	11.300	<0.0005
45	1190.00		3.6	<4	<6	<2	118.0	<0.10	<0.080	<0.050	11.7000	<0.0050	<0.070	7.190	<0.0050
46	2340.00	29600	0.3	<0.2	<0.3	<0.1	18.2	<0.05	0.940	<0.200	23.6000	<0.0300	<0.400	4.840	<0.0300
47	183.00	679	0.9	<0.2	<0.3	<0.1	95.2	<0.01	0.020	<0.005	0.0227	<0.0005	<0.007	1.020	<0.0005
48	331.00	698	-3.5	<0.2	<0.3	<0.1	145.0	<0.01	<0.008	<0.005	0.0660	<0.0005	<0.007	0.597	<0.0005
49	10.30	1060	2.3	0.2	<0.3	0.4	210.0	<0.01	0.090	<0.005	0.0993	0.0005	0.036	5.150	<0.0005
50	4.20	692	1.1	0.2	<0.3	0.6	161.0	<0.01	0.063	<0.005	0.0469	<0.0005	0.007	4.030	<0.0005

Table A7-3: Upper Mannville formation chemistry summary.

Key	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)	Extractable Silica (mg/L)/5	Extractable Silica (mg/L)	Ag (mg/L)
36	<0.0080	<0.0070	<0.010	<0.030	<0.020	5.340	0.410	<0.0001	<0.010	0.013	<0.30	<0.040	4.090	17.8	7.6	38.2	<0.010
37	<0.0008	0.0090	<0.001	0.021	<0.002	2.120	0.172	<0.0001	<0.001	0.016	2.31	<0.004	2.410	12.2	5.2	26.1	<0.001
38	0.0100	<0.0070	<0.010	<0.030	<0.020	3.660	0.881	<0.0001	<0.010	<0.010	<0.30	<0.040	2.200	9.8	4.2	21.0	<0.010
39	<0.0008	0.0033	0.002	<0.003	<0.002	0.237	0.010	0.0002	0.003	0.010	0.24	<0.004	3.870	17.6	7.6	37.8	<0.001
40	<0.0080	0.0130	<0.010	<0.030	<0.020	0.446	0.014	<0.0001	<0.010	<0.010	0.55	0.230	3.640	23.8	10.2	51.0	<0.010
41	<0.0080	0.0120	<0.010	<0.030	<0.020	0.398	0.020	<0.0001	<0.010	<0.010	0.47	0.150	3.290	21.3	9.1	45.5	<0.010
42	<0.0008	0.0059	<0.001	0.027	<0.002	1.680	0.209	<0.0001	<0.001	0.008	2.23	0.005	2.710	11.6	5.0	24.8	<0.001
43	<0.0080	0.0170	<0.010	<0.030	<0.020	0.467	0.021	<0.0001	0.010	0.012	0.57	0.060	3.420	22.0	9.4	47.2	<0.010
44	<0.0008	0.0019	0.003	0.010	<0.002	1.390	0.022	<0.0001	<0.001	<0.001	0.70	<0.004	3.850	18.8	8.1	40.3	0.002
45	<0.0080	<0.0070	0.011	<0.030	<0.020	3.240	0.846	<0.0001	<0.010	<0.010	<0.30	<0.040	4.180	17.7	7.6	38.0	<0.010
46	<0.0400	0.0550	<0.050	0.220	<0.100	2.510	0.725	<0.0001	<0.050	<0.050	2.90	<0.200	2.380	14.4	6.2	30.8	<0.050
47	<0.0008	0.0012	<0.001	0.024	<0.002	0.077	0.040	<0.0001	<0.001	<0.001	0.05	<0.004	6.100	52.0	22.2	111.0	<0.001
48	<0.0008	0.0016	<0.001	0.031	<0.002	0.057	0.059	<0.0001	<0.001	<0.001	<0.03	0.005	9.350	54.5	23.4	117.0	0.001
49	0.0057	0.0046	0.003	0.307	0.002	0.065	0.005	<0.0001	0.004	0.004	1.04	<0.004	3.080	12.7	5.4	27.1	<0.001
50	<0.0008	0.0030	<0.001	0.174	<0.002	0.039	0.002	<0.0001	<0.001	0.003	0.98	<0.004	3.220	13.6	5.8	29.0	<0.001

Table A7-3: Upper Mannville formation chemistry summary.

Key	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
36	43.9000	0.200	0.046	<0.0040	<0.010	<0.0060
37	36.3000	0.597	<0.004	<0.0004	<0.001	0.0083
38	23.3000	<0.080	<0.040	<0.0040	<0.010	0.0290
39	0.3540	0.193	<0.004	<0.0004	0.001	0.0054
40	1.7400	<0.080	<0.040	<0.0040	<0.010	<0.0060
41	1.3200	0.160	<0.040	<0.0040	<0.010	<0.0060
42	24.4000	0.574	<0.004	<0.0004	<0.001	0.0076
43	1.7800	<0.080	<0.040	<0.0040	<0.010	<0.0060
44	6.6200	0.283	<0.004	<0.0004	<0.001	0.0090
45	23.7000	2.030	<0.040	<0.0040	<0.010	0.4020
46	54.5000	1.800	0.200	0.0750	<0.050	0.0300
47	0.6060	10.400	<0.004	<0.0004	<0.001	0.0008
48	0.6590	26.900	<0.004	<0.0004	<0.001	0.0011
49	0.1440	1.240	<0.004	0.5500	0.045	<0.0006
50	0.0555	13.400	<0.004	0.3030	0.011	0.0209
			Note:	< denotes less than		
				UTM Zone 12, NAD 83		

Table A7-4: Lower Mannville formation chemistry summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	EUB Formation Code	Formation	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date
51	00/07-27-071-21W4-0	55.174896	113.1431	363517.3	6116349.7	3060	Wabiskaw	500.0	517.0	January 12, 2001
52	00/05-04-078-05W4-0	55.726726	110.72328	517379.9	6175700.4	3280	McMurray	338.0	340.5	February 6, 2001
53	00/02-08-084-17W4-0	56.264247	112.65067	397760.1	6236715.2	3060	Wabiskaw	251.0	254.0	April 13, 2001
54	16-02-087-09W4	56.520851	111.30949	480958.0	6264094.3	3280	McMurray	128.0	138.7	July 12, 1979
55	16-02-087-09W4	56.520851	111.30949	480958.0	6264094.3	3280	McMurray	176.8	179.9	July 11, 1978
56	08-27-088-09W4	56.660206	111.33672	479358.8	6279613.3	3280	McMurray	134.1	138.7	July 12, 1977
57	15-03-089-16W4	56.769241	112.48924	418297.9	6292496.7	3280	McMurray	224.0	227.0	July 7, 1978

Field Parameters

Key	Well Name	Field Temp (°C)	Field pH	Field Cond (mS/cm)	Field ORP (mV)	Field Eh (mV)	Field DO (mg/L)	Field P Alk (mg/L)	Field T-Alk (mg/L)
51	RENAISSANCE GAMBLER 7-27-71-21	21.6	7.79	46300	140	387	6.3	<2	1290
52	TRANSWEST HARDY 5-4-78-5	22.4	8.03	16800	141	387	4.4	<2	1216
53	SRI GRANOR 2-8-84-17	19.8	8.40	10080	327	575	4.4	<2	2440
54	ARC # 11-460	9.5	7.90						
55	ARC # 11-595	7.0	8.90						
56	ARC # 12-460	6.0	8.70						
57	ARC # 15-750	9.0	8.50						

Table A7-4: Lower Mannville formation chemistry summary.

Laboratory Parameters

Key	Laboratory Temp (°C)	Laboratory pH	Laboratory Cond (mS/cm)	Laboratory P-Alkalinity (mg $CaCO_3$/L)	Laboratory Total Alkalinity (mg $CaCO^3$/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	Cl by NAA (μg/mL)	Br by NAA (μg/mL)
51		7.74	36500.3	<5	1230	169.0	144.00	9830.0	104.0	1500	<6	14200.0	17000.00	53.20
52		8.10	14200.1	<5	1270	28.0	30.20	3190.0	14.7	1540	<6	4660.0	4650.00	14.20
53	19.2	8.73	8170.0	149	2950	12.0	16.90	2240.0	17.0	3230	179	1500.0	1570.00	3.71
54		8.40	22000.3		229	82.0	122.00	5525.0	26.7	266	10	8600.0		
55		8.90	26700.1		553	22.0	149.00	6688.0	48.3	556	65	11200.0		
56		8.30				34.0	46.00	2075.0	18.8	383	0	3180.0		
57		8.30	13900.1		687	11.8	62.00	3638.0	8.3	859	0	5200.0		

Key	I by NAA (μg/mL)	SO_4 (mg/L)	Hardness (mg/L $CaCO_3$)	TDS (mg/L)	Charge Balance Error (%)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)	Propionic acid (mg/L)	As (mg/L)	Al (mg/L)	Sb (mg/L)	Ba (mg/L)	Be (mg/L)
51	10.80	2.67	1010.00	25200	2.9	645.0	<6	<2	158.0	<0.10	0.200	<0.050	15.1000	<0.0050
52	1.67	1.24	194.00	8680	-4.6	<1	<2	<0.5	467.0	<0.01	<0.008	<0.005	0.4800	<0.0005
53	1.01	5.72	99.00	5560	2.3					<0.10	0.170	<0.050	0.1400	<0.0050
54		1106.00		15016	-2.8									
55		9.50		18136	-3.1						0.040			
56		52.00		5434	-0.4									
57		3.80		9518	1.0						0.080			

Table A7-4: Lower Mannville formation chemistry summary.

Key	Bi (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	P (mg/L)	Se (mg/L)	Si (mg/L)
51	<0.070	9.990	<0.0050	<0.0080	0.0070	<0.010	<0.030	<0.020	6.270	0.012	<0.0001	0.019	0.030	<0.30	<0.040	4.430
52	0.010	6.020	<0.0005	<0.0008	0.0027	<0.001	0.006	<0.002	0.962	0.114	<0.0001	<0.001	0.001	0.33	<0.004	2.900
53	<0.070	5.310	<0.0050	<0.0080	0.0130	<0.010	<0.030	<0.020	0.752	0.005	<0.0001	0.141	<0.010	<0.30	<0.040	4.280
54																
55						0.000	0.100	0.020		0.080	0.0003					
56																
57						0.004	0.000	0.006		0.000	0.0005					

Key	Extractable Si (mg/L)	SiO_2 (mg/L)	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
51	19.450		41.650	<0.010	27.3000	0.890	<0.040	<0.0040	<0.010	<0.0060
52	13.700		29.350	<0.001	3.3800	0.413	<0.004	<0.0004	0.002	0.0006
53	19.800		42.350	<0.010	1.6200	1.910	<0.040	<0.0040	0.013	<0.0060
54			3.600							
55			1.000							
56			42.000							
57			3.200							

Note: < denotes less than.
UTM Zone 12, NAD 83

Table A7-5: Devonian formation chemistry summary.

Key	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (masl)	Formation	Well Name
1	54.872635	112.664185	393212.7	6081887.1	556.2	Nisku	DELTA GRASSLAND 11-10-68-18
2	56.576718	112.965052	379284.7	6271997.7	522.7	Grosmont	PARA MCLEAN 10-28-87-19
3	55.603459	112.908031	379792.9	6163598.8	573.7	Grosmont	RENAISSANCE PORTAGE 16-20-76-19
4	55.736549	112.501663	405712.4	6177780.1	616.9	Nisku	TALISMAN ATMORE 8-28-66-17

Field Parameters

Key	Field Temp (°C)	Field pH	Field Cond (mS/cm)	Field ORP (mV)	Standard half cell potential at field T (mV)	Field Eh (mV)	Field DO (mg/L)	Field P-Alk (mg/L)	Field T-Alk (mg/L)
1	24.5	7.08	52800	-159	245	86	2.8	<2	796
2	22.2	7.48	12500	153	246	399	3.9	<2	2668
3	20.2	6.92	17000	112	247	359	2.0	<10	1810
4	21.5	7.15	57800	174	247	421	6.7	<2	736

Table A7-5: Devonian formation chemistry summary.

Laboratory Parameters

Key	Laboratory Temp (°C)	Laboratory pH	Laboratory Cond (mS/cm)	Laboratory P Alk (mg $CaCO_3$/L)	Laboratory T-Alk (mg $CaCO_3$/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	Sb (mg/L)	Ba (mg/L)
1		7.42	42700.4	<5	748	334.0	184.00	10100.0	66.0	911	<6	15900.0	<0.200	14.0000
2		8.11	9940.1	<5	2900	21.9	23.70	2580.0	21.9	3540		2150.0	<0.005	2.0400
3	18.9	8.00	14700.0	<5	1070	102.0	117.00	3820.0	44.7	1310	<6	5220.0	<0.050	1.6000
4		7.32	50200.8	<5	705	522.0	304.00	11900.0	98.0	859	<6	19300.0	<0.050	33.4000

Key	Cl by NAA (μg/mL)	Br by NAA (μg/mL)	I by NAA (μg/mL)	SO_4 (mg/L)	TDS (mg/L)	Charge Balance Error (%)	Acetic acid (mg/L)	Butyric acid (mg/L)	Formic acid (mg/L)	Propionic acid (mg/L)	As (mg/L)	Al (mg/L)	Ni (mg/L)	P (mg/L)
1	17900.00	56.30	10.00	2.60	27000	1.0	<0.2	<0.3	<0.1	7.8	<0.05	0.540	<0.050	2.50
2	2360.00	5.87	1.23	8.24	6540	-1.3	1.1	<2	<0.5	796.0	<0.01	0.011	0.003	0.30
3	5690.00	15.30	3.40	166.00	10100	2.8					<0.10	0.240	<0.010	1.20
4	21200.00	68.40	9.50	1.30	33600	1.1	<4	<6	<2	451.0	<0.10	0.130	0.012	<0.30

Table A7-5: Devonian formation chemistry summary.

Key	Be (mg/L)	Bi (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Li (mg/L)	Mn (mg/L)	Hg (mg/L)	Mo (mg/L)
1	<0.0300	<0.400	10.700	<0.0300	<0.0400	<0.0070	<0.050	0.250	<0.100	3.300	0.545	<0.0001	<0.050
2	<0.0005	<0.007	3.030	<0.0005	<0.0008	0.0026	<0.001	0.004	<0.002	1.240	0.076	<0.0001	0.002
3	<0.0050	<0.070	5.740	<0.0050	<0.0080	0.0210	<0.010	0.120	<0.020	1.520	0.012	<0.0001	<0.010
4	<0.0050	<0.070	14.100	<0.0050	0.0100	<0.0070	<0.010	0.270	<0.020	8.990	0.059	<0.0001	<0.010

Key	Se (mg/L)	Si (mg/L)	Extractable Si (mg/L)/5	Extractable Si (mg/L)	Extractable Silica (mg/L)/5	Extractable Silica (mg/L)	Ag (mg/L)	Sr (mg/L)	S (mg/L)	Tl (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
1	0.200	3.430	4.190	20.95	8.97	44.85	<0.050	40.9000	0.870	<0.200	<0.0200	<0.050	0.0300
2	<0.004	3.110	2.610	13.05	5.58	27.90	<0.001	2.3800	2.750	<0.004	<0.0004	<0.001	0.0017
3	<0.040	3.730	3.720	18.60	7.97	39.85	<0.010	6.4900	55.200	<0.040	<0.0040	0.011	0.0180
4	<0.040	6.740	5.740	28.70	12.30	61.50	<0.010	64.4000	0.430	<0.040	<0.0040	<0.010	0.0200

Note: < denotes less than.
UTM Zone 12, NAD 83

Table A7-6: Quaternary isotope summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (m)	Formation	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date	$^{87}Sr/^{86}Sr$
2	16-02-087-09W4	56.520851	111.309494	480958.0	6264094.3	429.77	Quaternary	7.0	8.5	August 3, 2000	0.708043
3	07-36-077-15W4	55.714398	112.187874	425371.4	6174932.8	662.48	Quaternary	5.1	8.2	June 22, 2001	0.709585
4	06-33-074-09W4	55.451416	111.329831	479138.6	6145075.9	666.83	Quaternary	9.3	15.4	May 9, 2001	0.716735
5	06-33-074-09W4	55.451377	111.329824	479139.0	6145071.6	667.10	Quaternary	37.9	41.0	May 8, 2001	0.711154
6	06-33-074-09W4	55.451383	111.329959	479130.8	6145072.1	666.99	Quaternary	72.4	75.4	May 8, 2001	0.710660
7	06-33-074-09W4	55.451376	111.329890	479135.2	6145071.6	666.92	Quaternary	117.3	120.3	May 9, 2001	0.709869
8	15-04-075-05W4	55.473040	110.707298	518502.7	6147472.0	648.17	Quaternary	11.2	17.3	May 11, 2001	0.713601
9	15-04-075-05W4	55.473007	110.707318	518501.3	6147468.2	648.26	Quaternary	76.6	79.6	May 11, 2001	0.711419
10	15-04-075-05W4	55.472975	110.707334	518500.4	6147164.8	648.20	Quaternary	155.4	158.5	May 10, 2001	0.708855
11	16-35-071-14W4	55.198740	112.503240	404319.5	6117937.9	566.93	Quaternary	39.0	48.2	July 11, 2000	0.708067
12	10-10-070-17W4	55.051690	112.499700	404193.4	6101571.2	566.93	Quaternary	42.7	45.7	July 12, 2000	0.708042
13	04-24-071-17W4	55.156830	112.488420	405163.5	6113254.6	548.64	Quaternary	24.4	30.5	July 12, 2000	0.708804
14	16-22-071-17W4	55.169970	112.520300	403164.0	6114760.6	562.36	Quaternary	28.0	29.6	July 13, 2000	0.708286
15	10-36-076-15W4	55.631550	112.188850	425152.1	6165714.3	569.37	Quaternary	64.9	69.5	July 13, 2000	0.709044
16	11-10-084-10W4	56.271950	111.500430	469009.1	6236460.1	651.97	Quaternary	18.0	20.4	July 18, 2000	0.709029
17	07-09-082-12W4	56.093130	111.814650	449314.9	6216743.6	742.19	Quaternary	56.1	59.1	July 18, 2000	0.708761
18	05-22-070-04W4	55.073460	110.537650	529521.6	6103063.6	672.20	Quaternary	61.0	70.7	July 24, 2000	0.709689
19	05-22-070-04W4	55.073460	110.537650	529521.6	6103063.6	672.29	Quaternary	66.9	73.0	July 24, 2000	0.709630
19	05-22-070-04W4	55.073460	110.537650	529521.6	6103063.6	672.29	Quaternary	66.9	73.0	July 24, 2000	
20	16-31-076-07W4	55.628840	111.079810	494974.8	6164774.8	571.20	Quaternary	26.5	72.7	July 26, 2000	0.710485
21	04-35-071-10W4	55.187780	111.437420	472149.6	6115774.8	662.94	Quaternary	65.5	67.1	July 27, 2000	0.710211
32	09-24-085-09W4	56.386505	111.275414	482994.9	6249132.0	764.13	Quaternary	34.9	36.4	August 4, 2000	0.709744

Table A7-6: Quaternary isotope summary.

Key	$\delta^{13}C$ (permil (VPDB))	$\delta^{18}O$ (permil (VSMOW))	$\delta^{2}H$ (permil (VSMOW))	$\delta^{34}S_{sulphide}$ (permil (CDT))	$\delta^{34}S_{sulphate}$ (permil (CDT))	$\delta^{11}B$	226Ra (Bq/L)	228Ra (Bq/L)	228Th (Bq/L)	210Pb (Bq/L)
2	-12.7	-19.4	-147		9.8	43	<0.09	<0.15	<0.07	<0.08
3	-14.8	-18.5	-141	14.1	0.1					
4	-16.0	-17.6	-134		2.1					
5	-12.6	-18.4	-140		15.4					
6	-12.5	-18.3	-139		-1.4	7.0				
7	-12.9	-18.4	-141		6.0					
8	-13.2	-18.4	-142		0.6					
9	-21.5	-21.4	-157		12.3	13.7				
10	-19.4	-18.2	-139		17.9					
11	-12.8	-19.7	-149		-4.9	34	<0.12	<0.15	<0.08	
12	-14.5	-19.5	-145		0.2	25	<0.08	<0.13	<0.06	<0.10
13	-14.2	-18.3	-142		-2.4	16	<0.11	<0.17	<0.09	<0.07
14	-13.3	-19.2	-144		-7.1	13	<0.09	<0.13	<0.07	<0.08
15	-14.2	-18.5	-142		-3.1	7	<0.09	<0.14	0.16	<0.08
16	-12.4	-18.9	-144		-1.8	12	<0.08	<0.13	<0.06	<0.09
17	-15.0	-19.7	-150		8.8	22	<0.08	<0.11	<0.06	<0.09
18	-14.8	-18.4	-143		11.2	11	<0.09	<0.12	<0.06	<0.09
19	-14.2	-18.4	-142		11.6	13	<0.07	<0.13	<0.06	<0.08
19		-17.7	-140							
20	-15.1	-19.4	-143		17.0	23	<0.11	<0.19	<0.09	<0.08
21	-16.5	-19.6	-149		-4.6	27	<0.07	<0.11	<0.06	<0.08
32	-13.9	-19.8	-146		1.8	20	<0.08	<0.13	<0.06	<0.08
					Note:	UTM Zone 12, NAM 83				

Table A7-7: Empress formation isotope summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (m)	Formation	Completion Depth Top (m)	Completion Depth Bottom (m)
33	07-36-077-15W4	55.714379	112.187915	425369.0	6174930.7	662.40	Quaternary	227.5	230.7
34	12-01-073-06W4	55.293860	110.799660	512721.6	6127511.1	713.23	Quaternary	275.5	284.7
35	13-21-073-07W4	55.341278	111.031660	497991.9	6132770.0	728.79	Quaternary	290.0	300.0

Key	Sample Date	$^{87}Sr/^{86}Sr$	$\delta^{13}C$ (permil (VPDB))	$\delta^{18}O$ (permil (VSMOW))	$\delta^{2}H$ (permil (VSMOW))	$\delta^{34}S_{sulphide}$ (permil (CDT))	$\delta^{34}S_{sulphate}$ (permil (CDT))	$\delta^{11}B$
33	May 24, 2001	0.708788	-14.0	-18.3	-144		6.7	
34	July 25, 2000	0.708726	-18.4	-17.6	-142		40.8	25
35	April 26, 2001	0.708774	-19.1	-17.1	-140		15.9	38

Key	226Ra (Bq/L)	228Ra (Bq/L)	228Th (Bq/L)	210Pb (Bq/L)
33				
34	<0.08	<0.11	<0.07	<0.08
35				

Note: UTM Zone 12, NAM 83

Table A7-8: Upper Mannville formation isotope summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (m)	Formation	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date
36	00/04-11-067-13W4-0	54.779682	111.880104	443393.7	6070630.3	575.60	Grand Rapids	314.0	315.0	December 12, 2000
37	00/04-26-068-13W4-0	54.909420	111.882843	443399.4	6085068.7	584.60	Viking	249.9	252.4	January 7, 2001
38	00/05-26-070-16W4-0	55.089283	112.337989	414603.6	6105544.5	578.80	Grand Rapids	290.0	291.5	January 16, 2001
39	00/07-13-072-11W4-0	55.234301	111.553037	464829.5	6121004.3	650.90	Grand Rapids	311.7	313.2	January 5, 2001
40	00/06-24-077-09W4-0	55.685520	111.262275	483509.9	6171110.9	569.10	Clearwater	261.5	267.0	August 25, 2000
41	00/06-24-077-09W4-0	55.685964	111.105006	493398.2	6171134.0	553.60	Clearwater	242.0	250.0	August 25, 2000
42	00/11-26-069-11W4-0	55.005390	111.572071	463410.8	6095540.9	629.40	Viking	270.5	271.5	January 10, 2001
43	00/10-21-077-08W4-0	55.686310	111.179013	488744.9	6171182.1	562.80	Clearwater	256.0	260.5	August 25, 2000
44	00/10-33-065-03W4-0	54.670586	110.390694	539294.9	6058306.0	612.00	Grand Rapids	304.8	305.7	February 6, 2001
45	00/10-21-069-15W4-2	54.990913	112.222900	421757.2	6094464.2	546.20	Colony	319.7	320.4	January 5, 2001
46	00/07-01-067-15W4-2	54.768154	112.148811	426090.7	6069597.6	582.60	Colony	335.0	336.0	August 24, 2000
47	16-02-087-09W4	56.520851	111.309494	480958.0	6264094.3	429.16	Grand Rapids	28.2	32.8	July 3, 2000
48	07-36-085-07W4	56.411712	110.964122	502214.0	6251904.2		Grand Rapids	82.6	89.1	July 16, 2000
49	07-02-085-06W4	56.339120	110.832000	510385.8	6243836.3	483.11	Grand Rapids	69.8	72.8	July 19, 2000
50	15-05-086-07W4	56.448860	111.040080	497529.5	6256039.1	477.93	Grand Rapids	48.2	49.7	July 19, 2000

Table A7-8: Upper Mannville formation isotope summary.

Key	$^{87}Sr/^{86}Sr$	$\delta^{13}C$ (permil (VPDB))	$\delta^{18}O$ (permil (VSMOW))	$\delta^{2}H$ (permil (VSMOW))	$\delta^{34}S_{sulphide}$ (permil (CDT))	$\delta^{34}S_{sulphate}$ (permil (CDT))	$\delta^{11}B$	226Ra (Bq/L)	228Ra (Bq/L)	228Th (Bq/L)	210Pb (Bq/L)
36	0.709117	-11.7	-15.6	-122			30	1.04	2.07	<0.05	
37	0.708724	9.1	-16.6	-123			40	1.06	1.28	<0.07	
38	0.709077	-14.9	-16.8	-123			40	0.75	1.14	<0.06	
39	0.708406	5.9	-17.8	-134			42	0.60	<0.17	<0.07	
40	0.707852	-12.7	-19.4	-147				0.26	<0.13	<0.07	
41	0.707869	-13.7	-19.1	-147		17.4	42	<0.10	<0.12	<0.09	<0.09
42	0.708720	11.5	-16.0	-123			39	1.32	0.85	<0.07	
43	0.707891	-12.7	-19.4	-148			43	0.28	<0.14	<0.05	
44	0.708869	22.7	-17.2	-131			35	<0.05	<0.10	<0.04	<0.08
45	0.709072	-12.9	-16.1	-120			48	0.22	0.58	0.09	
46	0.709101	-12.6	-15.5	-128		5.1	44	1.35	1.72	<0.07	
47	0.708450	-14.4	-19.0	-144		21.9	27	<0.13	<0.20	<0.08	<0.08
48	0.710023	-13.9	-19.4	-146		9.0	24	0.24	<0.11	<0.07	
49	0.707628	-7.6	-19.9	-148		10.7	41	<0.09	<0.16	<0.07	<0.08
50	0.707544	-13.5	-19.7	-146		11.1	23	<0.16	<0.22	<0.12	<0.09

Note: UTM Zone 12, NAM 83

Table A7-9: Lower Mannville isotope summary.

Key	UWI	Latitude	Longitude	UTM Easting	UTM Northing	Ground Elevation (m)	Formation	Completion Depth Top (m)	Completion Depth Bottom (m)	Sample Date
51	00/07-27-071-21W4-0	55.174896	113.143097	363517.3	6116349.7	598.00	Wabiskaw	500	517	January 12, 2001
52	00/05-04-078-05W4-0	55.726726	110.723283	517379.9	6175700.4	585.90	McMurray	338	340.5	February 6, 2001
53	00/02-08-084-17W4-0	56.264247	112.650671	397760.1	6236715.2	530.80	Wabiskaw	251	254	April 13, 2001
56	08-27-088-09W4	56.660206	111.336723	479358.8	6279613.3	372.16	McMurray	131.3	136.3	August 2, 2000

Key	$^{87}Sr/^{86}Sr$	$\delta^{13}C$ (permil (VPDB))	$\delta^{18}O$ (permil (VSMOW))	$\delta^{2}H$ (permil (VSMOW))	$\delta^{34}S_{sulphide}$ (permil (CDT))	$\delta^{34}S_{sulphate}$ (permil (CDT))	$\delta^{11}B$
51	0.709109	-12.7	-16.7	-118			37
52	0.708156	24.2	-20.3	-149		6.4	50
53	0.707647	16.2	-20.3	-151		8.2	
56		19.5	-21.0	-157			

Key	226Ra (Bq/L)	228Ra (Bq/L)	228Th (Bq/L)	210Pb (Bq/L)
51	1.05	1.21	<0.07	
52	0.32	<0.08	<0.04	
53				
56				

Note: UTM Zone 12, NAM 83

Table A7-11: Radiocarbon analysis summary.

Key	Sample Identification	Waterloo Lab Number	$\delta^{13}C$ (‰)	CO_2	IsoTrace Lab Number	Uncorrected $^{14}C/^{12}C$ (pMC)	Corrected $^{14}C/^{12}C$ (pMC)	Age (yrs)	Maximum Age (yrs)	Minimum Age (yrs)
5	WEPA 00-1-41	22934	-13.45	6.0	TO-9639	57.79 ± 0.63	56.45 ± 0.62	1558	1649	1467
6	WEPA 00-1-76	22935	-13.48	4.4	TO-9640	52.52 ± 0.70	51.30 ± 0.68	2402	2512	2293
7	WEPA 00-1-120	22936	-13.95	5.9	TO-9641	54.31± 0.38	53.10± 0.37	2532	2590	2474
10	WEPA 00-3-158	22937	-21.13	6.6	TO-9642	3.62 ± 0.11	3.59 ± 0.11	30880	31137	30631
33	WR 99-1-230	22938	-15.2	5.4	TO-9643	26.99 ± 0.25	26.45 ± 0.25	11186	11265	11109

Notes: This analysis is conducted by the IsoTrace Radiocarbon Laboratory, Accelerator Mass Spectrometry Facility at the University of Toronto.
These results are the average of 2 separate analyses (normal precision).
The " Uncorrected" results are corrected for sputter fractionation only, using as a base their measured $\delta^{13}C$'s.
The "Corrected" results are corrected for natural and sputtering fractionation to a base of $\delta^{13}C = -25\%$.
The errors represent 68.3% confidence limits.
Ages were calculated using the Fontes Garnier method.

Appendix 8. Guide to Recent Publications on Inorganic Water-Rock Interactions Relevant to Deep-well Wastewater Disposal in Carbonate-Evaporite Formations in the Athabasca Oil Sands Area, Alberta

Appendix 8

Guide to Recent Publications on Inorganic Water-Rock Interactions Relevant to Deep-Well Wastewater Disposal in Carbonate-Evaporite Formations in the Athabasca Oil Sands Area, Alberta.

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Appendix 8: Guide to recent publications on inorganic water-rock interactions relevant to deepwell wastewater disposal in carbonate-evaporite formations in the Athabasca Oil Sands Area, Alberta

Contents

Guide to recent publications on inorganic water-rock interactions relevant to deep-well waste-water disposal in carbonate-evaporite formations in the Athabasca Oil Sands Area, Alberta.

1 Introduction

The rapid expansion of in situ bitumen-recovery projects based on SAGD technology in the Athabasca Oil Sands Area of northeast Alberta (e.g. Butler, 2001) has generated substantial new industry interest in the subject of waste-water disposal by deep-well injection. These projects produce a variety of liquid-waste streams requiring disposal, including steam-boiler blowdown water and excess produced water. Deepwell disposal can be an acceptable waste-management option for in situ projects, depending on site-specific circumstances. Deepwell injection of oilfield waters in the Province of Alberta is administered by the Alberta Energy and Utilities Board (EUB) as documented in EUB Guide 51 – Injection and Disposal Wells: Well Classifications, Completion, Logging, and Testing Requirements. Deepwell disposal of oilfield and industrial waste-waters in Alberta is considered to be a safe and viable disposal option where wells are properly constructed, operated, and monitored.

Under EUB Guide 51, matters of fluid-fluid, fluid-equipment, and fluid-formation compatibility are left primarily to the disposal well operator. Fluid-fluid and fluid-formation compatibility in the Athabasca oil-sands area are potentially of more interest to operators than in some parts of the Alberta Basin because of:

- the relatively shallow depth of disposal zones in Northeast Alberta in general;
- the degree of vertical and horizontal variability in formation-water chemistry due to cross-formational groundwater flow;
- the more limited number of overlying and laterally confining layers isolating disposal zones from surface, relative to deeper parts of the Alberta Basin;
- the presence of structural complexities in deep strata presumably related to Paleozoic salt collapse and karsting plus differential compaction of Lower Cretaceous sedimentary rock;
- the outcropping of some potential disposal zones along the deeply incised river valleys that cross-cut the modern landscape in the Athabasca Oil Sands Area.

Because of these complicating factors, operators in the Athabasca Oil Sands Area are exercising additional due-care and attention in design of their deepwell disposal projects. This extra care and attention often includes updating disposal designs to reflect current scientific knowledge. However, the scientific literature related to deepwell disposal has grown exponentially during the last decade, particularly with regards to issues of fluid-formation compatibility. Operators could find the sheer number of noteworthy scientific publications to be an obstacle to exercising extra due-care and attention in the permitting of their disposal projects in Athabasca. In light of this situation, the Alberta Geological Survey commissioned this review to assist the oil-sands industry in accessing the relevant scientific literature in an efficient and timely manner.

The substance of this review purposely reached to the very limits of modern research into rock-water interactions in the disposal-well context. A particular emphasis was placed on publications discussing fluid-formation interaction in carbonate-evaporite sequences. This was because such rocks form the deepest and most isolated disposal zones in much of Athabasca Oil Sands Area. But for the same reasons of time and efficiency cited above, this review did not explore the scientific literature related to karsting, waste disposal in salt-caverns, nuclear waste disposal, or carbon-dioxide sequestration in geologic media. However, all of these fields have continue to produce new insights into fluid-rock interaction that may be pertinent to deepwell disposal in Athabasca. The hydraulics of well injection or flow of injected liquids away from a disposal well were not reviewed for the same reasons.

The scope of this literature review is not meant to imply or suggest that disposal-well operators or their agents have an onus to explore any or all of the issues raised in this literature review as they might relate to their particular project. Rather, this review is being put into the public domain for information only, without comment or direction pertinent to regulatory or administrative activities of the EUB or any other government agency in the Province of Alberta.

This review has benefited from the comments of Dr. E.H. Perkins of the Alberta Research Council.

2 Scope of Work

This report is a guide to selected publications in the scientific literature on inorganic water-rock chemical interactions that might affect the disposal of oilfield wastewater in deep carbonate-evaporite formations. Searches were restricted to literature published since the Alberta Research Council evaluation of waste-water disposal in the Cold Lake Area. (Bachu et al., 1989). The intent is to identify research that provides new data and/or models for interpreting and predicting long-term water-rock interactions in carbonate-evaporite aquifers.

In addition to papers on waste-water injection, recent contributions in petroleum engineering, groundwater geochemistry and studies of diagenesis were examined for expositions of relevant chemical processes, quantitative models and computational methods. The behaviour of complex reacting systems is often non-linear, hence theoretical work on non-linear systems was also examined. The primary literature on determination of specific thermodynamic and kinetic data is voluminous and requires careful evaluation, hence such work was not reviewed in detail. Most of this primary work is cited and evaluated in the textbooks and papers mentioned below.

3 Applicability of this Review to the Athabasca Oil Sands Area, Alberta

The utility of the cited research in the prediction of long-term water-rock interactions in the Athabasca Oil Sands Area depends on aquifer mineralogy, formation-water composition, waste-water composition, rate of injection, regional geology and hydrogeology. There are numerous sources of these data in the public domain. Alberta-specific aquifer-mineralogy data can be found in numerous scientific papers and graduate theses or can be generated directly from core examination. The Alberta Energy and Utilities Board (EUB) maintains and curates an extensive collection of core at its Core Research Centre in Calgary, Alberta. Water chemistries are similarly available from the EUB or from various private companies who provide the same data in a digital or value-added form. Waste-water compositions and rates of injection are project specific, but some of this information can be garnered from project application reports and Environmental Impact Assessments on the public record, available through the EUB and/or Alberta Environment. Completion details of injection wells are of public record and available through the EUB.

4 Textbooks

A number of advanced textbooks on water-rock interaction have been published in the last decade. These contain the essential theoretical background for understanding the papers cited below and for computing predictive models in water-rock systems. They are listed below for quick reference.

- Phillips (1991): Flow and Reactions in Permeable Rocks.
- Anderson and Crerar (1993): Thermodynamics in Geochemistry. The Equilibrium Model.
- Nordstrom and Munoz (1994): Geochemical Thermodynamics (Second Edition).
- Ortoleva (1994): Geochemical Self-Organization.
- Bethke (1996): Geochemical Reaction Modeling.
- Lichtner et al. (1996): Reactive Transport in Porous Media.
- Boudreau (1996): Diagenetic Models and Their Implementation.

- Giles (1997): Diagenesis: A Quantitative Perspective.
- Lasaga (1998): Kinetic Theory in the Earth Sciences.

In addition, Lake et al. (2002) recently published Geochemistry and Fluid Flow. However, this book was not available to the authors at the time of this review.

5 Wastewater Injection - Case Studies and Reviews

Bachu et al. (1989) examined the regional and local effects of deep waste-water injection in the Cold Lake area of Alberta. They reviewed the data requirements, outlined potential mineral dissolution and precipitation reactions, and performed a series of calculations to evaluate the geochemical effects of waste injection. For the formation mineralogy and water compositions available to them, they determined that the most important geochemical phenomena to be expected were the dissolution/precipitation of calcite and quartz. Their geochemical analysis was combined with calculations of rock strength and numerical simulations to provide order-of-magnitude estimates of the effects of injection. They also used mass-balance calculations to estimate the impact of precipitation/dissolution on disposal aquifers.

While the Bachu et al. study is based on equilibrium thermodynamic analysis, papers by Gunter et al. (1997, 2000) emphasize long-term kinetic effects to evaluate the aquifer disposal of acid gases. These papers contain critical evaluations of published kinetic models and rate constants. Important conclusions are that carbonate minerals will probably reach equilibrium with injected water within 10 to 40 years and that reactions of carbonates with H_2SO_4 and H_2S can cause build up of CO_2 pressure with the possibility of fracturing the aquifer. Kopperson et al. (1998) also discusses acid-gas injection with water.

An important case study by Rosenbauer et al. (1997) gives the results from experiments and computed equilibrium behaviour of brine when injected into carbonate rocks. The solubility of anhydrite decreases with increasing temperature. This was shown to be sufficient to cause precipitation of large amounts of anhydrite at the proposed injection site. The comparison of output of computer codes SOLMINEQ and PHRQPITZ with experimental results illustrates the care that must be taken when interpreting the results of predictive calculations.

Spongberg's (1994) thesis on the feasibility of deep-well injection for brine disposal includes a review of relevant chemical processes described in the petroleum engineering literature but does not provide quantitative models.

Crother and Totten (1995) have published an abstract on the geochemical consequences of deep disposal of toxic waste, but their detailed results have not yet appeared in journals.

Apps and Tsang (1996) compiled a series of papers on deep-well injection of wastes. They include groups of papers on waste interactions as well as other aspects of deep-well injection practice and engineering.

At the time of this review, The U.S. National Groundwater Protection Council maintained a website at www.gwpc.org which contained an injection-well bibliography plus links to other related sites.

6 Petroleum engineering studies

There is a large, established petroleum-engineering literature on the chemical aspects of water injection. These studies provide data and models for short time-scale water-rock processes and are supported by direct observation and experimental results. Many of the studies are focused on the evaluation of a particular polymer, an inhibitor, or an acidization treatment and lack detailed petrographic study or geochemical modeling. Nevertheless, they can be good sources of insight and should not be overlooked. Examples of such papers outside of the realm of direct study of injection or disposal include Coulter and Jennings (1997) and Li et al. (1998).

Older references generally provide qualitative descriptions of phenomena. Important processes are:

- Mineral precipitation (scaling) due to mixing of injected and aquifer water and/or temperature and pressure changes;
- Enhancement of permeability due to mineral dissolution;
- Mechanical destruction of permeability due to migration of fines released by mineral dissolution or clay-mineral disaggregation;
- Destruction of permeability due to clay-mineral swelling.

More recent workers have developed quantitative models of the same phenomena. Various groups have obtained a large body of experimental data to calibrate such models. The experimental studies are not referenced here, but are cited in the following selected papers, which present new equilibrium and kinetic models and derived model parameters.

Bertero et al. (1988) show the applicability of equilibrium calculations to prediction of scale formation using the EQ3/6 geochemical program.
Granbakken et al. (1991) describe a kinetic model for scale formation and provide rate constants for precipitation and dissolution of common scale minerals.

Paige and Murray (1994) discuss general experience of produced-water injection projects in oilfields.

Chang and Civan (1997) provide an empirical model for chemically induced formation damage resulting from fines migration, clay swelling and chemical dissolution and precipitation. Using the published model equations and a finite difference code, they derive precipitation rate constants, solid deposition and entrainment coefficients, cation-exchange coefficients and pore-throat plugging coefficients by fitting computed model output with laboratory core plug tests.

Atkinson and Mecik (1997) discuss the thermodynamics and effects of temperature, pressure and non-ideal solutions on the solubility of gypsum ($CaSO_4 \bullet 2H_2O$), anhydrite ($CaSO_4$), barite ($BaSO_4$), celestine ($SrSO_4$) and calcite ($CaCO_3$). They derive heat capacity constants for the solid phases, volume changes for the solubility reactions and Pitzer coefficients for the activities of the ionic species.

Raines and Dewers (1997a) examine models of gypsum and calcite precipitation and dissolution when both surface reaction rates and hydrodynamic conditions influence kinetics.

Araque-Martinez and Lake (1999) describe a new approach to modeling equilibrium and kinetics of precipitation/dissolution reactions and their effect on well impairment.

Civan (2000) presents improved models for the interpretation and prediction of porosity and permeability in rocks in which the pore topology is evolving by geochemical and geomechanical water-rock interactions.

Also of interest is the paper by Thomas et al. (1995) which describes the use of an expert system along with the standard geochemical codes PHREEQE, PHRQPITZ and SOLMINEQ to predict potential formation damage due to chemical and mechanical processes resulting from water injection. Details of the data and algorithms used are not provided.

Bunney et al. (1996) have published an abstract on the assessment of chemical disequilibrium in oil reservoirs and implications for diagenetic modeling, but these results have not yet appeared in journals.

7 Groundwater Studies

Although the temperatures and pressures are lower than would be found in deep wells, geochemical studies of groundwater systems can provide estimates of slow reaction rates of natural processes. These studies are supported by direct observation of water chemistry and interpretations based on the output of established computer codes.

An important process recognized in these studies in carbonate rock is dedolomitization. One mechanism involves dissolution of anhydrite or gypsum, enriching the brine in Ca ions to the point of calcite saturation. As calcite precipitates, the required CO_2 is generated by dissolution of dolomite. The net result is a large increase in pore volume. This process is one of several invoked to explain the formation of karst terrains with obvious implications for water injection in anhydrite and dolomite bearing formations.

The classic study by Plummer et al. (1990) describes the results of a modeling study to determine geochemical reactions controlling groundwater chemistry in a well-studied limestone aquifer. In addition to dedolomitization, halite dissolution and sulfate reduction are found to be important. Estimates of rates of dissolution and precipitation are obtained. In a deep aquifer, dissolution processes could affect aquifer integrity, while the sulfate reduction could lead to the generation of H_2S.

Raines and Dewers (1997b) give the results of experimental and in situ dissolution of gypsum. These results and computer simulations suggest that reactive solutions can penetrate much further into gypsum-karst conduits than previously thought possible.

Ayora et al. (1998) discuss a reactive transport model of dedolomitization in which the main processes are calcite precipitation and dolomite dissolution in brines arbitrarily enriched in Ca and SO_4. Their model gives estimates of reaction rates and explains observed mineral textures.

Hill (1995) uses data on sulfur isotopes to postulate a complex series of processes for karst formation. Initially, hydrocarbons react with sulfate ions from evaporite minerals to produce H_2S. After migration, the H_2S reacts with oxygenated water to produce sulfuric acid. This in turn dissolves carbonates to form major caverns.

Other important processes recognized in groundwater systems are carbonate dissolution or precipitation resulting from mixing of different waters, even when the original waters are in equilibrium with the mineral phase. This phenomenon is due to the non-linear relationship between activities and concentrations of ionic species in natural waters. This means that two waters, initially in equilibrium with a particular mineral, may become either undersaturated or oversaturated when they mix. Giles (1997, Chapter 7) summarizes and reviews work on this phenomenon.

8 Diagenesis Studies

Diagenesis is the geological term for the processes that change sediment to consolidated sedimentary rock after burial. Diagenetic studies are based on detailed study of rock mineralogy, fabric, cementation, porosity, and formation-water chemistry. Though diagenesis generally takes place on geologic time-scales, study of diagenetic processes offers much insight to fluid-formation compatiblity in deep-well disposal projects.

Giles' (1997) text is a comprehensive review of quantitative methods of analyzing diagenetic processes. Of particular relevance to waste-water injection are the examples of use of modern hydrochemical studies, illustration of the use of simple mass balance models, explanations of equilibrium thermodynamic modeling, chemical kinetic modeling, fluid flow and reactive-transport computations. It has an extensive reference list of papers published up until 1994.

The review papers by James and Choquette (1990), Choquette and James (1990), Hiatt and Kyser (2000) and Hutcheon (2000) on diagenesis of limestones list a number of burial diagenetic processes in carbonate rocks. They include:

- Dolomitization of limestone;
- Cementation of limestone by carbonate and/or sulfate cements;
- Replacement of dolomite by calcite, or "dedolomitization";
- Reduction of sulfate (anhydrite) by thermal processes at temperatures greater than 140° C.

This can result in precipitation of metal sulfides and/or production of H_2S. Additional diagenetic processes are the generation of CO_2 from clay-carbonate reactions and biogenic sulfate reduction to produce H_2S.

Dolomitization can enhance or reduce permeability, depending on the process leading to dolomitization. Sibley et al. (1994) review previous work and discuss the kinetics of the reaction in experiments and natural settings. They obtain interesting conclusions on the mechanism of dolomitization and provide a compilation of rate constants. In a major paper, Arvidson and Mackenzie (1999) review the literature and present the results of a series of experiments on the kinetics of dolomite precipitation. Their work confirms a strong temperature dependence for the precipitation reaction and a moderate dependency on saturation index.

Huang and Longo (1994) conclude that silicate-carbonate reactions can be an important inorganic source of CO_2 and lead to secondary porosity. They claim the reactions are sufficiently suppressed in closed systems that they cannot contribute to overpressure formation or generate enough pressure to cause fractures. On the other hand, Desrocher and Hutcheon (1998) conclude

> "that the majority of reaction mechanisms are capable, perhaps in combination with other mechanisms, of generating overpressure in the presence of realistic combinations and amounts of clay and carbonate minerals".

Simpson (1999) studied fluid chemistry in the Devonian Leduc and Nisku Formations in southern Alberta. This study contains a thorough review of processes generating H_2S: maturation of organic compounds, bacterial sulfate reduction (BSR) and thermal sulfate reduction (TSR). Only the latter two are thought to produce significant quantities of H_2S. Bacterial sulfate reduction in the subsurface appears to operate only up to temperatures of 40-50 °C, while thermal sulfate reduction is effective at higher temperatures. The kinetics of BSR reactions are reviewed in Eden et al. (1994), while Simpson's thesis summarizes the experimental and theoretical work on TSR.

9 Computer Codes for Path Modeling

Computer codes offer the means to simulate and experiment with fluid-fluid and fluid-formation compatibility issues. These codes include equilibrium as well as kinetic modeling, and offer the sophisticated user insight into rates of reaction as well as reaction-pathway analysis. Reaction-pathway analysis is important because there may be a multitude of possible reactions that a fluid-fluid or fluid-formation system can experience. Reaction-path models can identify the most likely pathways based on the physical chemistry and thermodynamic properties of the system under study. The most sophisticated codes link reaction to flow processes. As in any computer simulation, the quality of the output is proportional to the quality of the input parameters and the skill of the user.

Perkins et al. (1997) and Mäder et al. (1998) have recently published reviews of various computer codes for modeling water-rock interactions. Development of such codes and associated databases is an active area of research. To be useful in waste-water injection calculations, such codes must be capable of handling reactions in concentrated brines at high temperatures and pressures.

For prediction of the long-term behaviour of subsurface brines, programs that use kinetic models are essential. Three of the most popular and commercially available packages are:

- EQ3NR/EQ6 (Wolery, 1992a, 1992b, Wolery and Daveler, 1992, Daveler and Wolery, 1992) are a package of codes for solving speciation-solubility and reaction-path problems. Rate laws for irreversible reactions may be either relative rates or actual rates.
- The Geochemist's Workbench (Bethke, 2000) solves many of the same problems as EQ3NR/EQ6 and uses the same activity models and databases. It has a "user-friendly" interface and graphic output.
- GAMSPATH (Talman et al., 2000) (currently in a beta version) is similar to the code used by Gunter et al. (2000) to evaluate aquifer disposal of acid gases.

Reactive transport codes add spatial coordinates to the pathway models. Although they are not commercially available, two of the codes widely used in the academic community are OS3D/GIMRT (Steefel and Yabusaki, 1996) and MPATH (Lichtner, 1992):

- OS3D/GIMRT is a package containing two codes that use different numerical schemes to simulate multi-component reactive transfer. All mineral precipitation and dissolution reactions are governed by a kinetic formulation. The thermodynamic database is based on EQ3/6. No hydrodynamic flow calculation is done, so the user must supply a velocity field.
- MPATH models a space-time continuum with multi-component chemical reactions using several different forms of kinetic rate laws. As with OS3D/GIMRT, the user must supply a velocity field.

Several research groups are actively developing simulators that include both hydrodynamic modeling and reactive transport capabilities. Such capability is necessary to model density driven plumes and convection cells. Liu and Ortoleva (1996a, 1996b) describe CIRF.A, a fully coupled multiphase flow, contaminant transport and fluid and mineral reaction model. The code can simulate "chemical reactions involving rock, wastes and formation fluids and their effects on contaminant transport, rock permeability and porosity and the integrity of the reservoir confining units". They have used the code to make 10,000-year predictions of the fate of waste fluids in a carbonate reservoir.

Le Gallo et al. (1997) have developed DIAPHORE to simulate water-rock interactions at a reservoir scale and times up to a few million years. The code includes the effect of chemical reaction on mineral surface areas and permeabilities.

10 Nonlinear Phenomena and Instabilities

Models of energy and mass transfer in multi-component, multi-phase systems are almost always nonlinear. Nonlinear phenomena are of particular, albeit still academic, interest in formation-fluid compatibility in deep-well disposal because they can result in local changes to porosity and permeability. Local changes can lead to fingering or self-focused flow in parts of the aquifer away from the well bore, thereby altering the dynamics of the physical and chemical system in unpredictable ways.

Studies of nonlinear phenomena in the literature concentrate mostly on the expression of nonlinear behaviour in the governing equations of physical and chemical systems. A number of mathematical phenomena that occur in the solutions of such equations have counterparts in the real world systems. The interaction of numerical error, mathematical instabilities and genuine nonlinear phenomena are difficult to disentangle in realistic mathematical models of natural systems. Nonetheless, it is important to be aware of these phenomena when interpreting predictive calculations. All the model developers who work on reaction-path modeling (discussed above) and reactive chemical transport codes are aware of these issues.

Density inhomogeneities due to thermal or chemical processes are known to cause instabilities in flow patterns, resulting in plumes and/or convection cells (Phillips, 1991, Chapter 5). Phillips outlines mathematical methods for testing the possibility of such phenomena.

For many years, chemical engineers have been aware of the non-uniqueness of solutions of the chemical equilibrium problem as well as instabilities and multiple solutions for the equations describing chemical reactors (e.g. Denbigh and Turner, 1984). These phenomena are also known in actual engineering practice, hence such studies are part of ongoing chemical engineering research (e.g. Bildea et al., 2001) Some reactor designs (packed bed, tubular, etc.) are described by similar equations to those used in geochemical modeling. To the extent that geochemical models can be formulated as a set of nonlinear equations, they should be tested for uniqueness and stability of solutions.

Bethke (1992) discusses the nonlinearity of the equations describing the equilibrium distribution of species in aqueous systems and the possible existence of multiple solutions to such problems. He states that most modeling software will find only a single root, so it is imperative that the modeler pay careful attention to the construction and verification of computed solutions.

In addition to multiple solutions to equilibrium or steady-state problems, nonlinearity may result in a number of phenomena in dynamic systems (Nicolis, 1995, Epstein and Pojman, 1998). These include the well-known unpredictability of chaotic systems as well as the spontaneous appearance of various temporal and spatial patterns (self-organization). The implications of such behaviour for waste-water injection are that predictive models may not behave predictably and that self-organizing patterns may result in unforeseen spatial inhomogeneity of the water-rock system, possibly leading to spatial localization of dissolution/precipitation reactions.

Ortoleva's (1994) monograph reviews the mathematics of pattern formation due to the nonlinear behaviour of geochemical systems. His analysis of flow-driven reaction fronts involving precipitation and/or dissolution shows how multiple fronts, trapping fronts, and reverse fronts can be generated. Dissipative structures can develop at these fronts, resulting in compositional waves and oscillations, fingering, "worm-holes" and self-focusing flows. Other phenomena he considers include unstable coarsening fronts and precipitate patterning. Of particular interest is his analysis of basin-scale reaction driven advection phenomena (his Chapter 14). The direct applicability of these models to waste-injection problems is difficult to assess. Most of the models serve to provide explanations of observed phenomena rather than predict future behaviour of natural systems.

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