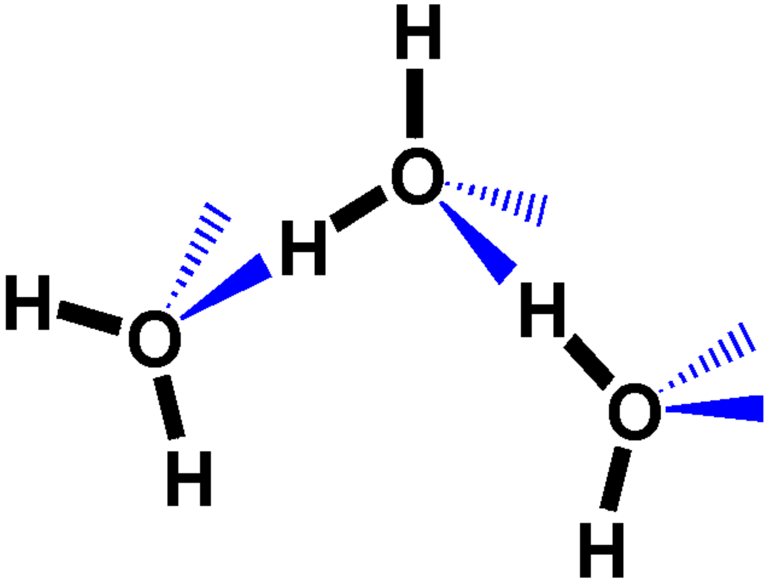
EUB/AGS Geo-Note 2002-02

# Geochemical and Isotope Data for Formation Water from Selected Wells, Cretaceous to Quaternary Succession, Athabasca Oil Sands (In Situ) Area, Alberta



Alberta Energy and Utilities Board
Alberta Geological Survey

# Geochemical and Isotope Data for Formation Water from Selected Wells, Cretaceous to Quaternary Succession, Athabasca Oil Sands (In Situ) Area, Alberta

T.G. Lemay
Alberta Geological Survey

December 2002

©Her Majesty the Queen in Right of Alberta, 2002

The Alberta Energy and Utilities Board/Alberta Geological Survey (EUB/AGS) and its employees and contractors make no warranty, guarantee or representation, express or implied, or assume any legal liability regarding the correctness, accuracy, completeness, or reliability of this publication. Any digital data and software supplied with this publication are subject to the licence conditions (specified in 'Licence Agreement for Digital Products'). The data are supplied on the understanding that they are for the sole use of the licensee and will not be redistributed in any form, in whole or in part, to third parties. Any references to proprietary software in the documentation, and/or any use of proprietary data formats in this release, do not constitute endorsement by the EUB/AGS of any manufacturer's product.

**If this product is an EUB/AGS Special Report, the information is provided as received from the author and has not been edited for conformity to EUB/AGS standards.**

When using information from this publication in other publications or presentations, due acknowledgment should be given to the EUB/AGS. The following reference format is recommended: Lemay, T.G. (2002): Geochemical and isotope data for formation water from selected wells, Cretaceous to Quaternary succession, Athabasca Oil Sands (in situ) Area, Alberta; Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2002-02.

Published September 2002 by:
Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 - 98th Avenue
Edmonton, Alberta
T6B 2X3

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918

Web site: www.ags.gov.ab.ca

## Contents

### Tables

### Figures

## Acknowledgments

This project was funded jointly by the Government of Alberta through the Energy and Utilities Board and by the Government of Canada through the Ministry of Western Economic Diversification under the Western Economic Partnership Agreement.

Norwest Labs performed the standard laboratory water-analyses. The stable isotope values for $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S$ and $\delta^{13}C$ were determined by the Isotope Science Laboratory at the University of Calgary, headed by Steve Taylor. Dr. M. Wieser at the University of Calgary determined the stable isotope values of $\delta^{11}B$. The Isotope Laboratory at the University of Saskatchewan, headed by Dr. Chris Holmden, determined the $^{87}Sr/^{86}Sr$ values. The neutron atomic adsorption analyses for chloride, bromide and iodide were performed by Dr. John Duke at the SLOWPOKE Nuclear Reactor Facility at the University of Alberta. The data used to construct the Approximate Edmonton Meteoric Water Line were gathered from the Global Network for Isotopes in Precipitation database. The University of Copenhagen, Copenhagen, Denmark, performed the $\delta^{18}O$ and $\delta^{2}H$ analyses used to construct the Edmonton meteoric water line.

# Abstract

Sampling of selected wells from Quaternary drift aquifers, Quaternary-Tertiary buried channel aquifers and Lower Cretaceous aquifers, in the Athabasca Oil Sands (in situ) Area, was conducted between the summer of 1999 and the spring of 2001. The purpose of the sampling program was to obtain high-quality water samples that could be used to better define baseline groundwater chemistry in these various geological units.

For each of the 44 samples collected, field determinations of pH, oxidation-reduction potential, temperature, conductivity, dissolved oxygen and total alkalinity were determined. Samples were collected by the Alberta Geological Survey and analyzed by various laboratories for concentrations of major, minor and trace elements and radionuclides. The samples were also analyzed in the laboratory in order to determine $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, $\delta^{34}S_{SO4}$, $\delta^{34}S_{S}$, $\delta^{11}B$ and $^{87}Sr/^{86}Sr$ values.

The objective of this Geo-Note is to make the hydrogeochemical data collected available to government, industry and the general public. Preliminary interpretation of the data are offered as well, focusing on major ion chemistry, total dissolved solids, chloride/bromide mass ratios, and the isotope systematics of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, $\delta^{11}B$ and $^{87}Sr/^{86}Sr$.

Preliminary interpretation indicates that water in the Quaternary drift aquifers, Quaternary-Tertiary buried channel aquifers and Lower Cretaceous aquifers in the Athabasca Oil Sands (in situ) Area have a $\delta^{18}O$, $\delta^{2}H$ meteoric water signature and have undergone water rock interactions, including carbonate dissolution and ion exchange. Those water samples collected from wells completed at greater depths within the Lower Cretaceous formations maintain similarities to seawater, but do not have the same major ion concentrations as seawater, indicating that the water has undergone mixing with fresher water, presumably meteoric, resulting in dilution. The results of $\delta^{13}C_{DIC}$ analyses from the Lower Cretaceous formations aquifers indicate the possibility of microbiological processes occurring within this aquifer system.

# 1 Introduction

Between 1999 and 2001, the Alberta Geological Survey conducted a groundwater-sampling program in the Athabasca Oil Sands (in situ) Area of northeastern Alberta. The purpose was to document baseline groundwater conditions in advance of oil-sands development in the area. This project was funded jointly by the Government of Alberta, through the Energy and Utilities Board, and by the Government of Canada, through the Ministry of Western Economic Diversification, under the Western Economic Partnership Agreement. This Geo-Note is one in a series of Geo-Notes, detailing the results of the project work completed.

Twenty-one water samples were collected from Quaternary drift aquifers, three from Quaternary-Tertiary buried channel aquifers and 18 from Lower Cretaceous aquifers, including the Viking Formation, Colony Member, Grand Rapids Formation, Clearwater Formation, Wabiskaw Member and McMurray Formation. The stratigraphic relationships between these various units are presented in Figure 1. The wells were selected on the basis of 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 by various laboratories to determine concentrations of total dissolved solids (TDS), major, minor and trace elements, radionuclides, including U, Ra, Th and Pb, chloride, bromide and iodide, as well as $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{11}B$, $\delta^{34}S_{sulphide}$, $\delta^{34}S_{sulphate}$ 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 Lemay (2002a, 2002b). Tables 1 and 2 cross-reference sampling methods and sample-analyte type to the appropriate section in the sampling and sample-processing protocols documents.

In addition to the 44 water samples collected as part of this study, historical data were also incorporated into the data set. Data from 11 water samples previously collected from Quaternary drift aquifers and three previously collected water samples from wells completed in the McMurray Formation were added to the data set. The well-completion history and quality, verification of completion interval and geochemical criteria were used to determine the quality of these additional data. These data are considered less reliable than those collected as part of this study, primarily because the collection protocols for them are unknown. These are referred to as sample numbers 1, 22 to 31 and either 54 to 57 (for standard chemistry) or 54, 55 and 57 (for isotope chemistry) in Appendices A, B, C and D.

# 2 Study Area

The study area is located in the northeastern portion of Alberta, bounded on the west by the Athabasca River, to the north by the Athabasca and Clearwater rivers, to the east by the Alberta/Saskatchewan border and to the south by the Mostoos Upland (Figure 2). The study area extent (aside from the provincial boundary) was selected to represent natural hydraulic boundaries. The Athabasca and Clearwater rivers are natural drainage boundaries. The Mostoos upland was selected because it forms the hydraulic divide between the Cold Lake - Beaver River drainage basin to the south and the Athabasca River - Clearwater River drainage basin to the north. This area encompasses the southeast portion of the Energy and Utilities Board (EUB)-designated Athabasca Oil Sands Area. Some samples were collected just outside the study area when no suitable site was available inside the study area.

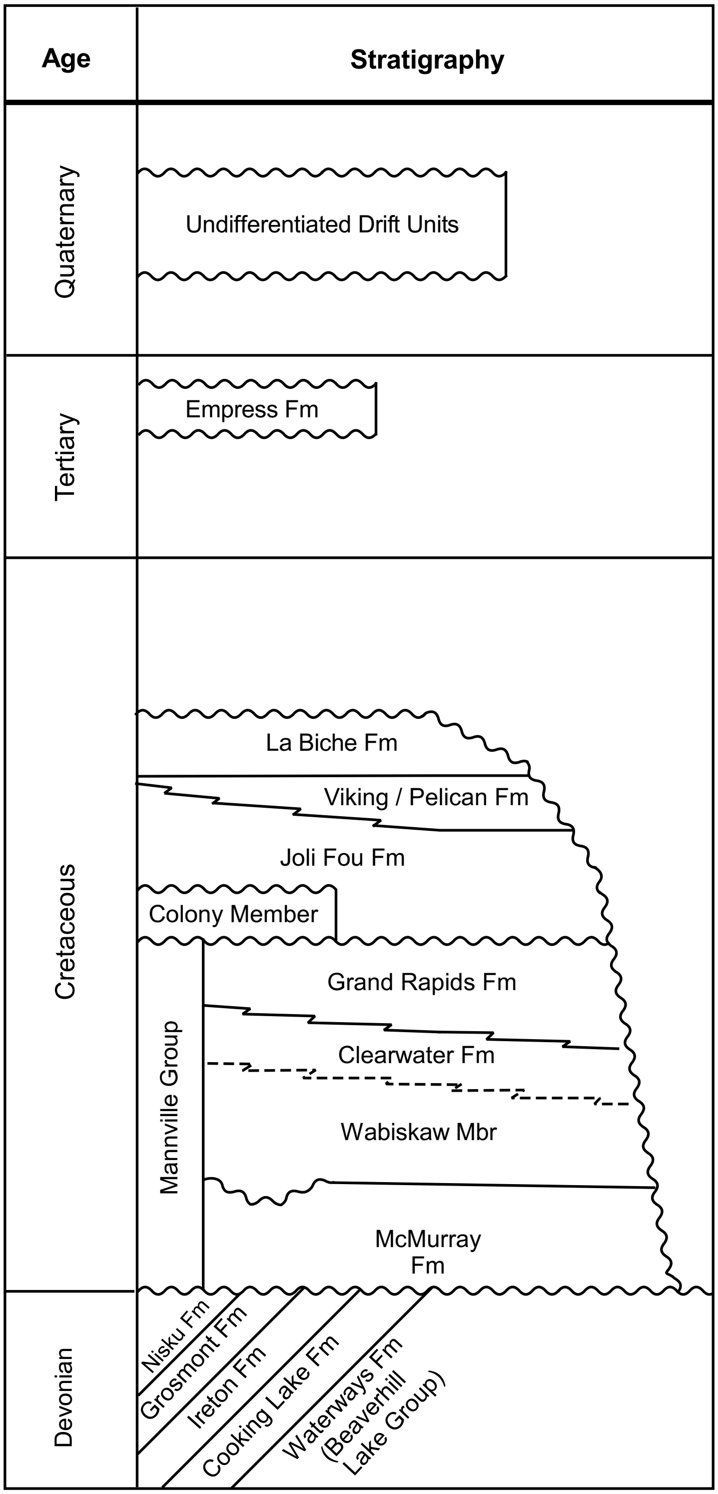


**Figure 1. Table of Quaternary to Devonian stratigraphic units in the Athabasca Oil Sands (in situ) Area, Alberta**

**Table 1. Sample type cross-referenced to the appropriate sampling protocols**

| Sample Type | Reference | Sections |
|---|---|---|
| Groundwater sample | Lemay (2002a) | 5, 7 and 8 |
| Formation water sample | Lemay (2002b) | 3 and 5 |

**Table 2. Analyte type cross-referenced to the appropriate sample processing protocols**

| Sample Type | Analyte | Reference | Section |
|---|---|---|---|
| Groundwater sample | Organic compounds | Lemay (2002a) | 8.2 |
| | Major, minor and trace elements | Lemay (2002a) | 8.3 |
| | Silica | Lemay (2002a) | 8.4 |
| | Anions (Cl, Br, I) | Lemay (2002a) | 8.5 |
| | Radiochemicals | Lemay (2002a) | 8.6 |
| | $^{18}O/^{16}O$ and $^{2}H/^{1}H$ | Lemay (2002a) | 8.7 |
| | $^{13}C/^{12}C$ | Lemay (2002a) | 8.8 |
| | $^{34}S/^{32}S$ in sulphide | Lemay (2002a) | 8.9 |
| | $^{34}S/^{32}S$ in sulphate | Lemay (2002a) | 8.10 |
| | $^{34}S/^{32}S$ in sulphide and sulphate | Lemay (2002a) | 8.11 |
| | $^{87}Sr/^{86}Sr$ | Lemay (2002a) | 8.12 |
| | $^{11}B/^{10}B$ | Lemay (2002a) | 8.13 |
| | $^{14}C$ | Lemay (2002a) | 8.14 |
| | | | |
| Formation water sample | Organic compounds | Lemay (2002b) | 5.2 |
| | Major, minor and trace elements | Lemay (2002b) | 5.3 |
| | Silica | Lemay (2002b) | 5.4 |
| | Anions (Cl, Br, I) | Lemay (2002b) | 5.5 |
| | Radiochemicals | Lemay (2002b) | 5.6 |
| | $^{18}O/^{16}O$ and $^{2}H/^{1}H$ | Lemay (2002b) | 5.7 |
| | $^{13}C/^{12}C$ | Lemay (2002b) | 5.8 |
| | $^{34}S/^{32}S$ in sulphide | Lemay (2002b) | 5.9 |
| | $^{34}S/^{32}S$ in sulphate | Lemay (2002b) | 5.10 |
| | $^{34}S/^{32}S$ in sulphide and sulphate | Lemay (2002b) | 5.11 |
| | $^{87}Sr/^{86}Sr$ | Lemay (2002b) | 5.12 |
| | $^{11}B/^{10}B$ | Lemay (2002b) | 5.13 |
| | $^{14}C$ | Lemay (2002b) | 5.14 |

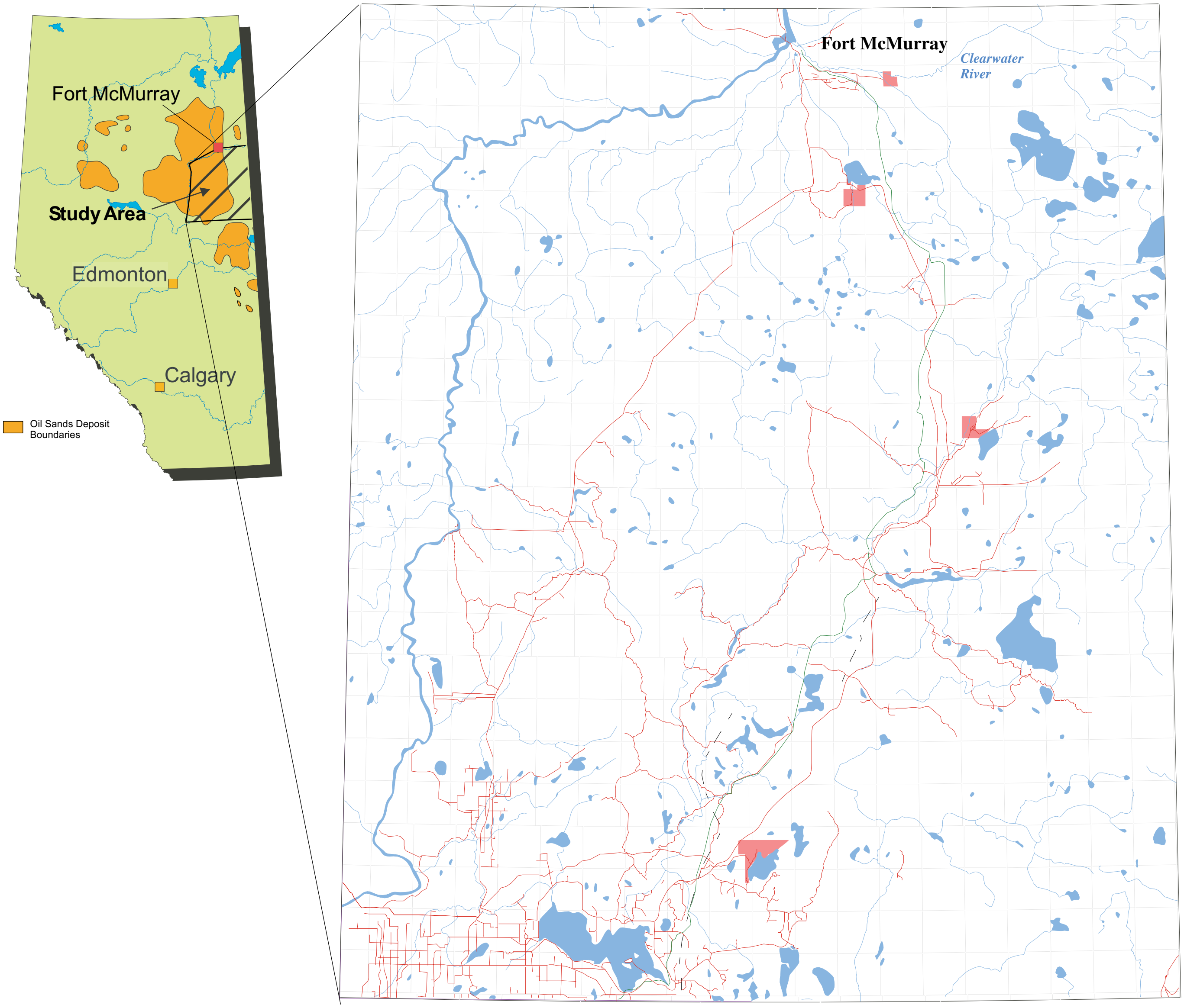


**Figure 2. Study area location map.**

# 3 Observations and Preliminary Interpretations

The data are presented by geological unit in Appendices A, B, C and D, Tables 3 through 10. Sample locations are plotted on Figures 3, 4, 5 and 6.

## 3.1 Groundwater Chemistry

### 3.1.1 Error, Accuracy and Precision

In an effort to ensure that error, accuracy and precision could be estimated and quantified, quality assurance/quality control (QA/QC) samples were collected during formation-water sampling activities. These QA/QC samples included standards, sample-split replicates, sample duplicates and blank samples. A rigorous analysis of error, accuracy and precision has not yet been completed and, therefore, no comments have been made regarding this topic. However, strict, careful and detailed protocols were followed during sampling activities, and preliminary examination of the data indicates that the care taken during sampling is reflected in a high quality data set. The QA/QC data are presented without comment in Appendix E, Tables 11 and 12.

### 3.1.2 Major Ion Chemistry

Observations

- Quaternary drift aquifers have Ca-Mg-$HCO_3$, mixed cation-$HCO_3$ and Na-$HCO_3$ water types (Figure 7a).
- Quaternary-Tertiary buried channel aquifers have mixed cation-$HCO_3$ or Na-$HCO_3$ water types (Figure 7b).
- Lower Cretaceous aquifers have mixed cation-$HCO_3$, Na-$HCO_3$, Na-Cl-$HCO_3$ and Na-Cl water types.
    - o Mixed cation-$HCO_3$ and Na-$HCO_3$ water types are present in the shallower wells (Figure 8a).
    - o Na-Cl-$HCO_3$ and Na-Cl water types are dominant in the deeper wells (Figure 8b).

Preliminary Interpretations - Quaternary Drift Aquifers

- Progression of water types in the Quaternary drift aquifers is typical of normal changes in groundwater chemistry along flow paths in glacial sediments (e.g., Freeze and Cherry, 1979, p. 285).
- Dominant reactions in the Quaternary drift aquifers appear to be carbonate dissolution and cation exchange (e.g., Macpherson and Townsend, 1998).
- Groundwater samples are similar to Type II and Type III water from glacial deposits as described in Freeze and Cherry (1979, p. 284) where:
    - o Type II water is slightly alkaline, has TDS < 1000 mg/L, with Ca and Mg being the dominant cations while $HCO_3$ is the dominant anion.
    - o Type III water is slightly alkaline, has TDS ˜ 1000 mg/L, in which Na, Mg and Ca are the dominant cations and $HCO_3$ and $SO_4$ are the dominant cations.

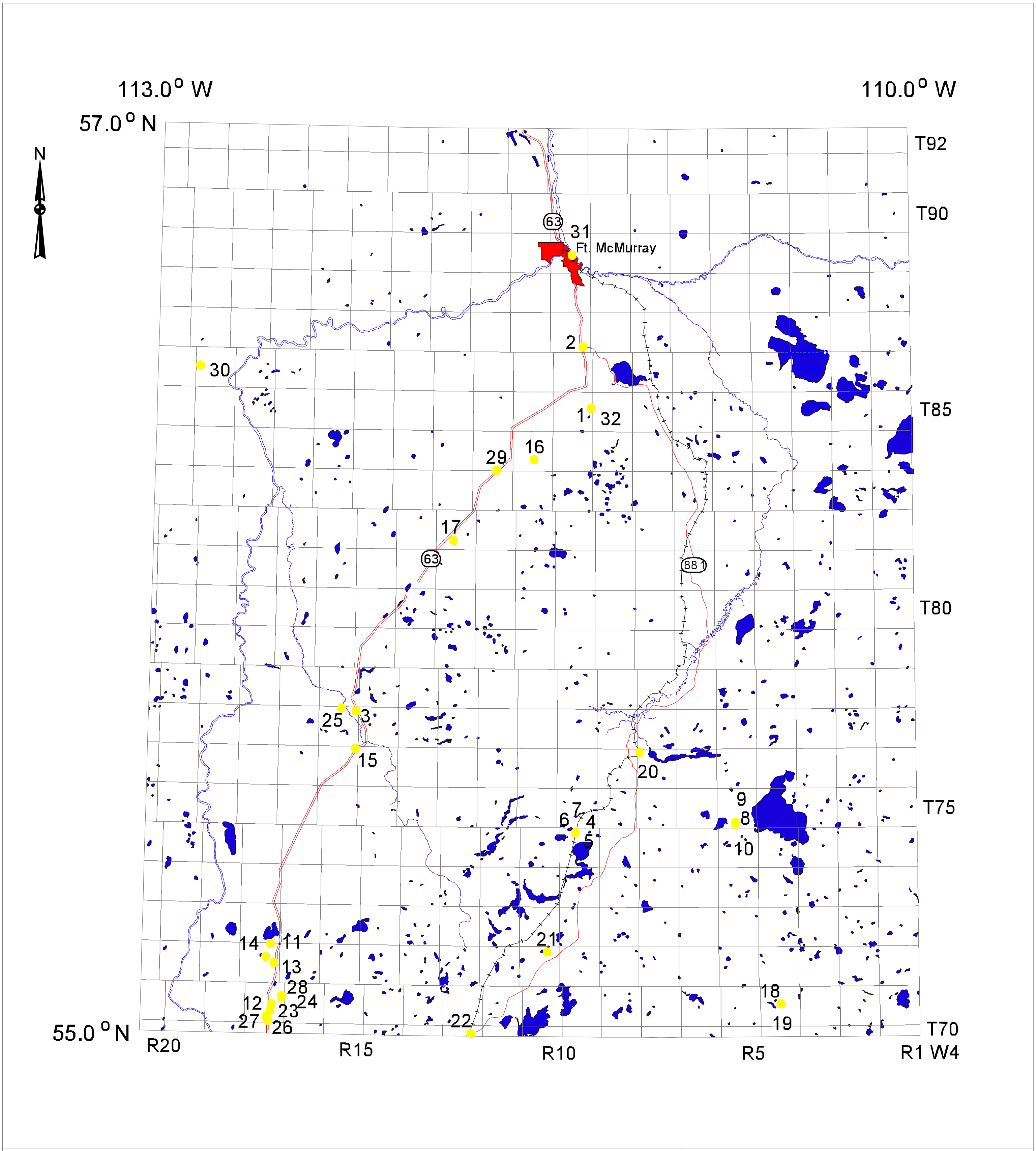


**Figure 3**
**Quaternary drift-aquifer water-sample locations**

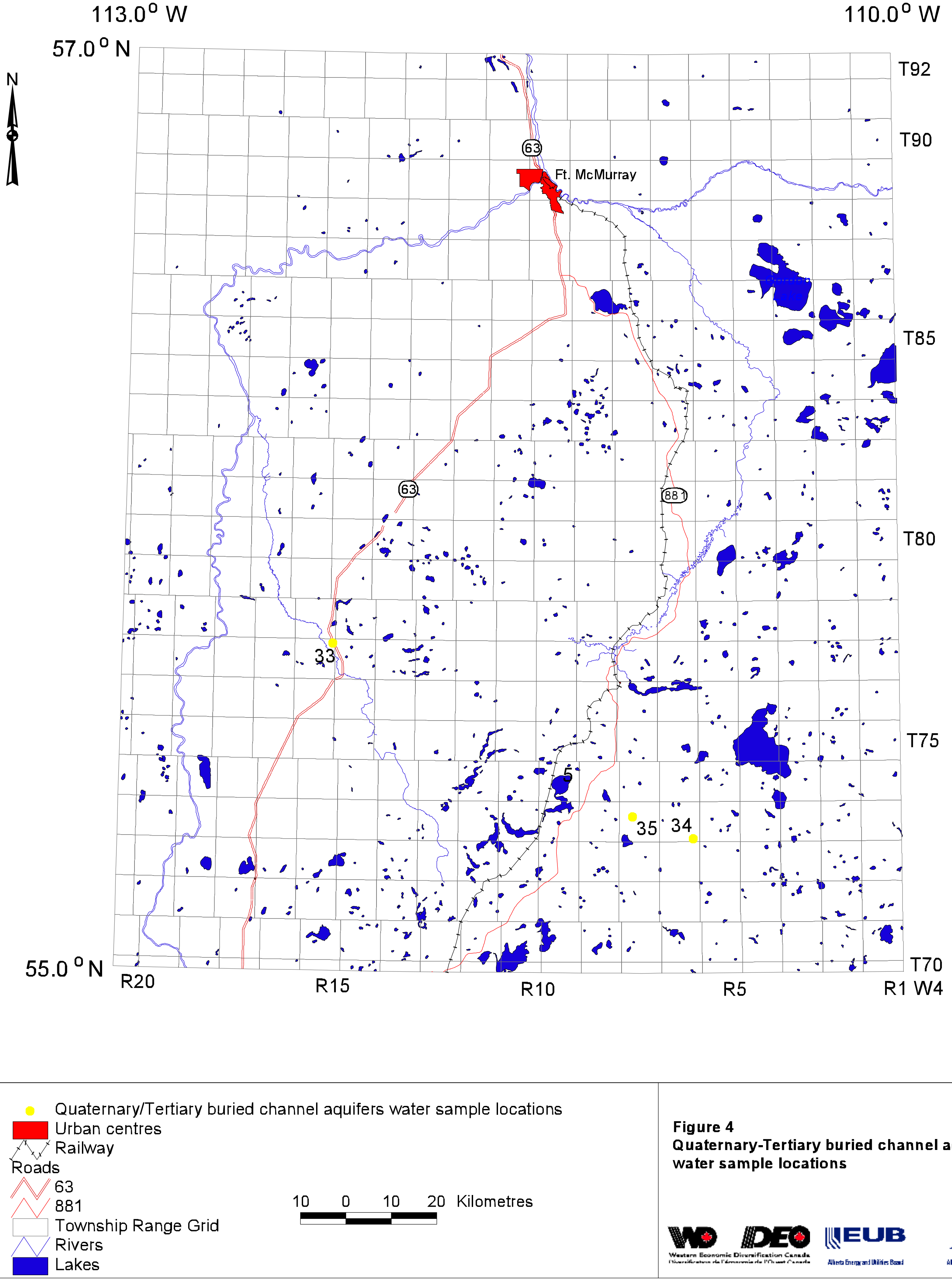


**Figure 4**
**Quaternary-Tertiary buried channel aquifer water sample locations**

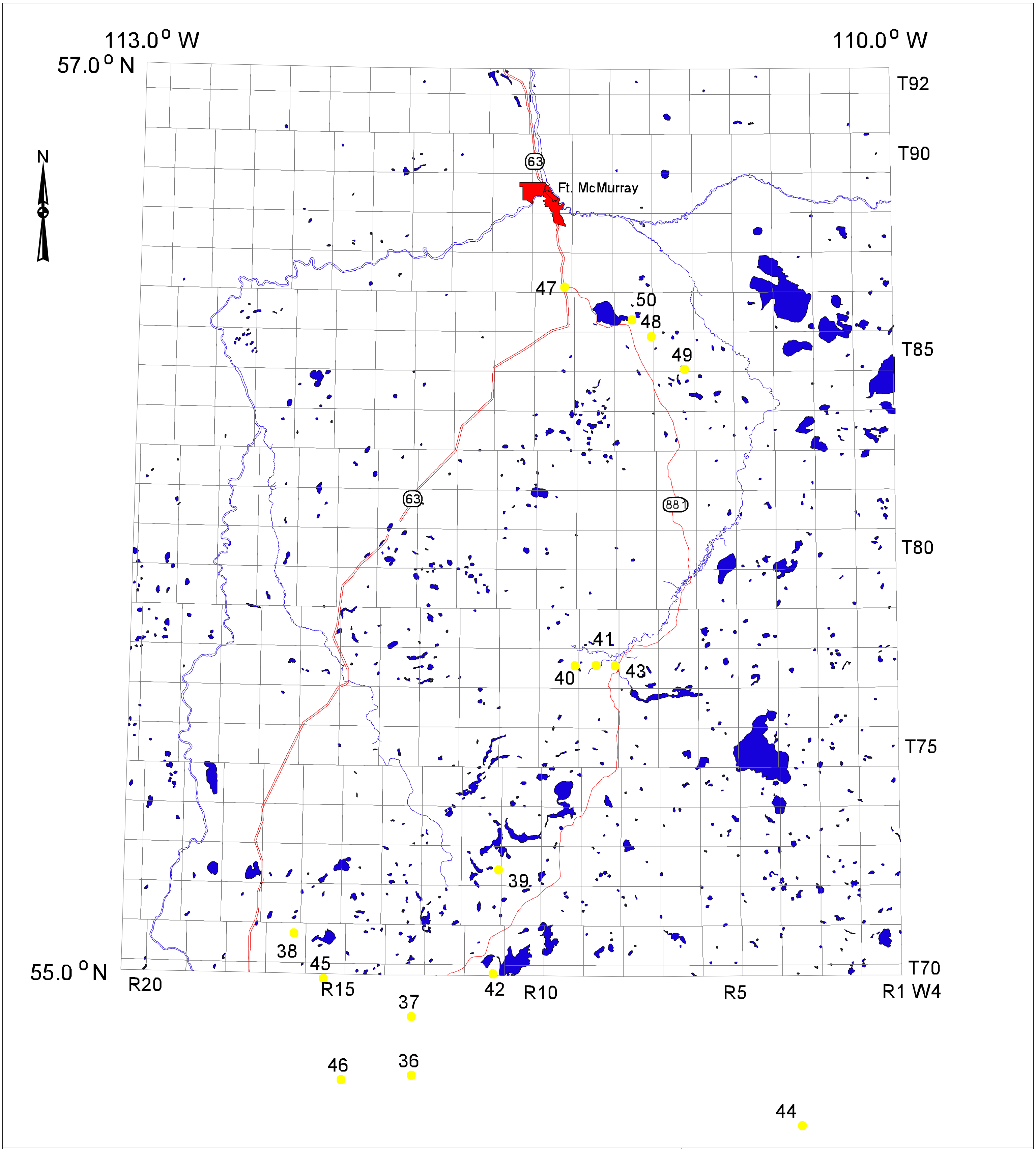


**Figure 5**
**Colony Member and Viking, Grand Rapids and Clearwater formations formation-water sample locations**

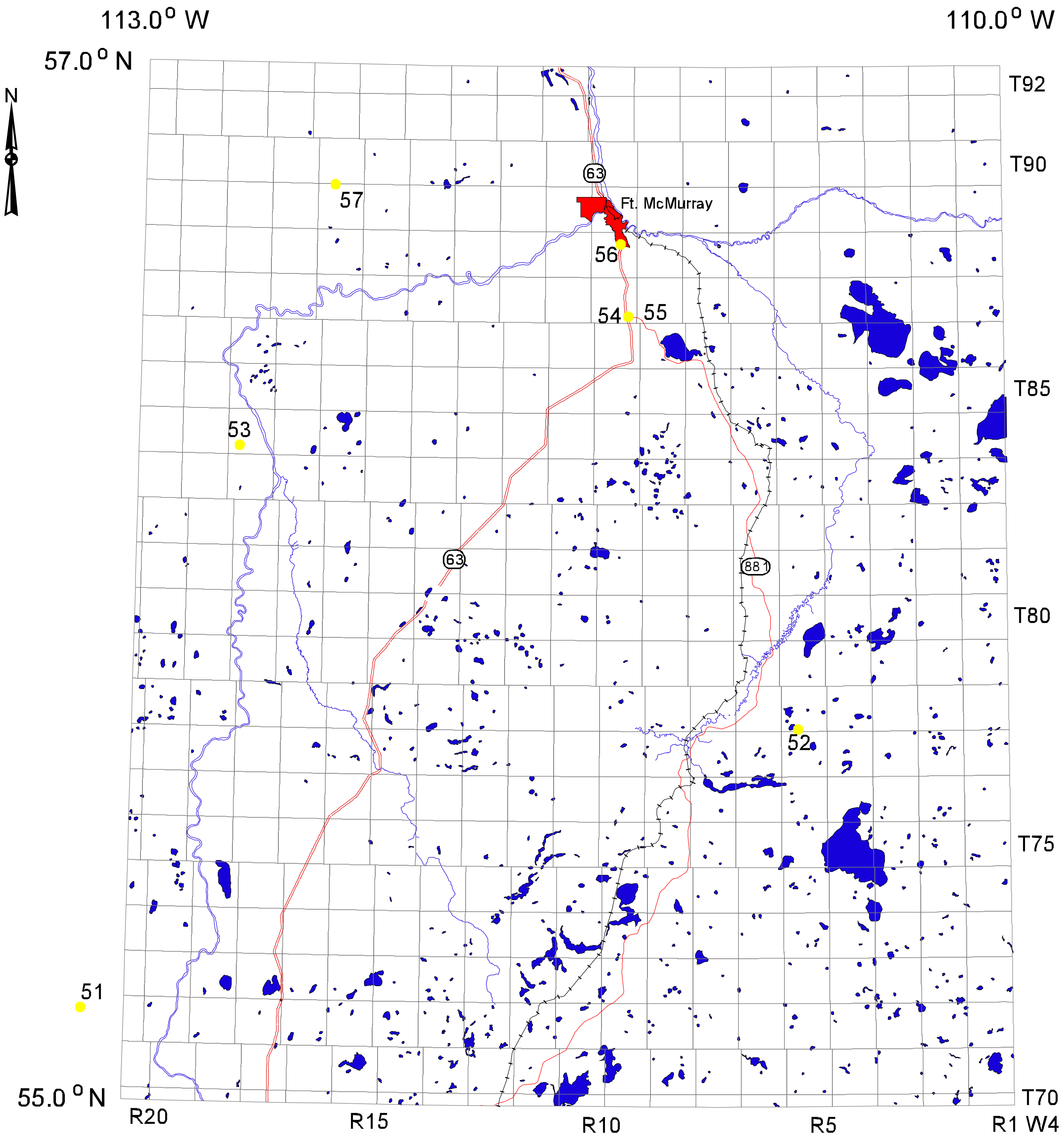


**Figure 6**
**Wabiskaw Member and McMurray Formation formation-water sample locations**

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

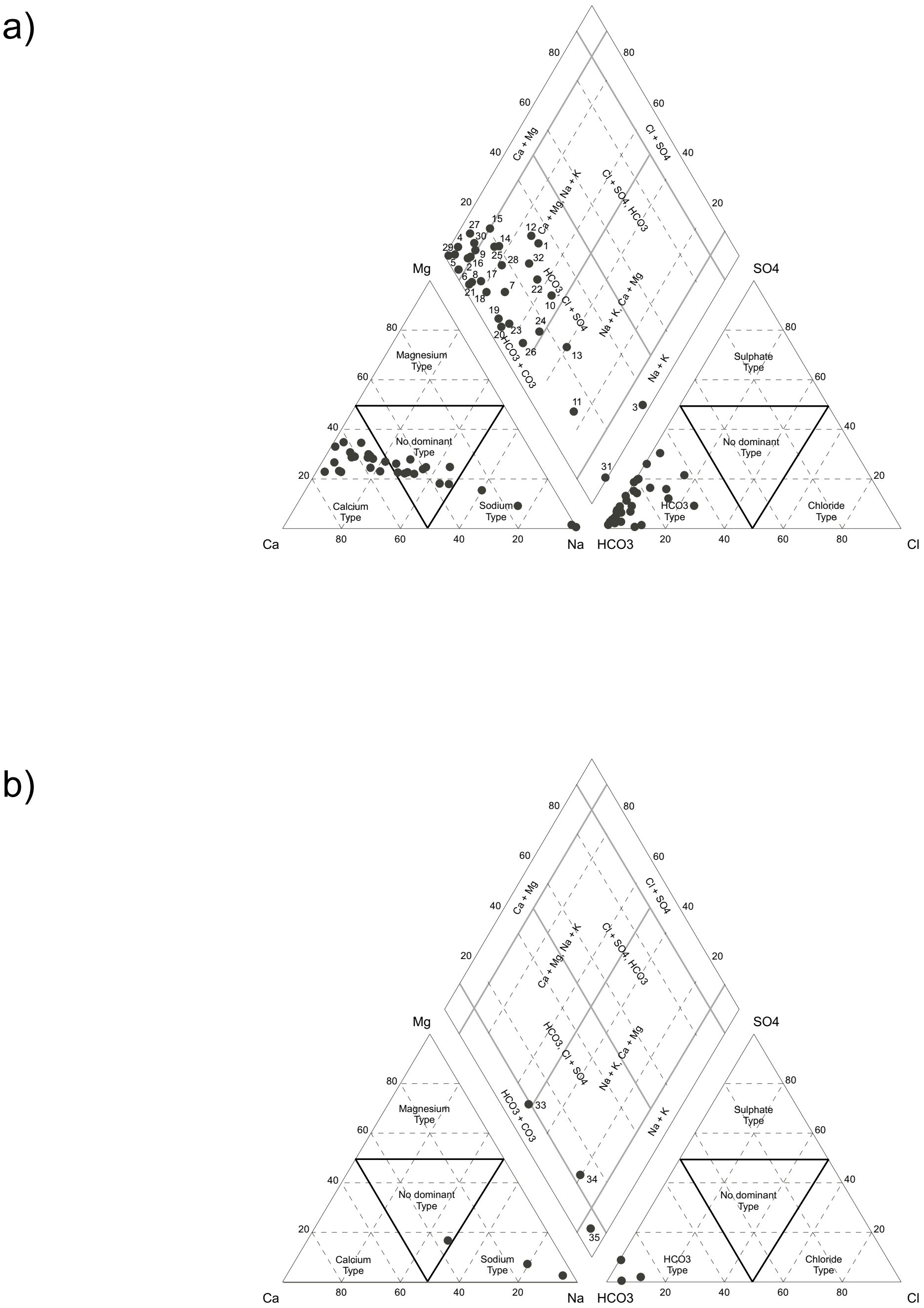


**Figure 7. Piper plots of a) Quaternary drift aquifer-water samples and b) Quaternary/Tertiary buried channel aquifer-water samples in the Athabasca Oil Sands (in situ) Area.**

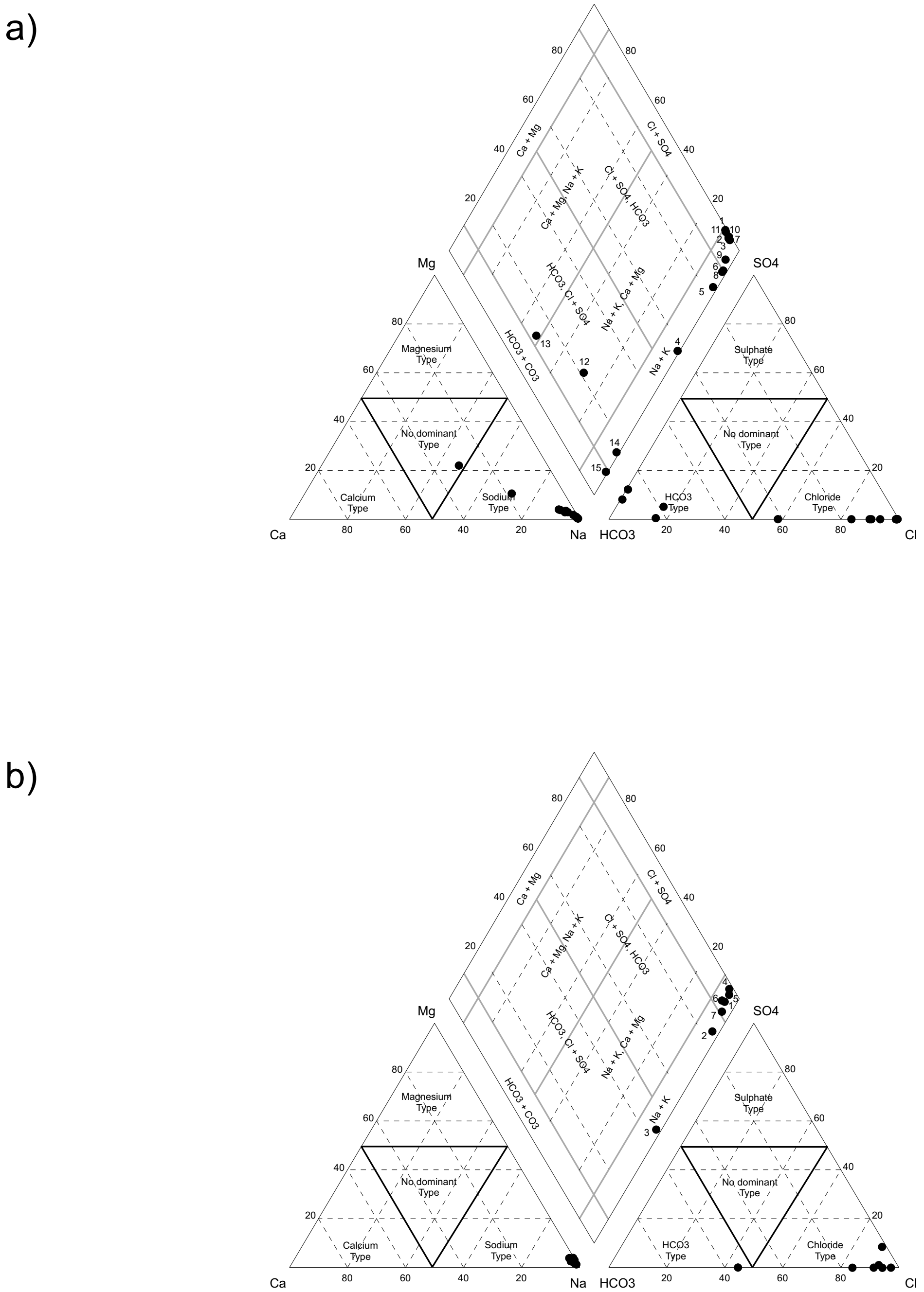


**Figure 8. Piper plots of Early Cretaceous a) Colony Member and Viking, Grand Rapids and Clearwater formations formation-water samples and b) Wabiskaw Member and McMurray Formation formation-water samples in the Athabasca Oil Sands (in situ) Area.**

Preliminary Interpretations - Quaternary-Tertiary Buried Channel Aquifers

- The water types are consistent with end members of an evolutionary pathway of groundwater through glacial sediment (e.g., Freeze and Cherry, 1979; and Macpherson and Townsend, 1998).
- The dominant reaction in these aquifers appears to be cation exchange.
- Groundwater samples are similar to Type II and Type III water from glacial deposits as described in Freeze and Cherry (1979, p.284).

Preliminary Interpretations- Lower Cretaceous Aquifers

- Cation exchange is the most likely reaction resulting in the observed mixed cation-$HCO_3$ and Na-$HCO_3$ water types.
- The Na-Cl-$HCO_3$ and Na-Cl water types are most likely representative of the less flushed part of the succession (e.g., Macpherson and Townsend, 1998).

### 3.1.3 Total Dissolved Solids (TDS)

Observations

- The TDS values within the Quaternary Drift aquifers, the Quaternary-Tertiary buried channel aquifers and the shallowest Lower Cretaceous aquifers (represented by samples 47, 48, 49 and 50) are between 231 mg/L and 1440 mg/L.
- No obvious trend in TDS with depth in the Quaternary drift aquifers was observed.
- TDS values increase with depth in the Quaternary-Tertiary and shallowest Lower Cretaceous aquifers.
- TDS values in the deeper Lower Cretaceous aquifers are between 2430 and 29 600 mg/L.

Preliminary Interpretations

- The TDS values in the Quaternary drift aquifers, Quaternary-Tertiary buried channel aquifers and shallowest Lower Cretaceous aquifers are similar to the Type II and Type III water from glacial deposits as described by Freeze and Cherry (1979, p.284) and, therefore, appear to have evolved according to similar mechanisms.
- Sample 39, collected from a Lower Cretaceous gas well, could be water of condensation according to EUB Guide 4 (Alberta Energy and Utilities Board, 1985) as its TDS is less than 4000 mg/L. The water of condensation - formation water cutoff value is currently being reviewed in order to better define the difference between water of condensation and formation water. It is, therefore, uncertain if this water sample is truly representative of formation water or is water of condensation.
- The other samples from oil- and gas-producing wells all have TDS values greater than the 4000 mg/L cutoff, but less than the TDS of seawater, which is approximately 35 000 mg/L (Drever, 1997, p. 345), suggesting that the groundwater in the Lower Cretaceous sediments (which are of marine origin) is not connate (i.e., entombed) seawater.

### 3.1.4 Chloride/Bromide Mass Ratios

Observations

- Aside from samples 3, 6 and 8, Quaternary drift aquifer water samples have Cl/Br mass ratios less than 300 (Figure 9a).
- Samples 3, 6 and 8 have Cl/Br mass ratios between approximately 500 and 900 (Figure 9a).
- There is a general trend of increasing Cl/Br mass ratio with increasing Cl concentration in the Quaternary drift aquifers.
- Quaternary-Tertiary buried channel aquifer water samples have Cl/Br mass ratios less than 200 (Figure 9b).
- There is a general trend of increasing Cl/Br mass ratio with increasing Cl concentration in the Quaternary-Tertiary buried channel aquifers.
- Lower Cretaceous aquifer water samples have Cl/Br mass ratios between 250 and 450 (Figure 10a and Figure 10b).
- Cl/Br mass ratios are essentially stable regardless of Cl concentration in the Lower Cretaceous aquifers.

Preliminary Interpretations

- The Quaternary drift-aquifer water samples have Cl/Br mass ratios consistent with atmospheric precipitation and shallow groundwater (Davis et al., 1998).
- Cl/Br mass ratios for Quaternary drift aquifer water samples 3, 6 and 8, although elevated, fall within the range reported for groundwater by Davis et al. (1998).
- The Quaternary-Tertiary aquifer water samples have Cl/Br mass ratios consistent with atmospheric precipitation and shallow groundwater (Davis et al., 1998).
- The essentially constant Cl/Br mass ratios for the Lower Cretaceous formation water samples indicates the likelihood of a single dominant source of Cl and Br in these aquifers.
- The range of Cl/Br mass ratios for the Lower Cretaceous formation water samples is slightly greater than the general range of values for shallow groundwater reported by Davis et al. (1998), but do fall within the entire range of Cl/Br mass ratios for groundwater (Davis et al., 1998).
- Lower Cretaceous formation water sample Cl/Br mass ratios are similar to the seawater Cl/Br mass ratio of 289.
- All Cl/Br mass ratios are less than that predicted for water that has been affected by the dissolution of halite from deeper formations (Davis et al., 1998), or from the application of road salt (Briggins and Cross, 1995).

## 3.2 Isotope Chemistry

### 3.2.1 δ18O and δ2H

The measured values of $\delta^{18}O$ and $\delta^{2}H$ are usually compared to a meteoric water line in order to assess the similarities between the water samples and global or local precipitation and infer the reasons for any differences. Samples collected during this project are compared to two such meteoric water lines, a Global Meteoric Water Line (GMWL) and an Approximate Edmonton Meteoric Water Line (AEMWL). The Rozanski et al. (1993) GMWL was chosen over the Craig (1961) GMWL because it is a more recent interpretation of the data. The equation of the line is given as $\delta^{2}H = 8.17\ \delta^{18}O + 11.27$. The AEMWL was constructed using data collected between 1960 and 1969 from a sample site in Edmonton

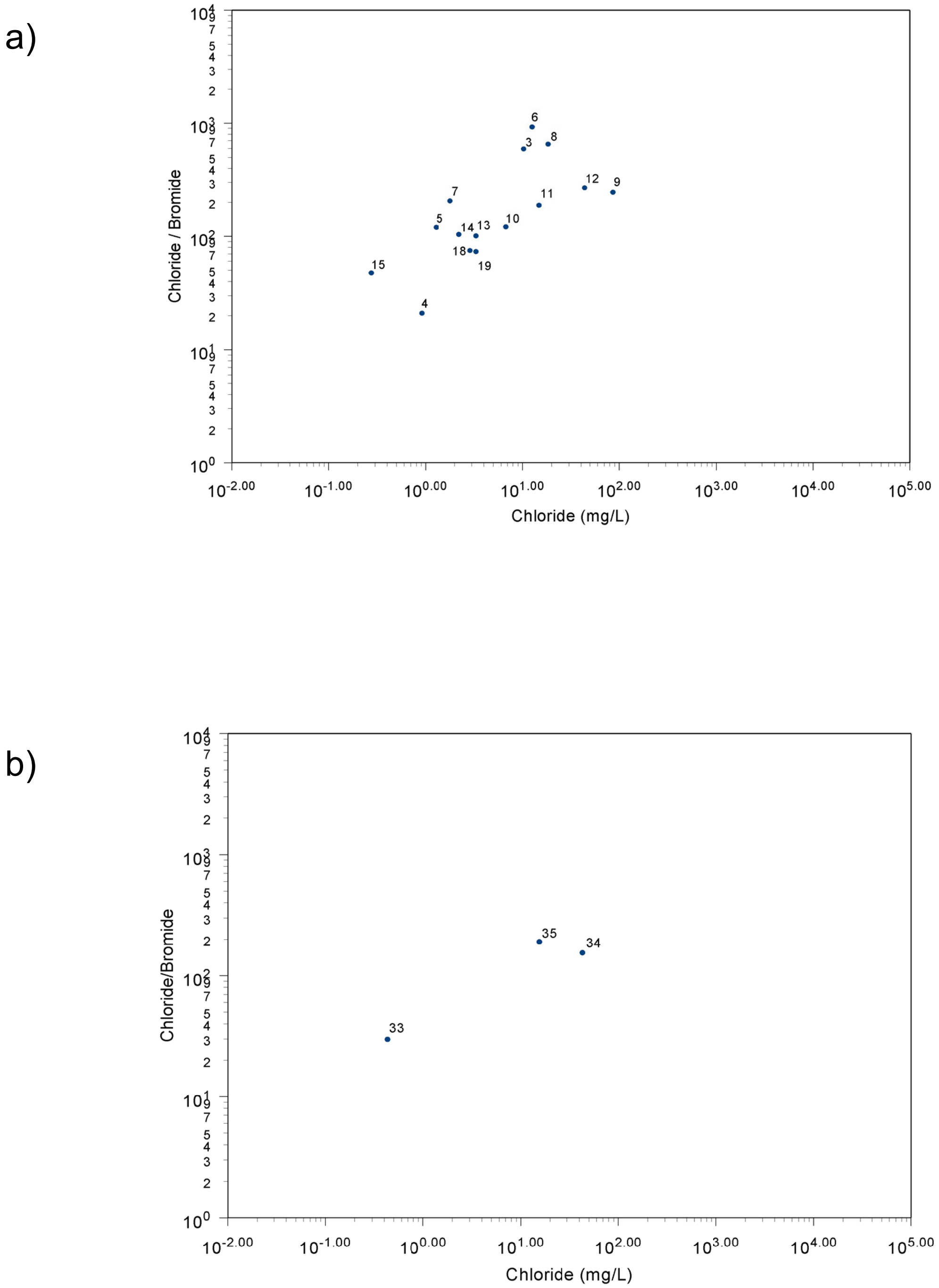


**Figure 9. Chloride/Bromide mass ratio vs. chloride concentration of a) Quaternary drift aquifer-water samples and b) Quaternary/Tertiary buried channel aquifer water-samples in the Athabasca Oil Sands (in situ) Area.**

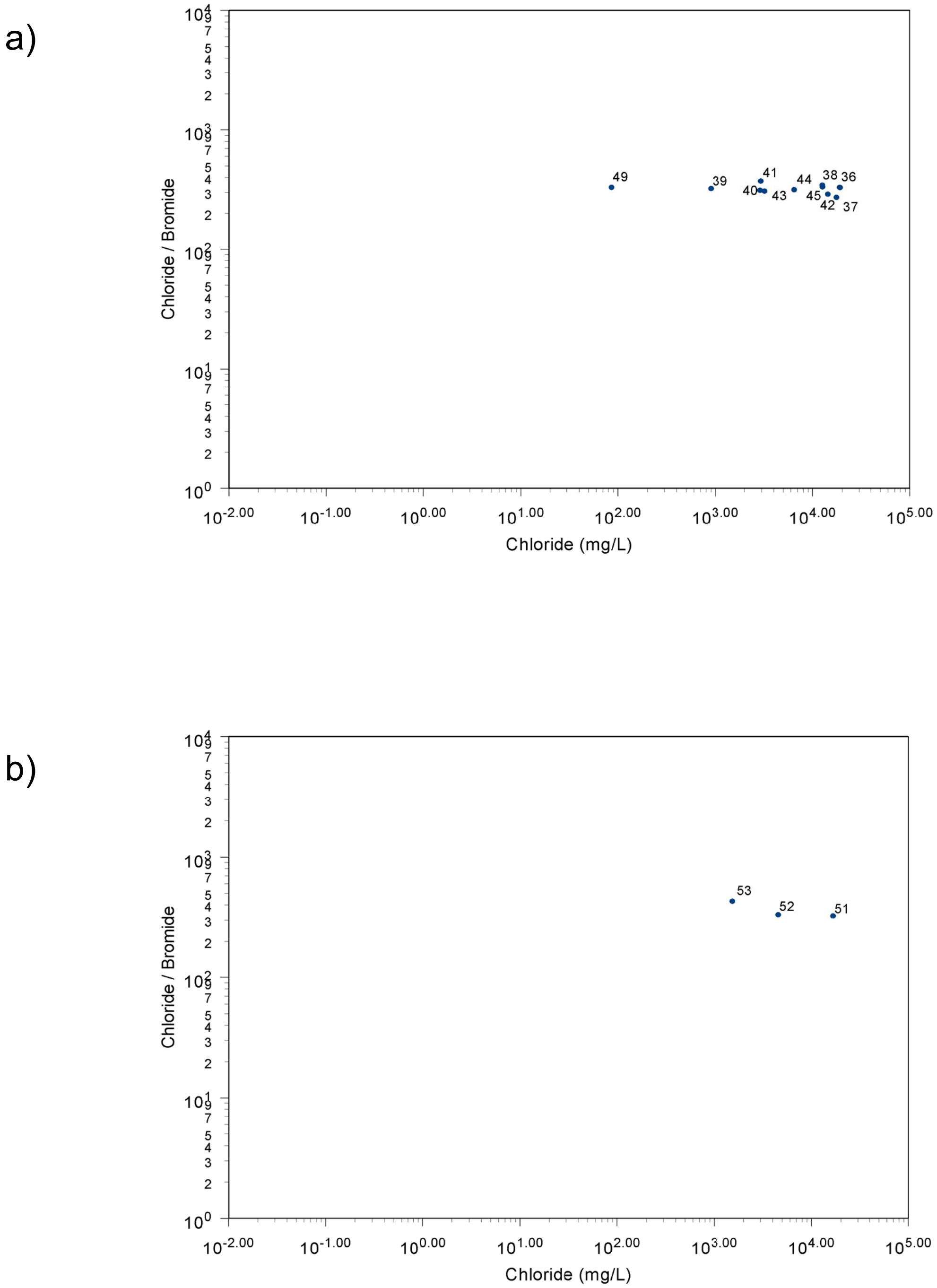


**Figure 10. Chloride/Bromide mass ratio vs. chloride concentration of Early Cretaceous a) Colony Member and Viking, Grand Rapids and Clearwater formations formation-water samples, and b) Wabiskaw Member and McMurray Formation formation-water samples in the Athabasca Oil Sands (in situ) Area.**

and compiled into the Global Network for Isotopes in Precipitation Database (IAEA/WMO, 2001). Linear regression of the data results in a line with an equation of $\delta^2H = 7.66\ \delta^{18}O - 1.00$. In addition, the sample results are compared to data reported by Connolly et al. (1990) and Hitchon and Friedman (1969). From this data, formation water line equations were determined using regression of the data from each investigation and are designated as the Connolly Formation Water Line (CFWL) and the Hitchon Friedman Formation Water Line (HFFWL). The equations are:

$\delta^2H = 3.57\ \delta^{18}O - 62.1$ CFWL
$\delta^2H = 3.81\ \delta^{18}O - 72.8$ HFFWL

Observations

- Data from the Quaternary drift aquifers (Figure 11a) plot on, above and below the GMWL and the AEMWL.
    - o All Quaternary drift aquifer water sample $\delta^{18}O$ and $\delta^2H$ values are less than the $\delta^{18}O$ and $\delta^2H$ weighted annual average value (Rozanski et al., 1993) of $\delta^{18}O$ and $\delta^2H$ for Edmonton (-17.1‰, -131‰, temperature 3.2°C).
- Data from the Quaternary drift aquifers (Figure 11a) plot below the CFWL and at the intercept between the HFFWL and GMWL.
- All three samples from Quaternary-Tertiary buried channel aquifers plot below the GMWL and AEMWL (Figure 11b).
    - o All the Quaternary-Tertiary buried channel aquifer water values are less than the $\delta^{18}O$ and $\delta^2H$ weighted annual average value (Rozanski et al., 1993) of $\delta^{18}O$ and $\delta^2H$ for Edmonton.
- All three samples from Quaternary-Tertiary buried channel aquifers plot below the CFWL and along the HFFWL.
- Water samples from the Lower Cretaceous - Viking, Colony, Grand Rapids and Clearwater formations appear to have a bimodal distribution and plot on, above and below the GMWL and AEMWL (Figure 12a).
    - o Points plotting along the upper portion of the GMWL correspond to sample locations southwest of the Mostoos Uplands.
    - o Points plotting along the lower portion of the GMWL correspond to sample locations north of the Mostoos Uplands.
    - o The water samples located to the north of the Mostoos Uplands have values that are less than the $\delta^{18}O$ and $\delta^2H$ weighted annual average value (Rozanski et al., 1993) for Edmonton, while those located to the southwest of the Mostoos Uplands are greater than the $\delta^{18}O$ and $\delta^2H$ weighted annual average value.
- Points 36, 37, 38, 42, 45 and 46 plot close to the intercept of the CFWL with the GMWL.
- Points 40, 41, 43, 47, 48, 49 and 50 plot close to the intercept of the HFFWL with the GMWL.
- Samples collected from Lower Cretaceous wells completed in the Wabiskaw Member and McMurray Formation all plot above the GMWL and AEMWL (Figure 12b).
    - o The highest isotopic values in the Wabiskaw Member correspond to a sample southwest of the Mostoos uplands.
    - o The water sample located to the southwest of the Mostoos Uplands is greater than the weighted annual average value (Rozanski et al., 1993) of $\delta^{18}O$ and $\delta^2H$ for Edmonton.
    - o The sample sites located to the north of the Uplands have values less than the weighted annual average value (Rozanski et al., 1993) of $\delta^{18}O$ and $\delta^2H$ for Edmonton.
- Point 51 plots close to the intercept of the CFWL with the GMWL.
- Points 52, 53 and 56 plot near the intercept of the HFFWL with the GMWL.

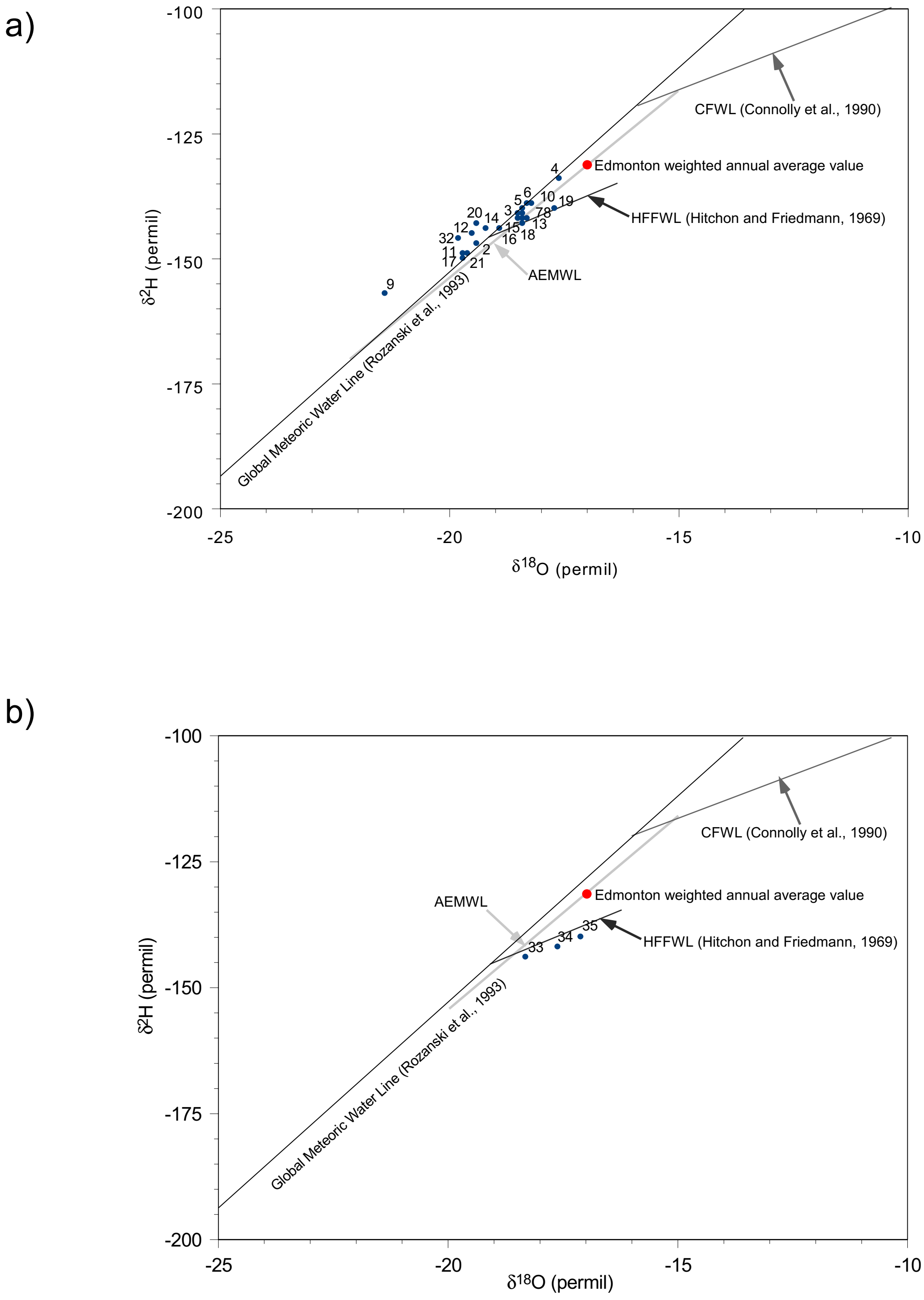


**Figure 11. Measured $\delta^{18}$O vs $\delta^2$H values of a) Quaternary drift aquifer-water samples and b) Quaternary/Tertiary buried channel aquifer-water samples in the Athabasca Oil Sands (in situ) Area.**

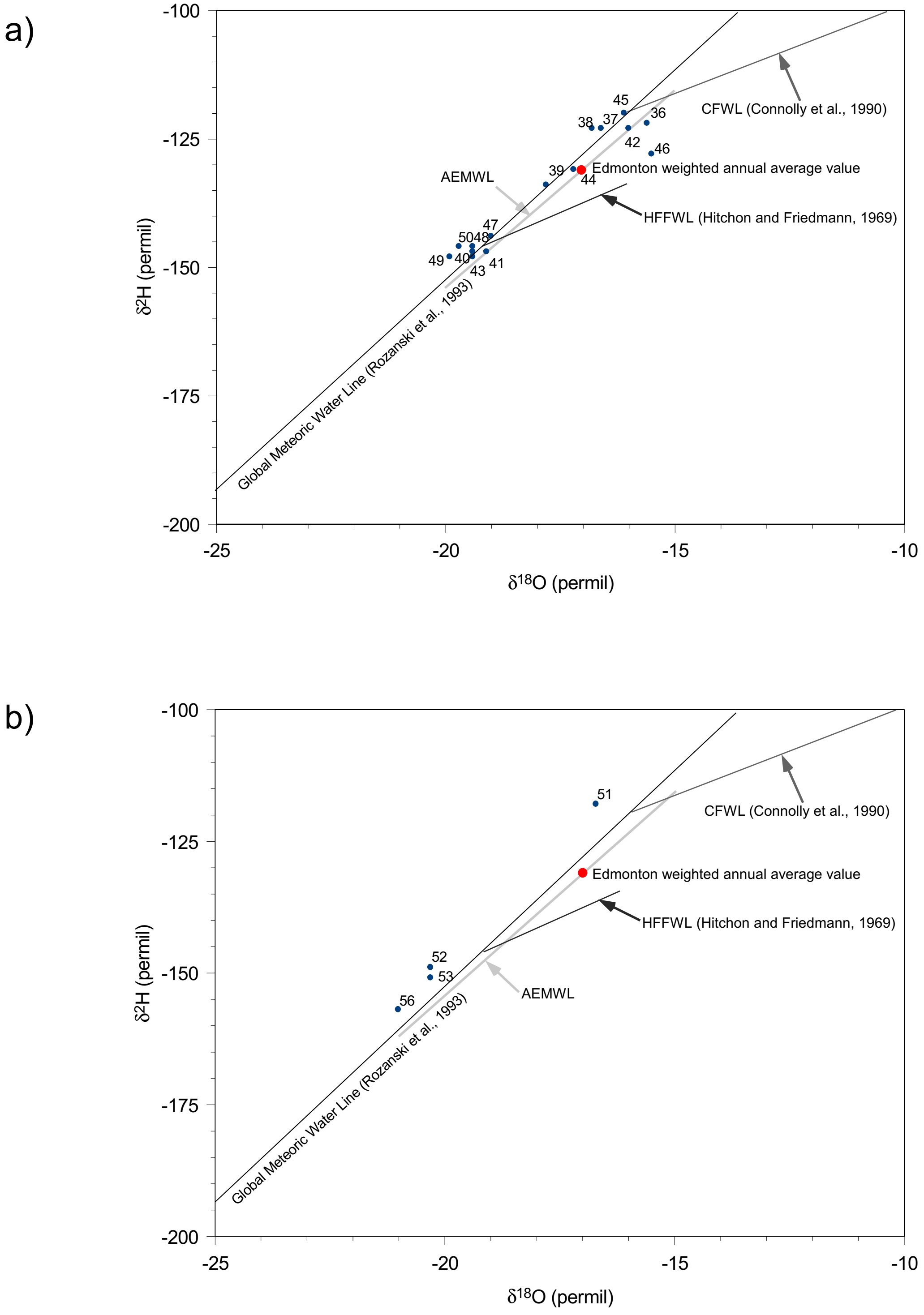


**Figure 12. Measured $\delta^{18}O$ vs $\delta^{2}H$ values of Early Cretaceous a) Colony Member and Viking, Grand Rapids and Clearwater formations formation-water samples, and b) Wabiskaw Member and McMurray Formation formation-water samples in the Athabasca Oil Sands (in situ) Area.**

- Samples 9, 52, 53 and 56 have $\delta^{18}O$ values similar to values reported by Grasby et al., (2000) as being of glacial origin.

Preliminary Interpretations

The $\delta^{18}O$ and $\delta^{2}H$ values of the water samples fall close to the GMWL and AEMWL, indicating that the water within these aquifers most likely has a meteoric water origin, or has mixed with meteoric water to give the observed isotopic values. The coincidence of the data clusters with the presented Formation Water Lines is more difficult to explain. The geographic and stratigraphic positions of the samples indicate that: 1) Cretaceous water samples from south of the Mostoos Uplands are similar to the meteoric end member defined by Connolly et al. (1990) for an area north and west of Edmonton, Alberta; and 2) Cretaceous aquifer water samples from north of the Mostoos Uplands and Quaternary-Tertiary aquifer water samples are similar to the meteoric end member defined by Hitchon and Friedman (1969) for the entire Alberta Basin. The implications on recharge history and fluid flow within the Cretaceous are as yet unclear, but appear to indicate differences between the end member compositions for the original basin fluids and meteoric waters for the area between Edmonton and the Mostoos Uplands and the Alberta Basin as a whole. It should be noted that the interpretation of paleoclimate or mixing relationships based on isotopic data should be done with care since many additional meteorological and water-rock processes can affect isotopic compositions. The following climatic interpretations are based on an initial examination of the data:

- Variance from the GMWL and AEMWL can be explained by differences in humidity at time of recharge, causing a shift of the data parallel to the line (Clark and Fritz, 1997, p. 44).
    - Drier conditions shift the line up.
    - More humid conditions shift the line down.
    - The weighted annual average value of $\delta^{18}O$ and $\delta^{2}H$ for Edmonton plots below the GMWL.
- Differences in temperature at time of recharge will also cause a shift in isotopic compositions, this time along the line (Clark and Fritz, 1997, p. 64).
    - Warmer temperatures during recharge result in points that plot toward the positive end of the line.
    - Colder temperatures during recharge result in points that plot toward the negative end of the line.
- With the exception of points 36, 37, 38, 42, 44, 45, 46 and 51, all the $\delta^{18}O$ and $\delta^{2}H$ sample values are less than the weighted annual average value (Rozanski et al., 1993) of $\delta^{18}O$ and $\delta^{2}H$ for Edmonton, possibly indicating that the water in these aquifers was recharged during times of colder mean annual temperatures than $3.2^{o}C$.
- Point 44 has a $\delta^{18}O$ value slightly less than the weighted annual average value for Edmonton and a $\delta^{2}H$ value approximately equal to the weighted annual average value for Edmonton, possibly indicating that the water in this aquifer was recharged during times of slightly colder mean annual temperatures than $3.2^{o}C$ and that subsequent meteoric or water-rock reactions have somewhat affected the $^{2}H$ concentrations. However, the measured differences are within the analytical error.
- Points 36, 37, 38, 42, 45, 46 and 51 have greater $\delta^{18}O$ and $\delta^{2}H$ values than the weighted annual average value (Rozanski et al., 1993) of $\delta^{18}O$ and $\delta^{2}H$ for Edmonton, possibly indicating that the water in these aquifers was recharged during times of warmer mean annual temperatures than $3.2^{o}C$.
- Water samples from the Quaternary drift aquifers plot above, on and below the GMWL.

  - Samples plotting above the GMWL could indicate drier conditions than current world averages during recharge.
  - Samples plotting below the GMWL could indicate more humid conditions than current world averages during recharge.
  - Samples plotting on the GMWL could indicate similar humidity levels to those of current world averages during recharge.
- Water samples from the Quaternary drift aquifers plot above, on and below the AEMWL.
  - Samples plotting above this AEMWL could indicate recharge under drier conditions than current Edmonton conditions.
  - Samples plotting approximately on this AEMWL could indicate recharge under similar humidity conditions to current Edmonton conditions.
  - Samples plotting below the AEMWL could indicate recharge under more humid conditions than current Edmonton conditions.
- Water samples from the Quaternary-Tertiary buried channel aquifers plot below the GMWL, possibly indicating more humid conditions than current world averages during recharge.
- Water samples from the Quaternary-Tertiary buried channel aquifers plot below the AEMWL possibly indicating that humidity during recharge was greater than that of present day Edmonton.
- Water samples from the Lower Cretaceous - Viking, Colony, Grand Rapids and Clearwater aquifers plot above, on and below the GMWL.
  - Samples plotting above the GMWL could indicate drier conditions than current world averages during recharge.
  - Samples plotting below the GMWL could indicate more humid conditions than current world averages during recharge.
  - Samples plotting on the GMWL could indicate similar humidity levels to those of current world averages.
- Water samples from the Lower Cretaceous - Viking, Colony, Grand Rapids and Clearwater aquifers plot above, on and below the AEMWL.
  - Samples plotting above this line possibly indicate recharge during drier conditions than current Edmonton.
  - Samples 36 and 42 plot approximately on the AEMWL and could indicate humidity conditions similar to humidity levels of current Edmonton.
  - Sample 46 plots below the AEMWL possibly indicating conditions during recharge that were more humid than the current Edmonton annual average.
- Water samples from the Lower Cretaceous - Wabiskaw and McMurray Formations plot above the GMWL and the AEMWL indicating the possibility that drier conditions than current world averages or Edmonton averages prevailed during recharge of these aquifers.
- Samples 9, 52, 53 and 56 could have been recharged by glacial meltwater, or by meteoric water dominated by snowmelt mixing with formation water, or by mixing of meteoric or formation water with glacial meltwater.
  - $\delta^{18}O$ values are between -20.3 ‰ and -21.4 ‰ (this study).
  - $\delta^{18}O$ values for interpreted glacial meltwater are between -22 ‰ and -28 ‰ (Grasby et al., 2000; Clark et al., 2000).
  - $\delta^{18}O$ values for local snow samples are between -20.4 ‰ to -30.6 ‰ (Alberta Geological Survey unpublished data).

### 3.2.2 $\delta^{13}C$ in Dissolved Inorganic Carbon (DIC)

Observations

- In the Quaternary drift aquifers, there appears to be a general trend of decreasing $\delta^{13}C_{DIC}$ with increasing $HCO_3$ concentration (Figure 13a).
- In the Quaternary-Tertiary buried channel aquifers $\delta^{13}C_{DIC}$ decreases with increasing $HCO_3$ concentration (Figure 13b).
    - o Samples 34 and 35 appear to form one cluster of data whereas sample 33 plots apart from the other two points.
- Two groups of data exist in the Lower Cretaceous - Viking, Colony, Grand Rapids and Clearwater formations (Figure 14a).
    - o Samples 36, 38, 40, 41, 43, 45, 46, 47, 48, 49 and 50 have similar negative $\delta^{13}C_{DIC}$ values regardless of $HCO_3$ concentration.
    - o Samples 37, 39, 42 and 44 have positive $\delta^{13}C_{DIC}$ values.
- Two groups of data exist in the Lower Cretaceous - Wabiskaw Member and McMurray Formation (Figure 14b).
    - o Sample 51 has a negative $\delta^{13}C_{DIC}$ value and is located to the southwest of the Mostoos Uplands.
    - o Samples 52, 53 and 56 have similar positive values regardless of $HCO_3$ concentration and are located to the north of the Mostoos Uplands.

Preliminary Interpretations

- The majority of the $\delta^{13}C_{DIC}$ values within the Quaternary drift aquifers and Lower Cretaceous - Viking, Grand Rapids and Clearwater formations and Colony Member can be explained by carbonate dissolution, as detailed in Clark and Fritz (1997, p. 122-123).
- Samples 33 and 51 also appear consistent with a carbonate dissolution pathway controlling $\delta^{13}C_{DIC}$.
- Samples 9, 10, 34 and 35 have $\delta^{13}C_{DIC}$ lower than expected if carbonate dissolution was controlling DIC.
    - o A possibility could be that carbonate dissolution within these aquifers is not a significant contributor to DIC and the majority of the DIC is from reactions between water and soil $CO_2$.
    - o A possible DIC source for these wells could involve oxidation of organic matter, such as coal or petroleum, that have $\delta^{13}C$ values similar to those of the above samples.
- Samples 37, 39, 42, 44, 52, 53 and 56 are consistent with $\delta^{13}C_{DIC}$ being affected by DIC input from microbe-assisted methanogenesis as described in Clark and Fritz (1997, p. 128).

### 3.2.3 Isotope Ratio of $^{87}Sr/^{86}Sr$

Observations

- Strontium concentrations in an AGS-installed piezometer nest, represented by samples 4 (shallowest), 5, 6 and 7 (deepest), increase with depth, whereas $^{87}Sr/^{86}Sr$ values decrease with depth (Figure 15).

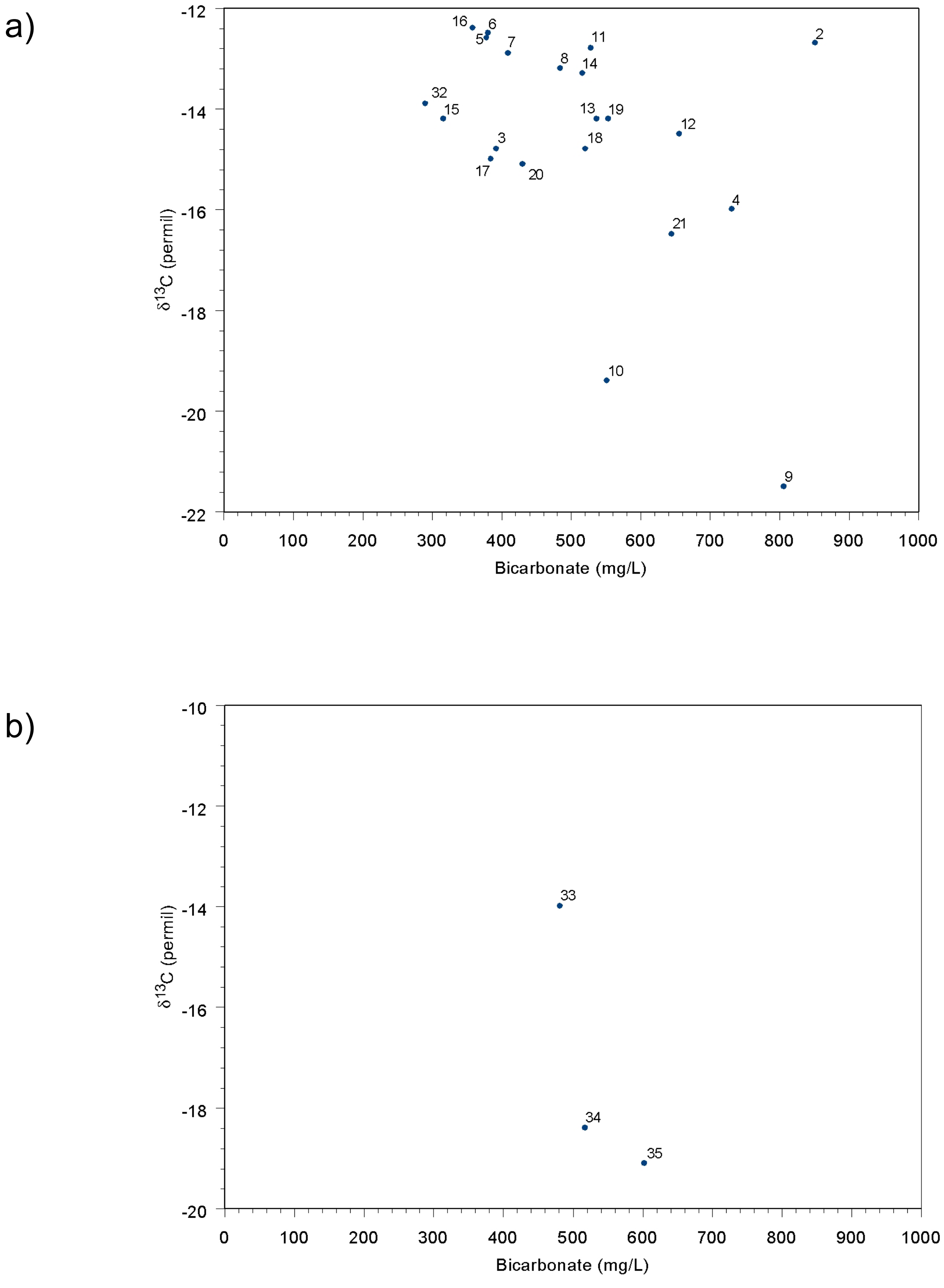


**Figure 13. Measured $\delta^{13}C_{DIC}$ values vs. bicarbonate concentration of a) Quaternary drift aquifer-water samples, and b) Quaternary/Tertiary buried channel aquifer-water samples in the Athabasca Oil Sands (in situ) Area.**

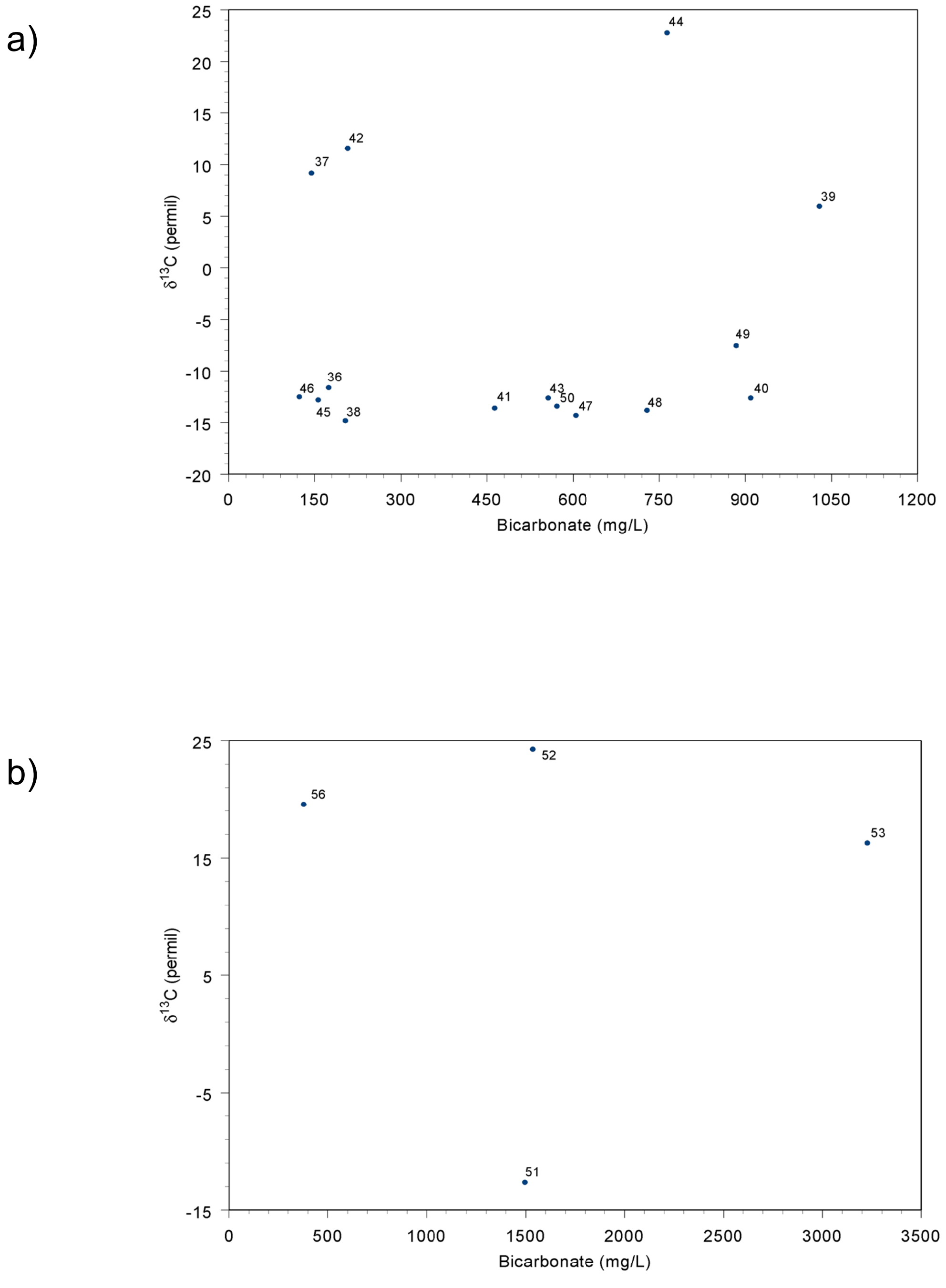


**Figure 14. Measured $^{13}C_{DIC}$ values vs. bicarbonate concentration of Early Cretaceous a) Colony Member and Viking, Grand Rapids and Clearwater formations, formation-water samples, and b) Wabiskaw Member and McMurray Formation formation-water samples in the Athabasca Oil Sands (in situ) Area.**

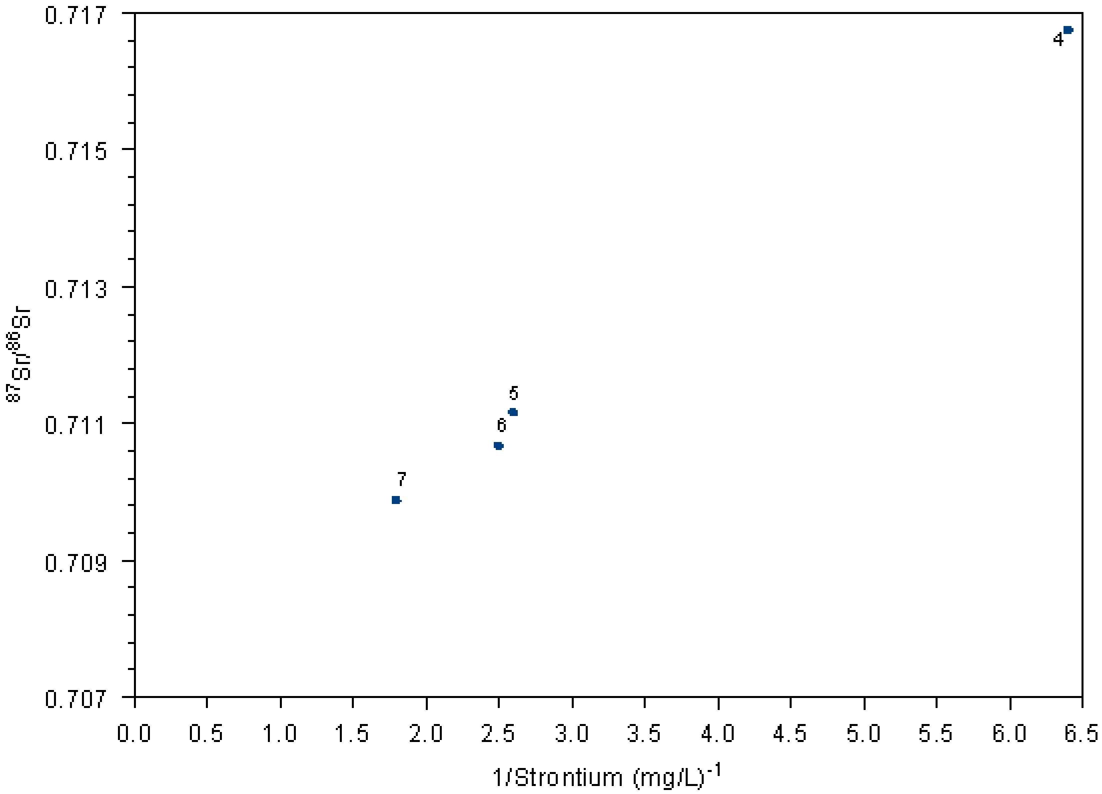


**Figure 15. Example of two-component mixing within a Quaternary drift aquifer system.**

- An overall decrease of $^{87}Sr/^{86}Sr$ values is observed with increasing strontium concentrations within the Quaternary drift aquifers (Figure 16a).
- The $^{87}Sr/^{86}Sr$ values in the Quaternary-Tertiary buried channel aquifers are almost constant regardless of Sr concentration (Figure 16b).
- The $^{87}Sr/^{86}Sr$ values in the Lower Cretaceous aquifers are approximately constant regardless of Sr concentrations (Figure 17a and Figure 17b).

Preliminary Interpretations

- The linear relationship in Figure 15 is indicative of a two-component mixing system (Faure, 1986, p. 141-143).
  - Changes in $^{87}Sr/^{86}Sr$ ratios can be caused by two processes:
  - mixing of two or more $^{87}Sr/^{86}Sr$ distinct water-types
  - water-rock interaction releasing Sr with different $^{87}Sr/^{86}Sr$ ratios into solution
  - Given the complex lithology and aquifer relationships at this site, $^{87}Sr/^{86}Sr$ ratio values are likely controlled by both processes.
- Consistent $^{87}Sr/^{86}Sr$ values, regardless of Sr concentration in the Quaternary-Tertiary buried channel aquifers and Lower Cretaceous aquifers, indicate a similar strontium source and that a similar process within these aquifers may be controlling $^{87}Sr/^{86}Sr$ ratio values:
  - carbonate dissolution is a possibility
  - K-rich mineral dissolution is also a possibility
- In the Lower Cretaceous aquifers and the Quaternary-Tertiary buried channel aquifers $^{87}Sr/^{86}Sr$ values generally fall within a range of 0.709 to 0.707.

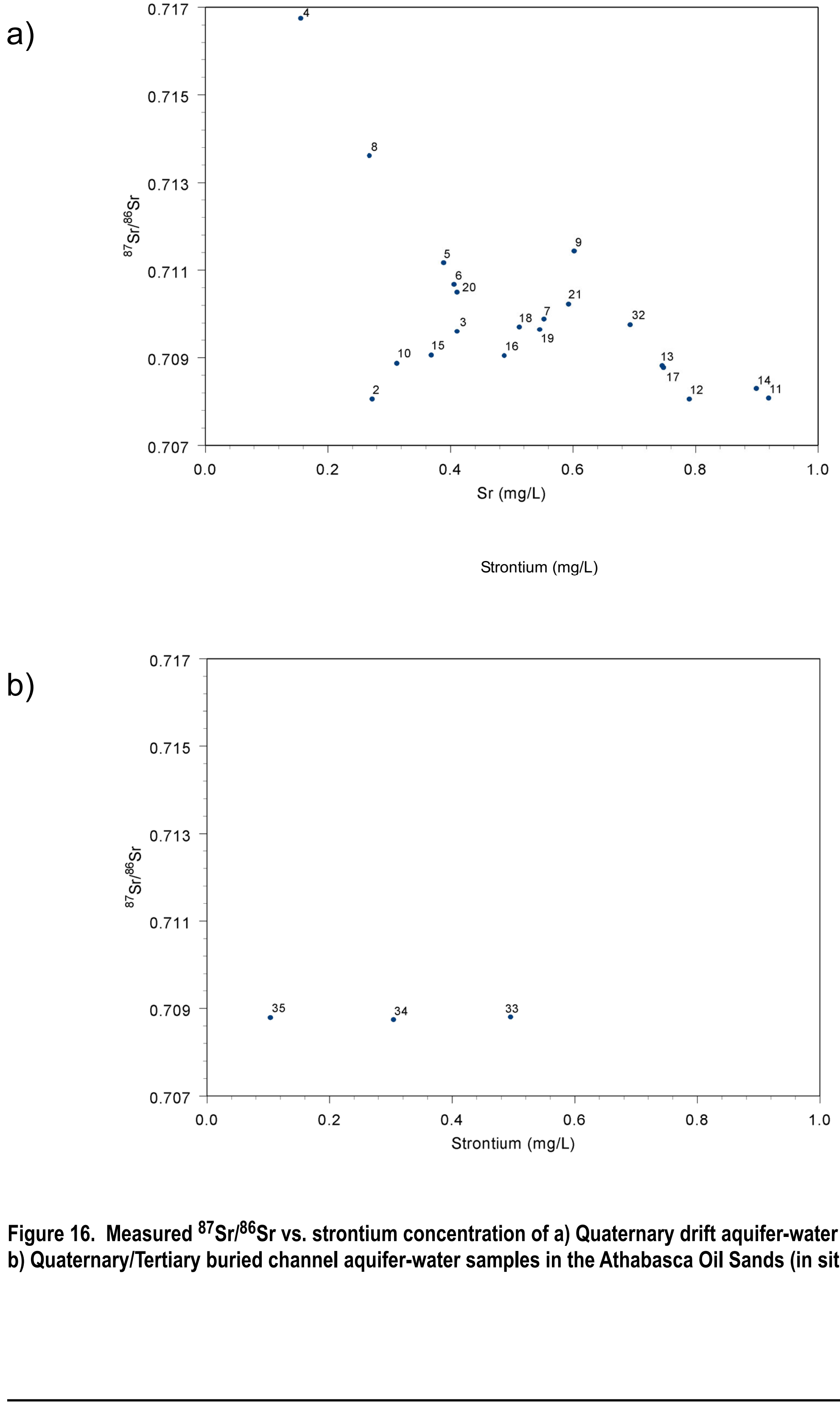


**Figure 16. Measured $^{87}Sr/^{86}Sr$ vs. strontium concentration of a) Quaternary drift aquifer-water samples, and b) Quaternary/Tertiary buried channel aquifer-water samples in the Athabasca Oil Sands (in situ) Area.**

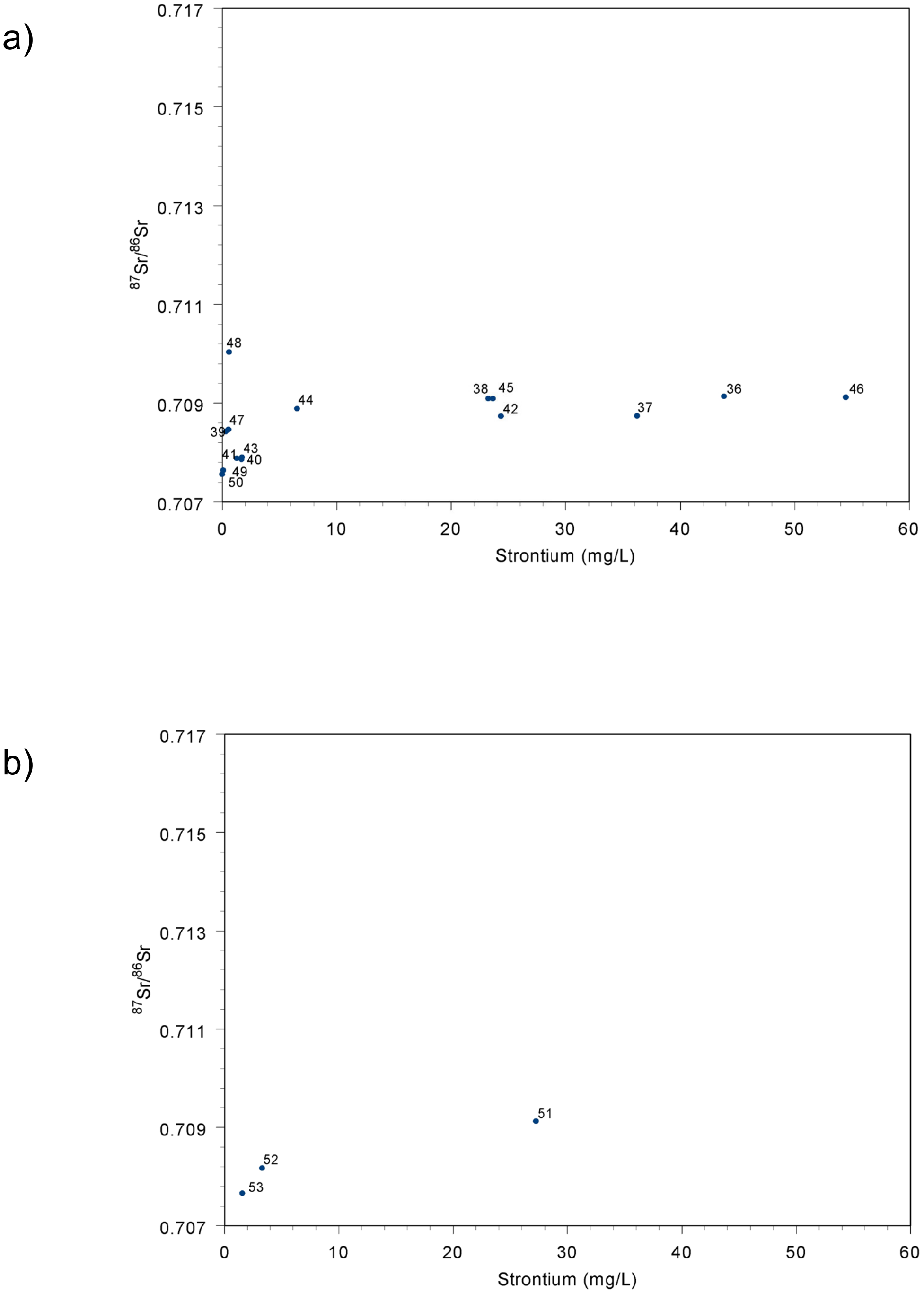


**Figure 17. Measured $^{87}Sr/^{86}Sr$ vs. strontium concentration of Early Cretaceous a) Colony Member and Viking, Grand Rapids and Clearwater formations formation-water samples, and b) Wabiskaw Member and McMurray Formation formation-water samples in the Athabasca Oil Sands (in situ) Area.**

  - This range is similar to most reported carbonate rock values (Mukhopadhyay and Brookins, 1976; and Faure et al., 1978).

### 3.2.4 δ11B

Observations

- In the Quaternary-Tertiary buried channel aquifers and Lower Cretaceous aquifers, boron concentration and $\delta^{11}B$ values generally increase with depth.
- A plot of $\delta^{11}B$ versus boron concentration shows two distinct groups of points (Figure 18).
  - Group 1 consists of Quaternary drift aquifers and Quaternary-Tertiary buried channel aquifers.
  - Group 2 consists of Lower Cretaceous aquifers.
  - The break appears to be at a boron concentration of approximately 0.6 mg/L and a $\delta^{11}B$ value of approximately 30‰.

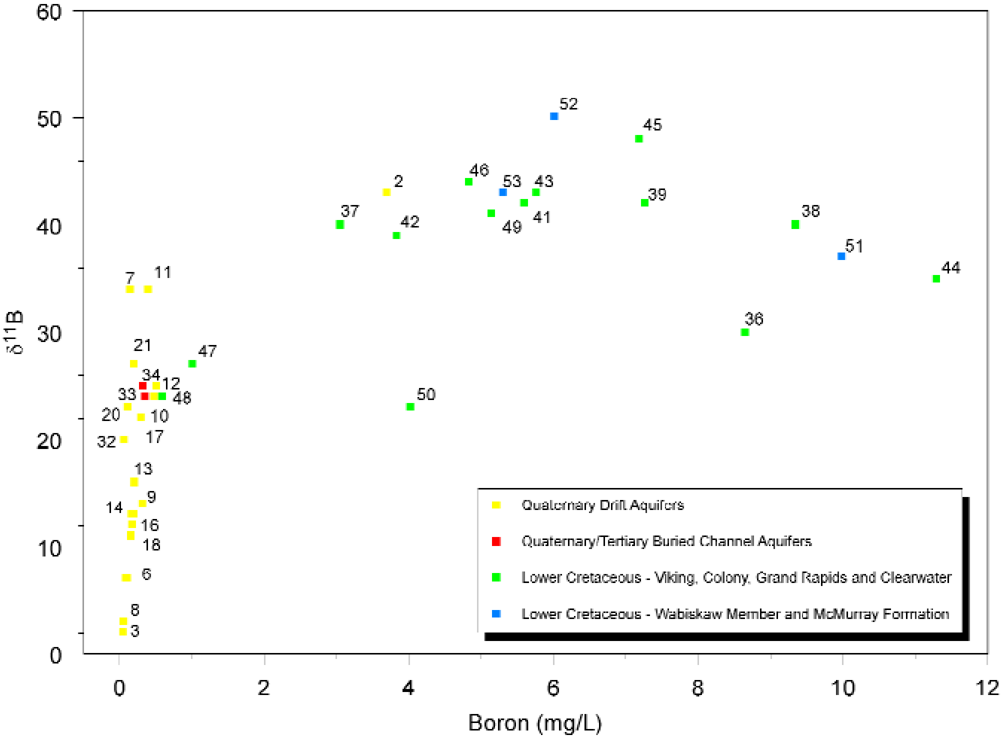


**Figure 18. Variation of $\delta^{11}B$ with boron concentration for aquifers in the Athabasca Oil Sands (in situ) Area.**

Preliminary Interpretations

- The groundwater values are generally consistent with the values for groundwater reported by Vengosh et al. (1994) of < 30‰.
- Most of the Lower Cretaceous Formation aquifers have $\delta^{11}B$ values similar to that of seawater, ~39‰ (Spivack and Edmond, 1987).
  - Those samples with $\delta^{11}B$ values greater than 39‰ may indicate that fractionation has occurred. Fractionation through adsorption onto clay minerals would result in enrichment in the $\delta^{11}B$ values of the water (Schwartz et al., 1969).
- Increased boron concentration in Quaternary drift and within Quaternary-Tertiary buried channel aquifers as the bedrock is approached could be caused by transport of boron from bedrock into

the Quaternary drift aquifers, which could occur potentially through either diffusion or advection.

- Quaternary drift-aquifer sample 2 plots within the area where most of the Lower Cretaceous water samples plot, indicating that perhaps this well was misidentified as being completed in a Quaternary drift aquifer, or that it is in hydraulic communication with a Lower Cretaceous aquifer.
- Lower Cretaceous samples 47, 48 and 50 have $\delta^{11}B$ values that place them within the upper range of $\delta^{11}B$ values for Quaternary drift and Quaternary-Tertiary buried channel aquifers, which could indicate that these wells have interacted with water with a different $\delta^{11}B$ signature. Possible sources of water with a lower $\delta^{11}B$ signature include Quaternary drift aquifer water or meteoric water.

## 4 Summary

The evolution of water chemistry in the Quaternary drift, Quaternary-Tertiary buried channel and shallow Lower Cretaceous aquifers in the Athabasca Oil Sands (in situ) Area appears to be dominated by meteoric recharge with an isotopically colder signature than the present day. Subsequent carbonate dissolution followed by ion exchange results in the wide range of water types present. The lowest observed $\delta^{18}O$ values point to snowmelt or glacial meltwater recharge to the Quaternary drift aquifers. Chloride/bromide mass ratios are consistent with other shallow groundwater samples and do not appear to indicate any contact with dissolved halite from deeper formations. $\delta^{13}C_{DIC}$ values indicate that carbonate dissolution is the dominant process controlling DIC concentrations and compositions. Certain samples indicate the oxidation of organic matter may also play a role in the nature of DIC in the Quaternary drift and Quaternary-Tertiary buried channel aquifers. Boron isotope values are consistent with other values for groundwater. An interesting trend of increasing boron concentration and $\delta^{11}B$ values with proximity to bedrock indicates the possibility of interaction between bedrock formation water with the Quaternary drift and Quaternary-Tertiary buried channel aquifers through either diffusion or advection. The shallower Lower Cretaceous aquifer samples show signs of mixing between original formation water and water with a more depleted $\delta^{11}B$ signature.

The deeper Lower Cretaceous wells possess a $\delta^{18}O$ - $\delta^{2}H$ meteoric water signature. However, unlike water samples from the Quaternary and Quaternary-Tertiary aquifers, the deeper Lower Cretaceous aquifers are dominated by Na-Cl type water. Oxygen, hydrogen and carbon isotope data also appear to be bimodal, with wells to the southwest of the Mostoos Uplands plotting separately from the wells located to the north of the Mostoos Uplands. This suggests that two flow systems within the Lower Cretaceous exist, separated by the uplands. Bacterial action, such as methanogenesis, and perhaps microbial oxidation of organic matter may explain the wide range of $\delta^{13}C_{DIC}$ values observed. As in the Quaternary drift, the lowest $\delta^{18}O$ values point to snowmelt or glacial meltwater recharge or trapping within the Lower Cretaceous McMurray Formation aquifers. Chloride/bromide ratios are similar to those of seawater. No indication of any contact with dissolved halite from deeper formations is observed. Boron isotope values are similar to those of seawater. Certain samples indicate that fractionation may be affecting the boron isotopic values, resulting in more enriched $\delta^{11}B$ in those aquifers.

## 5 References

Alberta Energy and Utilities Board (1985): Determining water production at gas wells; Alberta Energy and Utilities Board, EUB Guide 4, 34 p.

Briggins, D.R. and Cross, H.J. (1995): Well contamination by road salt: problems and possible solutions in Nova Scotia; *In* Proceedings XXVI IAH Congress, Edmonton, Alberta, Canada.

Clark, I.D. and Fritz, P. (1997): Environmental isotopes in hydrogeology; Lewis Publishers, Boca Raton, Florida, 328 p.

Clark, I.D., Douglas, M., Raven, K and Bottomley, D. (2000): Recharge and preservation of Laurentide Glacial Melt Water in the Canadian Shield; Groundwater, v. 38, 5, p. 735-742.

Connolly, C.A., Walter, L.M., Baadsgaard, H. and Longstaffe, F.J. (1990): Origin and evolution of formation waters, Alberta Basin, Western Canada Sedimentary Basin. II. Isotope systematics and water mixing; Applied Geochemistry, v. 5, p. 397-413.

Craig, H. (1961): Isotopic variations in meteoric waters; Science, v. 133, p. 1833-1834.

Davis, S.N., Whittemore, D.O. and Fabryka-Martin, J. (1998): Uses of chloride/bromide ratios in studies of potable water; Groundwater, v. 32, 2, p. 338-350.

Drever, J.I. (1997): The geochemistry of natural waters - surface and groundwater water environments (3rd Edition); Prentice Hall, Upper Saddle River, New Jersey, 436 p.

Faure, G., Assereto, R and Tremba, E.L. (1978): Strontium isotope composition of marine carbonates of Middle Triassic to Early Jurassic Age, Lombardic Alps, Italy; Sedimentology, v. 25, p. 523-543.

Faure, G. (1986): Principles of isotope geology (2nd Edition); John Wiley & Sons, New York, New York, 589 p.

Freeze, R.A. and Cherry, J.A. (1979): Groundwater; Prentice Hall, Englewood Cliffs, New Jersey, 604 p.
Grasby, S., Osadetz, K., Betcher, R. and Render, F. (2000): Reversal of the regional-scale flow system of the Williston Basin in response to Pleistocene glaciation; Geology, v 28, 7, p. 635-638.

Hitchon, B. and Friedman, I. (1969): Geochemistry and origin of formation waters in the Western Canada Sedimentary Basin - I. Stable isotopes of hydrogen and oxygen; Geochimica et Cosmochimica Acta, v. 33, p. 1321-1349.

IAEA/WMO (2001): Global network for isotopes in precipitation; The GNIP database, accessible at: http://isohis.iaea.org.

Lemay, T.G. (2002a): Sampling of groundwater from wells in the Athabasca Oil Sands (in situ) Area, Alberta, 1999-2001 - A compilation of protocols and methods; Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2002-10.

Lemay, T.G. (2002b): Sampling of formation water from wells in the Athabasca Oil Sands (in situ) Area, Alberta, 1999-2001 - A compilation of protocols and methods; Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2002-11.

Macpherson, G.L. and Townsend, M.A. (1998): Water chemistry and sustainable yield; *In*: M. Sophocleous (editor); Perspectives on Sustainable Development of Water Resources in Kansas; Kansas Geological Survey, Bulletin 239.

Mukhopadhyay, B. and Brookins, D.G. (1976): Strontium isotopic composition of the Madera Formation (Pennsylvanian) near Albuquerque, New Mexico; Geochimica et Cosmochimica Acta, v. 40, p. 611-616.

Rozanski, K., Araguas-Araguas, L. and Gonfiantini, R. (1993): Isotopic patterns in modern global precipitation. *In*: Continental Isotope Indicators of Climate; American Geophysical Union Monograph.

Schwartz, H.P., Agyei, E.K. and McCullen, C.C. (1969): Boron isotopic fractionation during clay adsorption from seawater; Earth and Planetary Science Letters, v. 6, p. 1-5.

Spivack, A.J. and Edmond, J.M. (1987): Boron isotope exchange between seawater and ocean crust; Geochimica et Cosmochica Acta, v. 51, p. 1033-1043.

Vengosh, A., Heumann, K.G., Juraske, S. and Kasher, R. (1994): Boron isotope application for tracing sources of contamination in groundwater; Environmental Science and Technology, v. 28, p. 1968-1974.

## Appendix A, Table 3. Quaternary Drift-Aquifer Chemistry

| Key | Site ID | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (masl) | EUB Formation Code | Formation | Completion Depth Top (m) | Completion Depth Bottom (m) | Sample Date | Field Temp ($^oC$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2000038 | 09-24-085-09W4 | 56.386505 | 111.275414 | 482994.9 | 6249132.0 | 763.5 | 20 | Quaternary | 11.3 | 12.8 | July 11, 1979 | 7.0 |
| 2 | 2000045 | 16-02-087-09W4 | 56.520851 | 111.309494 | 480958.0 | 6264094.3 | 429.8 | 20 | Quaternary | 7.0 | 8.5 | August 3, 2000 | 6.4 |
| 3 | 2001003 | 07-36-077-15W4 | 55.714398 | 112.187874 | 425371.4 | 6174932.8 | 662.5 | 20 | Quaternary | 5.1 | 8.2 | June 22, 2001 | 6.4 |
| 4 | 2001006 | 06-33-074-09W4 | 55.451416 | 111.329831 | 479138.6 | 6145075.9 | 666.8 | 20 | Quaternary | 9.3 | 15.4 | May 9, 2001 | 6.3 |
| 5 | 2001007 | 06-33-074-09W4 | 55.451377 | 111.329824 | 479139.0 | 6145071.6 | 667.1 | 20 | Quaternary | 37.9 | 41.0 | May 8, 2001 | 6.2 |
| 6 | 2001008 | 06-33-074-09W4 | 55.451383 | 111.329959 | 479130.8 | 6145072.1 | 667.0 | 20 | Quaternary | 72.4 | 75.4 | May 8, 2001 | 7.0 |
| 7 | 2001009 | 06-33-074-09W4 | 55.451376 | 111.329890 | 479135.2 | 6145071.6 | 666.9 | 20 | Quaternary | 117.3 | 120.3 | May 9, 2001 | 5.6 |
| 8 | 2001012 | 15-04-075-05W4 | 55.473040 | 110.707298 | 518502.7 | 6147472.0 | 648.2 | 20 | Quaternary | 11.2 | 17.3 | May 11, 2001 | 6.6 |
| 9 | 2001013 | 15-04-075-05W4 | 55.473007 | 110.707318 | 518501.3 | 6147468.2 | 648.3 | 20 | Quaternary | 76.6 | 79.6 | May 11, 2001 | 8.3 |
| 10 | 2001014 | 15-04-075-05W4 | 55.472975 | 110.707334 | 518500.4 | 6147164.8 | 648.2 | 20 | Quaternary | 155.4 | 158.5 | May 10, 2001 | 7.1 |
| 11 | 9000001 | 16-35-071-14W4 | 55.198740 | 112.503240 | 404319.5 | 6117937.9 | 566.9 | 20 | Quaternary | 39.0 | 48.2 | July 11, 2000 | 8.3 |
| 12 | 9000002 | 10-10-070-17W4 | 55.051690 | 112.499700 | 404193.4 | 6101571.2 | 566.9 | 20 | Quaternary | 42.7 | 45.7 | July 12, 2000 | 10.4 |
| 13 | 9000003 | 04-24-071-17W4 | 55.156830 | 112.488420 | 405163.5 | 6113254.6 | 548.6 | 20 | Quaternary | 24.4 | 30.5 | July 12, 2000 | 6.8 |
| 14 | 9000004 | 16-22-071-17W4 | 55.169970 | 112.520300 | 403164.0 | 6114760.6 | 562.4 | 20 | Quaternary | 28.0 | 29.6 | July 13, 2000 | 7.2 |
| 15 | 9000005 | 10-36-076-15W4 | 55.631550 | 112.188850 | 425152.1 | 6165714.3 | 569.4 | 20 | Quaternary | 64.9 | 69.5 | July 13, 2000 | 6.4 |
| 16 | 9000006 | 11-10-084-10W4 | 56.271950 | 111.500430 | 469009.1 | 6236460.1 | 652.0 | 20 | Quaternary | 18.0 | 20.4 | July 18, 2000 | 6.5 |
| 17 | 9000007 | 07-09-082-12W4 | 56.093130 | 111.814650 | 449314.9 | 6216743.6 | 742.2 | 20 | Quaternary | 56.1 | 59.1 | July 18, 2000 | 6.5 |
| 18 | 9000010 | 05-22-070-04W4 | 55.073460 | 110.537650 | 529521.6 | 6103063.6 | 672.2 | 20 | Quaternary | 61.0 | 70.7 | July 24, 2000 | 7.6 |
| 19 | 9000011 | 05-22-070-04W4 | 55.073460 | 110.537650 | 529521.6 | 6103063.6 | 672.3 | 20 | Quaternary | 66.9 | 73.0 | July 24, 2000 | 6.9 |
| 20 | 9000013 | 16-31-076-07W4 | 55.628840 | 111.079810 | 494974.8 | 6164774.8 | 571.2 | 20 | Quaternary | 26.5 | 72.7 | July 26, 2000 | 7.2 |
| 21 | 9000014 | 04-35-071-10W4 | 55.187780 | 111.437420 | 472149.6 | 6115774.8 | 662.9 | 20 | Quaternary | 65.5 | 67.1 | July 27, 2000 | 8.3 |
| 22 | 9000016 | 14-26-069-12W4 | 55.007050 | 111.727860 | 453448.5 | 6095818.1 | 585.2 | 20 | Quaternary | 54.9 | 46.4 | March 21, 1989 |  |
| 23 | 9000046 | 13-17-070-17W4 | 55.065766 | 112.494221 | 404576.8 | 6103129.9 | 560.8 | 20 | Quaternary | 33.5 | 35.0 | September 26, 1991 |  |
| 24 | 9000051 | 15-24-070-17W4 | 55.080280 | 112.454887 | 407122.3 | 6104692.0 | 570.0 | 20 | Quaternary | 23.8 | 29.9 | September 13, 1990 |  |
| 25 | 9000264 | 14-34-077-15W4 | 55.719738 | 112.244484 | 421825.8 | 6175589.5 | 617.2 | 20 | Quaternary | 110.0 | 116.4 | August 24, 1983 |  |
| 26 | 9000311 | 07-03-070-17W4 | 55.029363 | 112.506931 | 403678.3 | 6099096.8 | 557.8 | 20 | Quaternary | 16.8 | 22.9 | September 8, 1992 |  |
| 27 | 9000312 | 14-03-070-17W4 | 55.036685 | 112.513280 | 403289.7 | 6099920.6 | 560.8 | 20 | Quaternary | 12.2 | 12.5 | August 12, 1988 |  |
| 28 | 9000314 | 02-25-070-17W4 | 55.083872 | 112.456115 | 407052.3 | 6105093.4 | 570.0 | 20 | Quaternary | 9.7 | 10.1 | September 13, 1990 |  |
| 29 | 9000315 | 02-03-084-11W4 | 56.248077 | 111.648768 | 459797.8 | 6233879.7 | 641.9 | 20 | Quaternary | 15.8 | 27.4 | November 20, 1990 |  |
| 30 | 9000316 | NW-19-086-18W4 | 56.468058 | 112.830515 | 387226.0 | 6259677.2 | 529.0 | 20 | Quaternary | 49.7 | 51.2 | January 27, 1987 |  |
| 31 | 9000317 | NW-15-089-09W4 | 56.722509 | 111.354662 | 478295.1 | 6286553.6 | 246.0 | 20 | Quaternary | 32.0 | 3.5 | August 9, 1989 |  |
| 32 | 2000039 | 09-24-085-09W4 | 56.386505 | 111.275414 | 482994.9 | 6249132.0 | 764.1 | 20 | Quaternary | 34.9 | 36.4 | August 4, 2000 | 5.1 |

Note: < denotes less than.
UTM zone 12, NAD 83

**Appendix A, Table 3. Quaternary Drift-Aquifer Chemistry**

| Field Parameters | | | | | | | | Laboratory Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field pH | Field Cond (µS/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 Temp (°C) | Laboratory pH | Laboratory Cond (µS/cm) | Laboratory P-Alkalinity (mg $CaCO_3$/L) | Laboratory Total Alkalinity (mg $CaCO_3$/L) | Ca (mg/L) | Mg (mg/L) | Na (mg/L) |
| 7.20 | | | | | | | | | 7.70 | 800.0 | | | 77.0 | 30.00 | 61.0 |
| 9.02 | 1513 | -271 | 257 | -14 | 0.8 | <2 | 830 | | 8.85 | 2170.0 | 84 | 867 | 6.0 | 3.45 | 557.0 |
| 7.07 | 402 | -71 | 257 | 186 | 0.3 | <2 | 348 | | 7.24 | 566.0 | <5 | 322 | 105.0 | 19.30 | 4.8 |
| 6.81 | 651 | 127 | 257 | 384 | 0.8 | <2 | 666 | | 7.09 | 1020.0 | <5 | 601 | 168.0 | 50.60 | 4.3 |
| 7.44 | 349 | -155 | 257 | 102 | 0.0 | <2 | 370 | | 7.55 | 551.0 | <5 | 311 | 82.0 | 24.40 | 11.7 |
| 7.48 | 424 | -152 | 256 | 104 | 0.1 | <2 | | | 7.74 | 645.0 | <5 | 313 | 74.4 | 20.20 | 48.0 |
| 7.48 | 382 | -154 | 257 | 103 | 0.1 | <2 | 412 | | 7.65 | 601.0 | <5 | 336 | 81.5 | 24.50 | 24.2 |
| 7.08 | 506 | 69 | 257 | 326 | 0.2 | <2 | 474 | | 7.50 | 770.0 | <5 | 398 | 104.0 | 38.40 | 20.2 |
| 7.17 | 1100 | -49 | 255 | 206 | 0.1 | <2 | 676 | | 7.46 | 1540.0 | <5 | 662 | 101.0 | 48.50 | 167.0 |
| 7.67 | 594 | -136 | 256 | 120 | 0.0 | <2 | 522 | | 8.14 | 896.0 | <5 | 453 | 32.9 | 11.20 | 182.0 |
| 7.13 | 778 | -141 | 255 | 114 | 2.0 | <2 | 418 | | 7.31 | 1050.0 | | | 125.0 | 40.30 | 75.7 |
| 7.44 | 912 | -59 | 254 | 195 | 1.9 | <2 | 480 | | 7.60 | 1160.0 | | | 72.5 | 26.80 | 202.0 |
| 7.18 | 655 | -190 | 256 | 67 | 1.2 | <2 | 436 | | 7.32 | 875.0 | | | 120.0 | 36.50 | 41.6 |
| 7.15 | 610 | -152 | 256 | 104 | 0.2 | <2 | 410 | | 7.22 | 848.0 | <5 | 424 | 125.0 | 35.50 | 23.7 |
| 7.28 | 346 | -145 | 257 | 111 | 2.8 | <2 | 236 | | 7.19 | 467.0 | <5 | 260 | 68.6 | 18.90 | 11.6 |
| 7.28 | 391 | -124 | 257 | 132 | 0.1 | <2 | 286 | | 7.32 | 559.0 | <5 | 294 | 75.3 | 19.00 | 26.3 |
| 7.43 | 413 | -170 | 257 | 86 | 0.1 | <2 | 298 | | 7.37 | 596.0 | <5 | 316 | 76.2 | 18.90 | 34.2 |
| 7.40 | 542 | -174 | 256 | 82 | 0.1 | <2 | 500 | | 7.62 | 735.0 | <5 | 428 | 85.5 | 25.00 | 66.0 |
| 7.36 | 557 | -148 | 256 | 108 | 0.2 | <2 | 510 | | 7.63 | 765.0 | <5 | 454 | 85.5 | 25.30 | 74.5 |
| 7.29 | 427 | -157 | 256 | 99 | 0.2 | <10 | 1200 | | 7.58 | 603.0 | <5 | 353 | 84.0 | 26.90 | 24.6 |
| 7.36 | 818 | -105 | 255 | 150 | 0.2 | <2 | 540 | | 7.54 | 1140.0 | <5 | 529 | 112.0 | 42.40 | 120.0 |
| | | | | | | | | | 7.50 | 690.0 | | | 68.0 | 24.00 | 69.0 |
| | | | | | | | | | 7.66 | 990.0 | | 468 | 78.0 | 24.00 | 123.0 |
| | | | | | | | | | 7.55 | 912.0 | | 439 | 121.0 | 38.00 | 38.0 |
| | | | | | | | | | 8.40 | 660.0 | | 385 | 63.0 | 18.00 | 85.0 |
| | | | | | | | | | 7.44 | 882.0 | | 439 | 139.0 | 32.00 | 10.0 |
| | | | | | | | | | 7.60 | 875.0 | | 401 | 109.0 | 34.00 | 52.0 |
| | | | | | | | | | 7.50 | 675.0 | | 372 | 95.0 | 32.00 | 6.0 |
| | | | | | | | | | 7.33 | 378.0 | | 172 | 55.0 | 11.00 | 7.0 |
| | | | | | | | | | 8.70 | 1670.0 | | 844 | <1 | <1 | 415.0 |
| | | | | | | | | | 7.68 | 784.0 | | 310 | 79.0 | 22.00 | 58.0 |
| 8.09 | 297 | -168 | 258 | 90 | 0.1 | <2 | 310 | | 7.91 | 440.0 | <5 | 239 | 68.8 | 13.60 | 9.8 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

**Appendix A, Table 3. Quaternary Drift-Aquifer Chemistry**

| K (mg/L) | $HCO_3$ (mg/L) | $CO_3$ (mg/L) | Cl (mg/L) | Cl by NAA (ug/mL) | Br by NAA (ug/mL) | I by NAA (ug/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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.5 | 346 | 0 | 78.0 | | | | 36.60 | | 596 | 2.2 | | | | | | | |
| 2.5 | 852 | 101 | 126.0 | | | | 226.00 | 291.00 | 1440 | -1.4 | <0.2 | <0.3 | <0.1 | 221.0 | <0.01 | 0.031 | <0.005 |
| 2.4 | 393 | <6 | 9.4 | 10.50 | 0.02 | 0.01 | 7.84 | 341.00 | 342 | 1.6 | | | | | <0.01 | 0.031 | <0.005 |
| 1.3 | 732 | <6 | <0.5 | 0.93 | 0.05 | 0.01 | 6.87 | 628.00 | 591 | 2.5 | | | | | <0.01 | <0.008 | <0.005 |
| 3.6 | 379 | <6 | <0.5 | 1.31 | 0.01 | <0.01 | 5.11 | 305.00 | 313 | 2.9 | | | | | <0.01 | <0.008 | <0.005 |
| 9.9 | 381 | <6 | 11.0 | 12.80 | 0.01 | <0.01 | 30.20 | 269.00 | 381 | 3.6 | | | | | <0.01 | 0.011 | <0.005 |
| 5.1 | 410 | <6 | 5.0 | 1.83 | 0.01 | <0.01 | 6.08 | 304.00 | 348 | 2.0 | | | | | <0.01 | 0.010 | <0.005 |
| 2.8 | 485 | <6 | 15.9 | 18.70 | 0.03 | <0.01 | 28.00 | 418.00 | 448 | 1.7 | | | | | <0.01 | <0.008 | <0.005 |
| 5.8 | 807 | <6 | 82.7 | 88.00 | 0.36 | 0.46 | 138.00 | 452.00 | 941 | -5.7 | | | | | <0.01 | 0.012 | <0.005 |
| 4.7 | 552 | <6 | 5.4 | 6.87 | 0.06 | 0.03 | 54.20 | 128.00 | 562 | 1.3 | | | | | 0.030 | 0.012 | <0.005 |
| 4.8 | 529 | <6 | 15.3 | 15.10 | 0.08 | 0.02 | 188.00 | 479.00 | 710 | -0.2 | <0.2 | <0.3 | <0.1 | 0.5 | <0.01 | 0.081 | <0.005 |
| 4.7 | 656 | <6 | 34.2 | 44.60 | 0.17 | 0.03 | 108.00 | 291.00 | 771 | 2.7 | <0.2 | <0.3 | <0.1 | 157.0 | <0.01 | 0.039 | <0.005 |
| 4.5 | 537 | <6 | 3.6 | 3.38 | 0.03 | 0.01 | 103.00 | 449.00 | 573 | -0.6 | 0.3 | <0.3 | 0.4 | 176.0 | <0.01 | 0.052 | <0.005 |
| 4.4 | 517 | <6 | 4.4 | 2.25 | 0.02 | 0.00 | 101.00 | 457.00 | 547 | -1.9 | 0.4 | <0.3 | 0.6 | 155.0 | <0.01 | 0.057 | <0.005 |
| 3.2 | 317 | <6 | 1.2 | 0.28 | 0.01 | <0.01 | 21.50 | 249.00 | 281 | -1.0 | 0.2 | <0.3 | 0.2 | 105.0 | 0.010 | 0.033 | <0.005 |
| 4.2 | 359 | <6 | 0.9 | 0.63 | <0.02 | 0.01 | 20.50 | 266.00 | 323 | 1.8 | <0.2 | <0.3 | <0.1 | 107.0 | <0.001 | 0.008 | <0.005 |
| 6.6 | 385 | <6 | 0.8 | 0.18 | <0.04 | <0.01 | 21.00 | 268.00 | 347 | 1.8 | 0.3 | <0.3 | 0.3 | 113.0 | 0.020 | 0.030 | <0.005 |
| 4.6 | 521 | <6 | 3.2 | 2.94 | 0.04 | 0.03 | 19.80 | 316.00 | 461 | 1.5 | | | | | <0.01 | 0.017 | <0.005 |
| 5.0 | 554 | <6 | 2.8 | 3.39 | 0.05 | 0.03 | 18.40 | 318.00 | 484 | 0.9 | 0.2 | <0.3 | 0.4 | 147.0 | <0.01 | 0.017 | <0.005 |
| 4.0 | 431 | <6 | <0.5 | 0.72 | <0.04 | 0.01 | 8.26 | 320.00 | 360 | 2.3 | 0.2 | <0.3 | 0.2 | 126.0 | <0.01 | 0.038 | <0.005 |
| 10.6 | 645 | <6 | 4.8 | 4.33 | <0.05 | 0.04 | 178.00 | 453.00 | 785 | 0.5 | <0.2 | <0.3 | 0.2 | 163.0 | 0.020 | 0.028 | <0.005 |
| 3.0 | 460 | | 6.0 | | | | 24.00 | | 440 | 1.4 | | | | | | | |
| 5.1 | 571 | | 8.0 | | | | 80.00 | | 600 | 0.4 | | | | | | | |
| 4.8 | 535 | | 1.0 | | | | 95.00 | | 561 | 0.8 | | | | | | | |
| 5.5 | 459 | 5 | <2 | | | | 34.00 | | 439 | 1.2 | | | | | | | |
| 3.4 | 535 | | 0.8 | | | | 62.00 | | 511 | 0.0 | | | | | | | |
| 3.2 | 489 | | 12.0 | | | | 65.00 | | 516 | 4.3 | | | | | | | |
| 2.6 | 453 | | 1.0 | | | | 12.00 | | 372 | 0.0 | | | | | | | |
| | 210 | | 16.0 | | | | 2.00 | | 231 | 0.2 | | | | | | | |
| 1.8 | 944 | 42 | 58.0 | | | | <5 | | 988 | 2.8 | | | | | | | |
| 3.1 | 378 | | 46.0 | | | | 48.00 | | 443 | -0.8 | | | | | | | |
| 25.5 | 291 | <6 | <0.5 | 1.84 | <0.012 | <0.01 | 17.50 | 228.00 | 278 | 4.5 | <0.2 | <0.3 | <0.1 | 95.2 | <0.01 | 0.044 | <0.005 |

**Appendix A, Table 3. Quaternary Drift-Aquifer Chemistry**

| 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) | 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | |
| 0.0227 | <0.0005 | <0.007 | 3.700 | <0.0005 | <0.0008 | 0.0025 | 0.111 | 0.007 | <0.002 | 0.081 | 0.005 | <0.0001 | <0.001 | 0.073 | 0.64 | <0.004 | 2.920 | 27.7 |
| 0.2830 | <0.0005 | <0.007 | 0.060 | <0.0005 | <0.0008 | 0.0033 | 0.002 | 0.051 | 0.005 | 0.023 | 1.300 | <0.0001 | <0.001 | 0.004 | <0.03 | <0.004 | 8.510 | 42.7 |
| 0.1570 | <0.0005 | <0.007 | 0.037 | <0.0005 | <0.0008 | 0.0010 | <0.001 | 0.094 | <0.002 | 0.020 | 0.025 | <0.0001 | <0.001 | 0.003 | <0.03 | <0.004 | 10.700 | 20.7 |
| 0.1720 | <0.0005 | 0.008 | 0.088 | <0.0005 | <0.0008 | 0.0007 | 0.002 | 0.056 | <0.002 | 0.032 | 0.377 | <0.0001 | <0.001 | <0.001 | <0.03 | <0.004 | 11.000 | 18.1 |
| 0.1750 | <0.0005 | <0.007 | 0.116 | <0.0005 | <0.0008 | 0.0017 | 0.002 | 0.048 | <0.002 | 0.034 | 0.791 | <0.0001 | 0.010 | <0.001 | <0.03 | <0.004 | 9.340 | 17.1 |
| 0.2440 | <0.0005 | <0.007 | 0.158 | <0.0005 | <0.0008 | <0.0007 | 0.002 | 0.057 | <0.002 | 0.040 | 0.121 | <0.0001 | <0.001 | <0.001 | <0.03 | 0.004 | 11.800 | 18.9 |
| 0.1610 | <0.0005 | 0.007 | 0.066 | <0.0005 | <0.0008 | 0.0009 | 0.002 | 0.071 | <0.002 | 0.030 | 0.091 | <0.0001 | 0.001 | <0.001 | <0.03 | <0.004 | 11.700 | 17.0 |
| 0.0301 | <0.0005 | <0.007 | 0.330 | <0.0005 | <0.0008 | 0.0024 | 0.001 | 0.081 | <0.002 | 0.062 | 0.077 | <0.0001 | 0.002 | <0.001 | 0.11 | <0.004 | 11.000 | 17.8 |
| 0.0718 | <0.0005 | <0.007 | 0.487 | <0.0005 | <0.0008 | 0.0017 | 0.004 | 0.024 | <0.002 | 0.048 | 0.127 | <0.0001 | 0.034 | 0.002 | 0.39 | <0.004 | 14.900 | 21.4 |
| 0.0468 | <0.0005 | 0.112 | 0.405 | <0.0005 | <0.0008 | 0.0012 | 0.004 | 6.900 | <0.002 | 0.094 | 0.367 | <0.0001 | <0.001 | <0.001 | 0.49 | <0.004 | 8.480 | 41.6 |
| 0.0785 | <0.0005 | 0.019 | 0.517 | <0.0005 | <0.0008 | 0.0018 | 0.005 | 0.531 | <0.002 | 0.080 | 0.047 | <0.0001 | <0.001 | 0.004 | 0.25 | <0.004 | 7.570 | 36.3 |
| 0.0965 | <0.0005 | <0.007 | 0.214 | 0.0010 | <0.0008 | 0.0009 | 0.004 | 7.800 | <0.002 | 0.060 | 0.266 | <0.0001 | <0.001 | <0.001 | 0.59 | <0.004 | 9.720 | 47.6 |
| 0.0880 | <0.0005 | <0.007 | 0.208 | 0.0009 | <0.0008 | 0.0008 | 0.004 | 7.330 | <0.002 | 0.066 | 0.138 | <0.0001 | <0.001 | <0.001 | 0.58 | <0.004 | 10.900 | 53.5 |
| 0.0826 | <0.0005 | <0.007 | 0.099 | 0.0013 | <0.0008 | 0.0007 | 0.004 | 11.200 | <0.002 | 0.033 | 0.576 | <0.0001 | 0.003 | <0.001 | 0.76 | <0.004 | 10.100 | 48.9 |
| 0.0731 | <0.0005 | <0.007 | 0.186 | <0.0005 | <0.0008 | 0.0018 | 0.002 | 0.761 | <0.002 | 0.045 | 0.266 | <0.0001 | 0.006 | 0.004 | 0.25 | <0.004 | 9.920 | 13.6 |
| 0.1750 | <0.0005 | <0.007 | 0.308 | <0.0005 | <0.0008 | 0.0014 | 0.002 | 4.200 | <0.002 | 0.049 | 0.259 | <0.0001 | 0.015 | <0.001 | 0.47 | <0.004 | 10.300 | 46.1 |
| 0.0800 | <0.0005 | <0.007 | 0.168 | <0.0005 | <0.0008 | 0.0011 | 0.005 | 0.014 | <0.002 | 0.050 | 0.149 | <0.0001 | 0.003 | 0.005 | 0.06 | <0.004 | 12.900 | 21.2 |
| 0.0965 | <0.0005 | <0.007 | 0.176 | <0.0005 | <0.0008 | <0.0007 | 0.004 | 0.019 | <0.002 | 0.053 | 0.134 | <0.0001 | 0.003 | <0.001 | 0.05 | <0.004 | 12.800 | 20.8 |
| 0.1400 | <0.0005 | <0.007 | 0.122 | <0.0005 | <0.0008 | 0.0007 | 0.004 | 0.019 | <0.002 | 0.029 | 0.194 | <0.0001 | <0.001 | <0.001 | 0.04 | <0.004 | 11.300 | 20.7 |
| 0.0251 | <0.0005 | <0.007 | 0.209 | <0.0005 | <0.0008 | 0.0015 | 0.003 | 0.027 | <0.002 | 0.064 | 0.794 | <0.0001 | 0.005 | <0.001 | 0.03 | <0.004 | 9.280 | 19.2 |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | 0.160 | | | | | | | | | | |
| | | | | | | | | 4.480 | | | | | | | | | | |
| | | | | | | | | 2.400 | | | | | | | | | | |
| | | | | | | | | 5.310 | | | | | | | | | | |
| | | | | | | | | 0.760 | | | | | | | | | | |
| | | | | | | | | 4.190 | | | | | | | | | | |
| | | | | | | | | 3.930 | | | | | | | | | | |
| | | | | | | | | 0.100 | | | | | | | | | | |
| | | | | | | | | 0.770 | | | | | | | | | | |
| 0.1260 | <0.0005 | <0.007 | 0.073 | <0.0005 | <0.0008 | <0.0007 | 0.008 | 0.013 | <0.002 | 0.054 | 0.282 | <0.0001 | 0.002 | 0.006 | <0.03 | <0.004 | 11.300 | 10.4 |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |

**Appendix A, Table 3. Quaternary Drift-Aquifer Chemistry**

| 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) |
|---|---|---|---|---|---|---|---|---|
| 19.0 | | | | | | | | |
| | 59.5 | <0.001 | 0.2740 | 75.300 | <0.004 | <0.0004 | <0.001 | 0.0017 |
| | 91.5 | 0.001 | 0.4120 | 2.610 | <0.004 | <0.0004 | <0.001 | 0.0055 |
| | 44.3 | <0.001 | 0.1570 | 2.290 | <0.004 | <0.0004 | 0.001 | 0.0011 |
| | 38.8 | <0.001 | 0.3900 | 1.700 | <0.004 | <0.0004 | <0.001 | 0.0010 |
| | 36.6 | <0.001 | 0.4070 | 10.100 | <0.004 | <0.0004 | <0.001 | 0.0009 |
| | 40.5 | <0.001 | 0.5540 | 2.030 | <0.004 | <0.0004 | <0.001 | 0.0006 |
| | 38.9 | <0.001 | 0.2690 | 9.330 | <0.004 | <0.0004 | 0.004 | 0.0017 |
| | 38.1 | <0.001 | 0.6030 | 46.000 | <0.004 | <0.0004 | 0.002 | 0.0008 |
| | 45.7 | <0.001 | 0.3140 | 18.100 | <0.004 | 0.0009 | <0.001 | 0.0006 |
| | 89.0 | <0.001 | 0.9200 | 62.700 | <0.004 | <0.0004 | 0.003 | 0.0139 |
| | 77.5 | <0.001 | 0.7910 | 36.100 | <0.004 | <0.0004 | 0.003 | 0.0651 |
| | 102.0 | <0.001 | 0.7470 | 34.500 | <0.004 | <0.0004 | 0.002 | 0.0032 |
| | 114.5 | <0.001 | 0.9000 | 33.500 | <0.004 | <0.0004 | 0.002 | 0.0044 |
| | 104.5 | <0.001 | 0.3700 | 7.160 | <0.004 | <0.0004 | <0.001 | 0.0048 |
| | 29.0 | <0.001 | 0.4890 | 6.840 | <0.004 | <0.0004 | 0.002 | 0.0180 |
| | 98.5 | <0.001 | 0.7490 | 6.990 | <0.004 | <0.0004 | <0.001 | 0.0163 |
| | 45.3 | 0.001 | 0.5140 | 6.620 | <0.004 | <0.0004 | <0.001 | 0.0049 |
| | 44.5 | <0.001 | 0.5470 | 6.130 | <0.004 | <0.0004 | <0.001 | 0.0027 |
| | 44.1 | 0.001 | 0.4120 | 2.750 | <0.004 | <0.0004 | <0.001 | 0.0041 |
| | 41.1 | 0.001 | 0.5940 | 59.300 | <0.004 | <0.0004 | 0.001 | 0.0176 |
| 10.0 | | | | | | | | |
| 14.9 | | | | | | | | |
| 17.0 | | | | | | | | |
| | | | | | | | | |
| 17.2 | | | | | | | | |
| 18.0 | | | | | | | | |
| 17.5 | | | | | | | | |
| | | | | | | | | |
| 6.4 | | | | | | | | |
| 10.0 | | | | | | | | |
| 22.2 | | <0.001 | 0.6940 | 5.840 | <0.004 | <0.0004 | <0.001 | 0.0039 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

**Appendix A, Table 4. Quaternary Drift-Aquifer Isotope Chemistry**

| Key | Site ID | Chemistry Number | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (m) | Formation | Completion Depth Top (m) | Completion Depth Bottom (m) | Sample Date | $^{87}Sr/^{86}Sr$ | $\delta^{13}C$ (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 | 2000045 | 7 | 16-02-087-09W4 | 56.520851 | 111.309494 | 480958.0 | 6264094.3 | 429.77 | Quaternary | 7.0 | 8.5 | August 3, 2000 | 0.708043 | -12.7 | -19.4 | -147 |  | 9.8 | 43 | <0.09 | <0.15 | <0.07 | <0.08 |
| 3 | 2001003 | 1 | 07-36-077-15W4 | 55.714398 | 112.187874 | 425371.4 | 6174932.8 | 662.48 | Quaternary | 5.1 | 8.2 | June 22, 2001 | 0.709585 | -14.8 | -18.5 | -141 | 14.1 | 0.1 |  |  |  |  |  |
| 4 | 2001006 | 1 | 06-33-074-09W4 | 55.451416 | 111.329831 | 479138.6 | 6145075.9 | 666.83 | Quaternary | 9.3 | 15.4 | May 9, 2001 | 0.716735 | -16.0 | -17.6 | -134 |  | 2.1 |  |  |  |  |  |
| 5 | 2001007 | 1 | 06-33-074-09W4 | 55.451377 | 111.329824 | 479139.0 | 6145071.6 | 667.10 | Quaternary | 37.9 | 41.0 | May 8, 2001 | 0.711154 | -12.6 | -18.4 | -140 |  | 15.4 |  |  |  |  |  |
| 6 | 2001008 | 1 | 06-33-074-09W4 | 55.451383 | 111.329959 | 479130.8 | 6145072.1 | 666.99 | Quaternary | 72.4 | 75.4 | May 8, 2001 | 0.710660 | -12.5 | -18.3 | -139 |  | -1.4 | 7.0 |  |  |  |  |
| 7 | 2001009 | 1 | 06-33-074-09W4 | 55.451376 | 111.329890 | 479135.2 | 6145071.6 | 666.92 | Quaternary | 117.3 | 120.3 | May 9, 2001 | 0.709869 | -12.9 | -18.4 | -141 |  | 6.0 |  |  |  |  |  |
| 8 | 2001012 | 1 | 15-04-075-05W4 | 55.473040 | 110.707298 | 518502.7 | 6147472.0 | 648.17 | Quaternary | 11.2 | 17.3 | May 11, 2001 | 0.713601 | -13.2 | -18.4 | -142 |  | 0.6 |  |  |  |  |  |
| 9 | 2001013 | 1 | 15-04-075-05W4 | 55.473007 | 110.707318 | 518501.3 | 6147468.2 | 648.26 | Quaternary | 76.6 | 79.6 | May 11, 2001 | 0.711419 | -21.5 | -21.4 | -157 |  | 12.3 | 13.7 |  |  |  |  |
| 10 | 2001014 | 1 | 15-04-075-05W4 | 55.472975 | 110.707334 | 518500.4 | 6147164.8 | 648.20 | Quaternary | 155.4 | 158.5 | May 10, 2001 | 0.708855 | -19.4 | -18.2 | -139 |  | 17.9 |  |  |  |  |  |
| 11 | 9000001 | 1 | 16-35-071-14W4 | 55.198740 | 112.503240 | 404319.5 | 6117937.9 | 566.93 | Quaternary | 39.0 | 48.2 | July 11, 2000 | 0.708067 | -12.8 | -19.7 | -149 |  | -4.9 | 34 | <0.12 | <0.15 | <0.08 |  |
| 12 | 9000002 | 1 | 10-10-070-17W4 | 55.051690 | 112.499700 | 404193.4 | 6101571.2 | 566.93 | Quaternary | 42.7 | 45.7 | July 12, 2000 | 0.708042 | -14.5 | -19.5 | -145 |  | 0.2 | 25 | <0.08 | <0.13 | <0.06 | <0.10 |
| 13 | 9000003 | 1 | 04-24-071-17W4 | 55.156830 | 112.488420 | 405163.5 | 6113254.6 | 548.64 | Quaternary | 24.4 | 30.5 | July 12, 2000 | 0.708804 | -14.2 | -18.3 | -142 |  | -2.4 | 16 | <0.11 | <0.17 | <0.09 | <0.07 |
| 14 | 9000004 | 1 | 16-22-071-17W4 | 55.169970 | 112.520300 | 403164.0 | 6114760.6 | 562.36 | Quaternary | 28.0 | 29.6 | July 13, 2000 | 0.708286 | -13.3 | -19.2 | -144 |  | -7.1 | 13 | <0.09 | <0.13 | <0.07 | <0.08 |
| 15 | 9000005 | 1 | 10-36-076-15W4 | 55.631550 | 112.188850 | 425152.1 | 6165714.3 | 569.37 | Quaternary | 64.9 | 69.5 | July 13, 2000 | 0.709044 | -14.2 | -18.5 | -142 |  | -3.1 | 7 | <0.09 | <0.14 | 0.16 | <0.08 |
| 16 | 9000006 | 1 | 11-10-084-10W4 | 56.271950 | 111.500430 | 469009.1 | 6236460.1 | 651.97 | Quaternary | 18.0 | 20.4 | July 18, 2000 | 0.709029 | -12.4 | -18.9 | -144 |  | -1.8 | 12 | <0.08 | <0.13 | <0.06 | <0.09 |
| 17 | 9000007 | 1 | 07-09-082-12W4 | 56.093130 | 111.814650 | 449314.9 | 6216743.6 | 742.19 | Quaternary | 56.1 | 59.1 | July 18, 2000 | 0.708761 | -15.0 | -19.7 | -150 |  | 8.8 | 22 | <0.08 | <0.11 | <0.06 | <0.09 |
| 18 | 9000010 | 1 | 05-22-070-04W4 | 55.073460 | 110.537650 | 529521.6 | 6103063.6 | 672.20 | Quaternary | 61.0 | 70.7 | July 24, 2000 | 0.709689 | -14.8 | -18.4 | -143 |  | 11.2 | 11 | <0.09 | <0.12 | <0.06 | <0.09 |
| 19 | 9000011 | 1 | 05-22-070-04W4 | 55.073460 | 110.537650 | 529521.6 | 6103063.6 | 672.29 | Quaternary | 66.9 | 73.0 | July 24, 2000 | 0.709630 | -14.2 | -18.4 | -142 |  | 11.6 | 13 | <0.07 | <0.13 | <0.06 | <0.08 |
| 19 | 9000011 | 2 | 05-22-070-04W4 | 55.073460 | 110.537650 | 529521.6 | 6103063.6 | 672.29 | Quaternary | 66.9 | 73.0 | July 24, 2000 |  |  | -17.7 | -140 |  |  |  |  |  |  |  |
| 20 | 9000013 | 1 | 16-31-076-07W4 | 55.628840 | 111.079810 | 494974.8 | 6164774.8 | 571.20 | Quaternary | 26.5 | 72.7 | July 26, 2000 | 0.710485 | -15.1 | -19.4 | -143 |  | 17.0 | 23 | <0.11 | <0.19 | <0.09 | <0.08 |
| 21 | 9000014 | 1 | 04-35-071-10W4 | 55.187780 | 111.437420 | 472149.6 | 6115774.8 | 662.94 | Quaternary | 65.5 | 67.1 | July 27, 2000 | 0.710211 | -16.5 | -19.6 | -149 |  | -4.6 | 27 | <0.07 | <0.11 | <0.06 | <0.08 |
| 32 | 2000039 | 6 | 09-24-085-09W4 | 56.386505 | 111.275414 | 482994.9 | 6249132.0 | 764.13 | Quaternary | 34.9 | 36.4 | August 4, 2000 | 0.709744 | -13.9 | -19.8 | -146 |  | 1.8 | 20 | <0.08 | <0.13 | <0.06 | <0.08 |

Note: UTM Zone 12, NAM 83

## Appendix B, Table 5. Quaternary-Tertiary Buried Channel-Aquifer Chemistry

| Key | Site ID | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (masl) | EUB Formation Code | Formation | Completion Depth Top (m) | Completion Depth Bottom (m) | Sample Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 2001004 | 07-36-077-15W4 | 55.714379 | 112.187915 | 425369.0 | 6174930.7 | 662.4 | 20 | Quaternary | 227.5 | 230.6 | May 24, 2001 |
| 34 | 9000012 | 12-01-073-06W4 | 55.293860 | 110.799660 | 512721.6 | 6127511.1 | 713.2 | 20 | Quaternary | 275.5 | 284.7 | July 25, 2000 |
| 35 | 9000367 | 13-21-073-07W4 | 55.341278 | 111.031660 | 497991.9 | 6132770.0 | 728.8 | 20 | Quaternary | 290.0 | 300.0 | April 26, 2001 |
| | | | | | | | | | | | | |
| note: | < denotes less than | | | | | | | | | | | |
| | UTM Zone 12, NAD 83 | | | | | | | | | | | |

**Appendix B, Table 5. Quaternary-Tertiary Buried Channel-Aquifer Chemistry**

| Field Parameters | | | | | | | | | Laboratory Parameters | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field Temp (°C) | Field pH | Field Cond (µS/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 Temp (°C) | Laboratory pH | Laboratory Cond (µS/cm) | Laboratory P-Alkalinity (mg $CaCO_3$/L) | Laboratory Total Alkalinity (mg $CaCO_3$/L) |
| 6.0 | 7.72 | 492 | -171 | 257 | 86 | 0.1 | <2 | 406 | | 7.77 | 744.0 | <5 | 395 |
| 8.6 | 7.99 | 593 | -208 | 255 | 47 | 0.0 | <2 | 480 | | 8.13 | 787.0 | <5 | 425 |
| 7.6 | 7.90 | 689 | 22 | 256 | 278 | 2.3 | <2 | 564 | 18.2 | 8.36 | 832.0 | <5 | 495 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

## Appendix B, Table 5. Quaternary-Tertiary Buried Channel-Aquifer Chemistry

| 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 (ug/mL) | Br by NAA (ug/mL) | I by NAA (ug/mL) | $SO_4$ (mg/L) | Hardness (mg/L $CaCO_3$) | TDS (mg/L) | Charge Balance Error (%) | $SiO_2$ (mg/L) | Acetic acid (mg/L) | Butyric acid (mg/L) | Formic acid (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64.8 | 18.70 | 98.9 | 5.4 | 482 | <6 | <0.5 | 0.44 | 0.01 | <0.01 | 38.10 | 239.00 | 463 | 2.9 | | | | |
| 25.2 | 8.56 | 171.0 | 3.2 | 518 | <6 | 35.1 | 44.00 | 0.29 | 0.18 | 10.60 | 98.30 | 509 | -1.1 | | | | |
| 7.4 | 3.47 | 215.0 | 2.0 | 603 | <6 | 16.5 | 15.80 | 0.08 | 0.06 | 3.80 | 32.70 | 544 | -1.8 | | <0.2 | <0.3 | <0.1 |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

**Appendix B, Table 5. Quaternary-Tertiary Buried Channel-Aquifer Chemistry**

| Propionic acid (mg/L) | Extractable Si (mg/L) | Extractable Silica (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) | Li (mg/L) | Mn (mg/L) | Hg (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 18.3 | 39.1 | 0.020 | <0.080 | <0.005 | 0.0966 | <0.0005 | <0.007 | 0.360 | <0.0005 | <0.0008 | 0.0011 | 0.002 | 0.051 | <0.002 | 0.064 | 0.099 | <0.0001 |
|  | 17.7 | 38.0 | 0.020 | 0.036 | <0.005 | 0.1560 | <0.0005 | <0.007 | 0.333 | <0.0005 | <0.0008 | 0.0007 | 0.003 | 0.205 | <0.002 | 0.032 | 0.044 | <0.0001 |
| 164.0 | 35.7 | 76.5 | 0.010 | 0.021 | 0.005 | 0.1360 | 0.0005 | 0.007 | 0.438 | 0.0005 | 0.0008 | 0.0024 | 0.003 | 0.133 | <0.002 | 0.018 | 0.013 | <0.0001 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

## Appendix B, Table 5. Quaternary-Tertiary Buried Channel-Aquifer Chemistry

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mo (mg/L)** | **Ni (mg/L)** | **P (mg/L)** | **Se (mg/L)** | **Si (mg/L)** | **Ag (mg/L)** | **Sr (mg/L)** | **S (mg/L)** | **Tl (mg/L)** | **Ti (mg/L)** | **V (mg/L)** | **Zn (mg/L)** |
| 0.009 | <0.001 | 0.17 | <0.004 | 11.600 | <0.001 | 0.4970 | 12.700 | <0.004 | <0.0004 | <0.001 | 0.0007 |
| 0.014 | <0.001 | 0.65 | <0.004 | 7.630 | <0.001 | 0.3060 | 3.540 | <0.004 | <0.0004 | 0.002 | 0.0017 |
| 0.038 | 0.002 | 2.03 | <0.004 | 7.670 | <0.001 | 0.1050 | 1.270 | <0.004 | 0.0005 | <0.001 | 0.0041 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

## Appendix B, Table 6. Quaternary-Tertiary Buried Channel-Aquifer Isotope Chemistry

| Key | Site ID | Chemistry Number | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (m) | Formation | Completion Depth Top (m) | Completion Depth Bottom (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 2001004 | 1 | 07-36-077-15W4 | 55.714379 | 112.187915 | 425369.0 | 6174930.7 | 662.40 | Quaternary | 227.5 | 230.7 |
| 34 | 9000012 | 1 | 12-01-073-06W4 | 55.293860 | 110.799660 | 512721.6 | 6127511.1 | 713.23 | Quaternary | 275.5 | 284.7 |
| 35 | 9000367 | 1 | 13-21-073-07W4 | 55.341278 | 111.031660 | 497991.9 | 6132770.0 | 728.79 | Quaternary | 290.0 | 300.0 |

| Key | Site ID | 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 | 2001004 | May 24, 2001 | 0.708788 | -14.0 | -18.3 | -144 |  | 6.7 |  |
| 34 | 9000012 | July 25, 2000 | 0.708726 | -18.4 | -17.6 | -142 |  | 40.8 | 25 |
| 35 | 9000367 | 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

## Appendix C, Table 7. Lower Cretaceous-Viking, Colony, Grand Rapids and Clearwater Formation Water Chemistry

| Key | Site ID | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (masl) | EUB Formation Code | Formation or Member | Completion Depth Top (m) | Completion Depth Bottom (m) | Sample Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | 102661 | 00/04-11-067-13W4-0 | 54.779682 | 111.880104 | 443393.7 | 6070630.3 | 575.6 | 2620 | Grand Rapids | 314.0 | 315.0 | December 12, 2000 |
| 37 | 103831 | 00/04-26-068-13W4-0 | 54.909420 | 111.882843 | 443399.4 | 6085068.7 | 584.6 | 2140 | Viking | 249.9 | 252.4 | January 7, 2001 |
| 38 | 105768 | 00/05-26-070-16W4-0 | 55.089283 | 112.337989 | 414603.6 | 6105544.5 | 578.8 | 2620 | Grand Rapids | 290.0 | 291.5 | January 16, 2001 |
| 39 | 107271 | 00/07-13-072-11W4-0 | 55.234301 | 111.553037 | 464829.5 | 6121004.3 | 650.9 | 2620 | Grand Rapids | 311.7 | 313.2 | January 5, 2001 |
| 40 | 110385 | 00/06-24-077-09W4-0 | 55.685520 | 111.262275 | 483509.9 | 6171110.9 | 569.1 | 2800 | Clearwater | 261.5 | 267.0 | August 25, 2000 |
| 41 | 142553 | 00/06-24-077-09W4-0 | 55.685964 | 111.105006 | 493398.2 | 6171134.0 | 553.6 | 2800 | Clearwater | 242.0 | 250.0 | August 25, 2000 |
| 42 | 170361 | 00/11-26-069-11W4-0 | 55.005390 | 111.572071 | 463410.8 | 6095540.9 | 629.4 | 2140 | Viking | 270.5 | 271.5 | January 10, 2001 |
| 43 | 170634 | 00/10-21-077-08W4-0 | 55.686310 | 111.179013 | 488744.9 | 6171182.1 | 562.8 | 2800 | Clearwater | 256.0 | 260.5 | August 25, 2000 |
| 44 | 183134 | 00/10-33-065-03W4-0 | 54.670586 | 110.390694 | 539294.9 | 6058306.0 | 612.0 | 2620 | Grand Rapids | 304.8 | 305.7 | February 6, 2001 |
| 45 | 219663 | 00/10-21-069-15W4-2 | 54.990913 | 112.222900 | 421757.2 | 6094464.2 | 546.2 | 2560 | Colony | 319.7 | 320.4 | January 5, 2001 |
| 46 | 232669 | 00/07-01-067-15W4-2 | 54.768154 | 112.148811 | 426090.7 | 6069597.6 | 582.6 | 2560 | Colony | 335.0 | 336.0 | August 24, 2000 |
| 47 | 2000046 | 16-02-087-09W4 | 56.520851 | 111.309494 | 480958.0 | 6264094.3 | 429.2 | 2620 | Grand Rapids | 28.2 | 32.8 | July 3, 2000 |
| 48 | 9000015 | 07-36-085-07W4 | 56.411712 | 110.964122 | 502214.0 | 6251904.2 |  | 2620 | Grand Rapids | 82.6 | 89.1 | July 16, 2000 |
| 49 | 9000008 | 07-02-085-06W4 | 56.339120 | 110.832000 | 510385.8 | 6243836.3 | 483.1 | 2620 | Grand Rapids | 69.8 | 72.8 | July 19, 2000 |
| 50 | 9000009 | 15-05-086-07W4 | 56.448860 | 111.040080 | 497529.5 | 6256039.1 | 477.9 | 2620 | Grand Rapids | 48.2 | 49.7 | July 19, 2000 |

Note: < denotes less than
UTM Zone 12, NAD 83

## Appendix C, Table 7. Lower Cretaceous-Viking, Colony, Grand Rapids and Clearwater Formation Water Chemistry

| Field Temp (°C) | Field pH | Field Cond (µS/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 Temp (°C) | Laboratory pH | Laboratory Cond (µS/cm) | Laboratory P-Alkalinity (mg $CaCO_3$/L) | Laboratory Total Alkalinity ($CaCO_3$/L)) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.4 | 7.77 | 50100 | 166 | 247 | 413 | 6.5 | <2 | 220 |  | 7.75 | 42301.2 | <5 | 144 |
| 21.7 | 7.57 | 48600 | 157 | 246 | 403 | 5.6 | <2 | 220 |  | 7.68 | 38001.1 | <5 | 119 |
| 22.2 | 7.35 | 37300 | 164 | 246 | 410 | 6.1 | <2 | 238 |  | 7.56 | 30500.8 | <5 | 169 |
| 21.9 | 8.65 | 5880 | 132 | 246 | 378 | 5.6 | <2 | 954 |  | 8.67 | 3810.0 | 72 | 988 |
| 12.2 | 8.30 | 9790 | 144 | 253 | 397 | 6.1 | <2 | 600 |  | 8.41 | 9260.0 | 31 | 598 |
| 22.6 | 8.27 | 11070 | 134 | 246 | 380 | 6.6 | <2 | 470 |  | 8.40 | 8440.0 | 27 | 436 |
| 21.5 | 7.31 | 41100 | 122 | 247 | 369 | 6.0 | <2 | 236 |  | 7.51 | 32900.1 | <5 | 172 |
| 17.7 | 8.20 | 11120 | 120 | 249 | 369 | 6.8 | <2 | 482 |  | 8.36 | 9310.0 | 13 | 484 |
| 22.0 | 7.88 | 22200 | 137 | 246 | 383 | 3.2 | <2 | 648 |  | 8.00 | 18300.3 | <5 | 628 |
| 21.8 | 7.52 | 36800 | 163 | 246 | 409 | 5.7 | <2 | 230 |  | 7.56 | 30700.3 | <5 | 129 |
| 21.1 | 6.98 | 52600 | -36 | 247 | 211 | 7.1 | <2 | 177 |  | 7.59 | 46801.1 | <5 | 103 |
| 6.7 | 7.59 | 757 | -122 | 256 | 134 | 0.9 | <2 | 560 |  | 7.79 | 1100.0 | <5 | 497 |
| 4.4 | 7.76 | 746 | -223 | 258 | 35 | 0.1 |  |  |  | 7.72 | 1110.0 | <5 | 599 |
| 6.3 | 8.97 | 1163 | -309 | 257 | -52 | 0.0 | <2 | 764 |  | 8.72 | 1690.0 | 47 | 819 |
| 8.9 | 9.04 | 784 | -204 | 255 | 51 | 0.1 | <2 | 546 |  | 8.81 | 1100.0 | 58 | 587 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Appendix C, Table 7. Lower Cretaceous-Viking, Colony, Grand Rapids and Clearwater Formation Water Chemistry**

| 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 (ug/mL) | Br by NAA (ug/mL) | I by NAA (ug/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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 485.0 | 236.00 | 10700.0 | 59.2 | 176 | <6 | 16800.0 | 19300.00 | 59.30 | 10.50 | 0.60 | 2180.00 | 28400 | 3.4 | <4 | <6 | <2 |
| 283.0 | 198.00 | 10100.0 | 52.3 | 146 | <6 | 16300.0 | 17900.00 | 66.60 | 12.40 | 1.79 | 1520.00 | 27000 | 1.0 | <0.2 | <0.3 | <0.1 |
| 233.0 | 131.00 | 7650.0 | 37.0 | 205 | <6 | 11900.0 | 12800.00 | 37.60 | 7.66 | <0.20 | 1120.00 | 20000 | 2.5 | <4 | <6 | <2 |
| 3.4 | 2.12 | 989.0 | 3.9 | 1030 | 86 | 838.0 | 919.00 | 2.89 | 0.68 | 0.58 | 17.20 | 2430 | 0.1 | <0.2 | <0.3 | 0.2 |
| 12.0 | 10.60 | 2020.0 | 5.9 | 911 | <6 | 2710.0 | 2940.00 | 9.54 | 1.93 | <0.20 | 74.00 | 5120 | -1.0 | <0.2 | <0.3 | <0.1 |
| 11.0 | 8.44 | 1800.0 | 5.2 | 465 | 33 | 2590.0 | 3010.00 | 8.18 | 1.78 | 0.49 | 61.00 | 4680 | -1.3 | <0.2 | <0.3 | <0.1 |
| 210.0 | 142.00 | 8680.0 | 33.3 | 209 | <6 | 13100.0 | 14600.00 | 51.00 | 10.60 | 1.72 | 1110.00 | 22300 | 3.6 | <0.2 | <0.3 | <0.1 |
| 12.0 | 10.60 | 2040.0 | 6.3 | 558 | 16 | 2900.0 | 3280.00 | 10.80 | 2.13 | <0.20 | 74.00 | 5250 | -0.6 | <0.2 | <0.3 | <0.1 |
| 48.6 | 40.90 | 4300.0 | 20.2 | 765 | <6 | 6490.0 | 6610.00 | 21.20 | 3.79 | 0.85 | 289.00 | 11300 | -0.6 | <1 | <2 | <0.5 |
| 264.0 | 127.00 | 7790.0 | 39.0 | 158 | <6 | 11900.0 | 12900.00 | 39.20 | 7.90 | 6.10 | 1190.00 |  | 3.6 | <4 | <6 | <2 |
| 528.0 | 249.00 | 10700.0 | 45.0 | 125 | <6 | 18000.0 | 19500.00 | 60.10 | 10.10 | 5.40 | 2340.00 | 29600 | 0.3 | <0.2 | <0.3 | <0.1 |
| 46.4 | 16.40 | 210.0 | 3.0 | 606 | <6 | 73.5 | 77.10 | <0.06 | <0.01 | 31.20 | 183.00 | 679 | 0.9 | <0.2 | <0.3 | <0.1 |
| 77.0 | 33.70 | 137.0 | 8.2 | 730 | <6 | 2.7 | 3.14 | <0.05 | 0.01 | 80.60 | 331.00 | 698 | -3.5 | <0.2 | <0.3 | <0.1 |
| 2.3 | 1.08 | 457.0 | 1.8 | 885 | 56 | 98.8 | 87.90 | 0.27 | 0.13 | 3.72 | 10.30 | 1060 | 2.3 | 0.2 | <0.3 | 0.4 |
| 1.0 | 0.43 | 294.0 | 1.2 | 573 | 70 | 2.5 | 0.67 | <0.05 | <0.01 | 40.20 | 4.20 | 692 | 1.1 | 0.2 | <0.3 | 0.6 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

### Appendix C, Table 7. Lower Cretaceous-Viking, Colony, Grand Rapids and Clearwater Formation Water Chemistry

| 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) | Li (mg/L) | Mn (mg/L) | Hg (mg/L) | Mo (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 141.0 | <0.10 | 0.160 | <0.050 | 20.6000 | <0.0050 | 0.073 | 8.660 | 0.0054 | <0.0080 | <0.0070 | <0.010 | <0.030 | <0.020 | 5.340 | 0.410 | <0.0001 | <0.010 |
| <0.3 | <0.01 | <0.008 | <0.005 | 19.7000 | <0.0005 | <0.007 | 3.060 | 0.0072 | <0.0008 | 0.0090 | <0.001 | 0.021 | <0.002 | 2.120 | 0.172 | <0.0001 | <0.001 |
| 146.0 | <0.10 | <0.080 | <0.050 | 12.7000 | <0.0050 | <0.070 | 9.350 | <0.0050 | 0.0100 | <0.0070 | <0.010 | <0.030 | <0.020 | 3.660 | 0.881 | <0.0001 | <0.010 |
| 146.0 | 0.020 | 0.013 | <0.005 | 0.1620 | <0.0005 | <0.007 | 7.270 | <0.0005 | <0.0008 | 0.0033 | 0.002 | <0.003 | <0.002 | 0.237 | 0.010 | 0.0002 | 0.003 |
| 113.0 | <0.10 | <0.080 | <0.050 | 0.7630 | <0.0050 | <0.070 | 5.520 | <0.0050 | <0.0080 | 0.0130 | <0.010 | <0.030 | <0.020 | 0.446 | 0.014 | <0.0001 | <0.010 |
| 79.0 | <0.10 | <0.080 | <0.050 | 0.4950 | <0.0050 | <0.070 | 5.600 | <0.0050 | <0.0080 | 0.0120 | <0.010 | <0.030 | <0.020 | 0.398 | 0.020 | <0.0001 | <0.010 |
| <0.3 | <0.01 | <0.008 | <0.005 | 12.0000 | <0.0005 | <0.007 | 3.840 | <0.0005 | <0.0008 | 0.0059 | <0.001 | 0.027 | <0.002 | 1.680 | 0.209 | <0.0001 | <0.001 |
| 73.5 | <0.10 | <0.080 | <0.050 | 0.7360 | <0.0050 | <0.070 | 5.770 | <0.0050 | <0.0080 | 0.0170 | <0.010 | <0.030 | <0.020 | 0.467 | 0.021 | <0.0001 | 0.010 |
| 289.0 | <0.01 | <0.008 | <0.005 | 2.5100 | <0.0005 | 0.015 | 11.300 | <0.0005 | <0.0008 | 0.0019 | 0.003 | 0.010 | <0.002 | 1.390 | 0.022 | <0.0001 | <0.001 |
| 118.0 | <0.10 | <0.080 | <0.050 | 11.7000 | <0.0050 | <0.070 | 7.190 | <0.0050 | <0.0080 | <0.0070 | 0.011 | <0.030 | <0.020 | 3.240 | 0.846 | <0.0001 | <0.010 |
| 18.2 | <0.05 | 0.940 | <0.200 | 23.6000 | <0.0300 | <0.400 | 4.840 | <0.0300 | <0.0400 | 0.0550 | <0.050 | 0.220 | <0.100 | 2.510 | 0.725 | <0.0001 | <0.050 |
| 95.2 | <0.01 | 0.020 | <0.005 | 0.0227 | <0.0005 | <0.007 | 1.020 | <0.0005 | <0.0008 | 0.0012 | <0.001 | 0.024 | <0.002 | 0.077 | 0.040 | <0.0001 | <0.001 |
| 145.0 | <0.01 | <0.008 | <0.005 | 0.0660 | <0.0005 | <0.007 | 0.597 | <0.0005 | <0.0008 | 0.0016 | <0.001 | 0.031 | <0.002 | 0.057 | 0.059 | <0.0001 | <0.001 |
| 210.0 | <0.01 | 0.090 | <0.005 | 0.0993 | 0.0005 | 0.036 | 5.150 | <0.0005 | 0.0057 | 0.0046 | 0.003 | 0.307 | 0.002 | 0.065 | 0.005 | <0.0001 | 0.004 |
| 161.0 | <0.01 | 0.063 | <0.005 | 0.0469 | <0.0005 | 0.007 | 4.030 | <0.0005 | <0.0008 | 0.0030 | <0.001 | 0.174 | <0.002 | 0.039 | 0.002 | <0.0001 | <0.001 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Appendix C, Table 7. Lower Cretaceous-Viking, Colony, Grand Rapids and Clearwater Formation Water Chemistry**

| Ni (mg/L) | P (mg/L) | Se (mg/L) | Si (mg/L) | Extractable Si (mg/L)/5 | Extractable Si (mg/L) | Extractable Silica (mg/L)/5 | $SiO_2$ (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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.013 | <0.30 | <0.040 | 4.090 | 3.570 | 17.8 | 7.6 |  | 38.2 | <0.010 | 43.9000 | 0.200 | 0.046 | <0.0040 | <0.010 | <0.0060 |
| 0.016 | 2.31 | <0.004 | 2.410 | 2.440 | 12.2 | 5.2 |  | 26.1 | <0.001 | 36.3000 | 0.597 | <0.004 | <0.0004 | <0.001 | 0.0083 |
| <0.010 | <0.30 | <0.040 | 2.200 | 1.960 | 9.8 | 4.2 |  | 21.0 | <0.010 | 23.3000 | <0.080 | <0.040 | <0.0040 | <0.010 | 0.0290 |
| 0.010 | 0.24 | <0.004 | 3.870 | 3.530 | 17.6 | 7.6 |  | 37.8 | <0.001 | 0.3540 | 0.193 | <0.004 | <0.0004 | 0.001 | 0.0054 |
| <0.010 | 0.55 | 0.230 | 3.640 | 4.750 | 23.8 | 10.2 |  | 51.0 | <0.010 | 1.7400 | <0.080 | <0.040 | <0.0040 | <0.010 | <0.0060 |
| <0.010 | 0.47 | 0.150 | 3.290 | 4.250 | 21.3 | 9.1 |  | 45.5 | <0.010 | 1.3200 | 0.160 | <0.040 | <0.0040 | <0.010 | <0.0060 |
| 0.008 | 2.23 | 0.005 | 2.710 | 2.320 | 11.6 | 5.0 |  | 24.8 | <0.001 | 24.4000 | 0.574 | <0.004 | <0.0004 | <0.001 | 0.0076 |
| 0.012 | 0.57 | 0.060 | 3.420 | 4.410 | 22.0 | 9.4 |  | 47.2 | <0.010 | 1.7800 | <0.080 | <0.040 | <0.0040 | <0.010 | <0.0060 |
| <0.001 | 0.70 | <0.004 | 3.850 | 3.770 | 18.8 | 8.1 |  | 40.3 | 0.002 | 6.6200 | 0.283 | <0.004 | <0.0004 | <0.001 | 0.0090 |
| <0.010 | <0.30 | <0.040 | 4.180 | 3.550 | 17.7 | 7.6 |  | 38.0 | <0.010 | 23.7000 | 2.030 | <0.040 | <0.0040 | <0.010 | 0.4020 |
| <0.050 | 2.90 | <0.200 | 2.380 | 2.880 | 14.4 | 6.2 |  | 30.8 | <0.050 | 54.5000 | 1.800 | 0.200 | 0.0750 | <0.050 | 0.0300 |
| <0.001 | 0.05 | <0.004 | 6.100 | 10.400 | 52.0 | 22.2 |  | 111.0 | <0.001 | 0.6060 | 10.400 | <0.004 | <0.0004 | <0.001 | 0.0008 |
| <0.001 | <0.03 | 0.005 | 9.350 | 10.900 | 54.5 | 23.4 |  | 117.0 | 0.001 | 0.6590 | 26.900 | <0.004 | <0.0004 | <0.001 | 0.0011 |
| 0.004 | 1.04 | <0.004 | 3.080 | 2.540 | 12.7 | 5.4 |  | 27.1 | <0.001 | 0.1440 | 1.240 | <0.004 | 0.5500 | 0.045 | <0.0006 |
| 0.003 | 0.98 | <0.004 | 3.220 | 2.710 | 13.6 | 5.8 |  | 29.0 | <0.001 | 0.0555 | 13.400 | <0.004 | 0.3030 | 0.011 | 0.0209 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

## Appendix C, Table 8. Lower Cretaceous - Viking, Colony, Grand Rapids and Clearwater Formation Water Isotope Chemistry

| Key | Site ID | Chemistry Number | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (m) | Formation or Member | Completion Depth Top (m) | Completion Depth Bottom (m) | 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)) | $\delta^{11}B$ | 226Ra (Bq/L) | 228Ra (Bq/L) | 228Th (Bq/L) | 210Pb (Bq/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | 102661 | 1 | 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 | 0.709117 | -11.7 | -15.6 | -122 |  |  | 30 | 1.04 | 2.07 | <0.05 |  |
| 37 | 103831 | 1 | 00/04-26-068-13W4-0 | 54.909420 | 111.882843 | 443399.4 | 6085068.7 | 584.60 | Viking | 249.9 | 252.4 | January 7, 2001 | 0.708724 | 9.1 | -16.6 | -123 |  |  | 40 | 1.06 | 1.28 | <0.07 |  |
| 38 | 105768 | 1 | 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 | 0.709077 | -14.9 | -16.8 | -123 |  |  | 40 | 0.75 | 1.14 | <0.06 |  |
| 39 | 107271 | 1 | 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 | 0.708406 | 5.9 | -17.8 | -134 |  |  | 42 | 0.60 | <0.17 | <0.07 |  |
| 40 | 110385 | 1 | 00/06-24-077-09W4-0 | 55.685520 | 111.262275 | 483509.9 | 6171110.9 | 569.10 | Clearwater | 261.5 | 267.0 | August 25, 2000 | 0.707852 | -12.7 | -19.4 | -147 |  |  |  | 0.26 | <0.13 | <0.07 |  |
| 41 | 142553 | 1 | 00/06-24-077-09W4-0 | 55.685964 | 111.105006 | 493398.2 | 6171134.0 | 553.60 | Clearwater | 242.0 | 250.0 | August 25, 2000 | 0.707869 | -13.7 | -19.1 | -147 |  | 17.4 | 42 | <0.10 | <0.12 | <0.09 | <0.09 |
| 42 | 170361 | 1 | 00/11-26-069-11W4-0 | 55.005390 | 111.572071 | 463410.8 | 6095540.9 | 629.40 | Viking | 270.5 | 271.5 | January 10, 2001 | 0.708720 | 11.5 | -16.0 | -123 |  |  | 39 | 1.32 | 0.85 | <0.07 |  |
| 43 | 170634 | 1 | 00/10-21-077-08W4-0 | 55.686310 | 111.179013 | 488744.9 | 6171182.1 | 562.80 | Clearwater | 256.0 | 260.5 | August 25, 2000 | 0.707891 | -12.7 | -19.4 | -148 |  |  | 43 | 0.28 | <0.14 | <0.05 |  |
| 44 | 183134 | 2 | 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 | 0.708869 | 22.7 | -17.2 | -131 |  |  | 35 | <0.05 | <0.10 | <0.04 | <0.08 |
| 45 | 219663 | 1 | 00/10-21-069-15W4-2 | 54.990913 | 112.222900 | 421757.2 | 6094464.2 | 546.20 | Colony | 319.7 | 320.4 | January 5, 2001 | 0.709072 | -12.9 | -16.1 | -120 |  |  | 48 | 0.22 | 0.58 | 0.09 |  |
| 46 | 232669 | 1 | 00/07-01-067-15W4-2 | 54.768154 | 112.148811 | 426090.7 | 6069597.6 | 582.60 | Colony | 335.0 | 336.0 | August 24, 2000 | 0.709101 | -12.6 | -15.5 | -128 |  | 5.1 | 44 | 1.35 | 1.72 | <0.07 |  |
| 47 | 2000046 | 18 | 16-02-087-09W4 | 56.520851 | 111.309494 | 480958.0 | 6264094.3 | 429.16 | Grand Rapids | 28.2 | 32.8 | July 3, 2000 | 0.708450 | -14.4 | -19.0 | -144 |  | 21.9 | 27 | <0.13 | <0.20 | <0.08 | <0.08 |
| 48 | 9000015 | 1 | 07-36-085-07W4 | 56.411712 | 110.964122 | 502214.0 | 6251904.2 |  | Grand Rapids | 82.6 | 89.1 | July 16, 2000 | 0.710023 | -13.9 | -19.4 | -146 |  | 9.0 | 24 | 0.24 | <0.11 | <0.07 |  |
| 49 | 9000008 | 1 | 07-02-085-06W4 | 56.339120 | 110.832000 | 510385.8 | 6243836.3 | 483.11 | Grand Rapids | 69.8 | 72.8 | July 19, 2000 | 0.707628 | -7.6 | -19.9 | -148 |  | 10.7 | 41 | <0.09 | <0.16 | <0.07 | <0.08 |
| 50 | 9000009 | 1 | 15-05-086-07W4 | 56.448860 | 111.040080 | 497529.5 | 6256039.1 | 477.93 | Grand Rapids | 48.2 | 49.7 | July 19, 2000 | 0.707544 | -13.5 | -19.7 | -146 |  | 11.1 | 23 | <0.16 | <0.22 | <0.12 | <0.09 |

Note: UTM Zone 12, NAM 83

## Appendix D, Table 9. Lower Cretaceous - Wabiskaw and McMurray Formation Water Chemistry

| Key | Site ID | Chemistry Number | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (masl) | EUB Formation Code | Formation or Member | Completion Depth Top (m) | Completion Depth Bottom (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 106636 | 1 | 00/07-27-071-21W4-0 | 55.174896 | 113.143097 | 363517.3 | 6116349.7 | 598.0 | 3060 | Wabiskaw | 500.0 | 517.0 |
| 52 | 142706 | 2 | 00/05-04-078-05W4-0 | 55.726726 | 110.723283 | 517379.9 | 6175700.4 | 585.9 | 3280 | McMurray | 338.0 | 340.5 |
| 53 | 179024 | 1 | 00/02-08-084-17W4-0 | 56.264247 | 112.650671 | 397760.1 | 6236715.2 | 530.8 | 3060 | Wabiskaw | 251.0 | 254.0 |
| 54 | 2000047 | 1 | 16-02-087-09W4 | 56.520851 | 111.309494 | 480958.0 | 6264094.3 | 429.5 | 3280 | McMurray | 128.0 | 138.7 |
| 55 | 2000048 | 4 | 16-02-087-09W4 | 56.520851 | 111.309494 | 480958.0 | 6264094.3 | 429.8 | 3280 | McMurray | 176.8 | 179.9 |
| 56 | 2000052 | 3 | 08-27-088-09W4 | 56.660206 | 111.336723 | 479358.8 | 6279613.3 | 372.2 | 3280 | McMurray | 134.1 | 138.7 |
| 57 | 2000068 | 4 | 15-03-089-16W4 | 56.769241 | 112.489243 | 418297.9 | 6292496.7 | 480.1 | 3280 | McMurray | 224.0 | 227.0 |

Note: < denotes less than.

UTM Zone 12, NAD 83

**Appendix D, Table 9. Lower Cretaceous - Wabiskaw and McMurray Formation Water Chemistry**

| | Field Parameters | | | | | | | | | | Laboratory |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Date** | **Well Name** | **Field Temp (°C)** | **Field pH** | **Field Cond (µS/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 Temp (°C)** |
| January 12, 2001 | RENAISSANCE GAMBLER 7-27-71-21 | 21.6 | 7.79 | 46300 | 140 | 247 | 387 | 6.3 | <2 | 1290 | |
| February 6, 2001 | TRANSWEST HARDY 5-4-78-5 | 22.4 | 8.03 | 16800 | 141 | 246 | 387 | 4.4 | <2 | 1216 | |
| April 13, 2001 | SRI GRANOR 2-8-84-17 | 19.8 | 8.40 | 10080 | 327 | 248 | 575 | 4.4 | <2 | 2440 | 19.2 |
| July 12, 1979 | ARC # 11-460 | 9.5 | 7.90 | | | | | | | | |
| July 11, 1978 | ARC # 11-595 | 7.0 | 8.90 | | | | | | | | |
| July 12, 1977 | ARC # 12-460 | 6.0 | 8.70 | | | | | | | | |
| July 7, 1978 | ARC # 15-750 | 9.0 | 8.50 | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

## Appendix D, Table 9. Lower Cretaceous - Wabiskaw and McMurray Formation Water Chemistry

| Laboratory Parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Laboratory pH | Laboratory Cond (µS/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 (ug/mL) | Br by NAA (ug/mL) | I by NAA (ug/mL) | $SO_4$ (mg/L) |
| 7.74 | 36500.3 | <5 | 1230 | 169.0 | 144.00 | 9830.0 | 104.0 | 1500 | <6 | 14200.0 | 17000.00 | 53.20 | 10.80 | 2.67 |
| 8.10 | 14200.1 | <5 | 1270 | 28.0 | 30.20 | 3190.0 | 14.7 | 1540 | <6 | 4660.0 | 4650.00 | 14.20 | 1.67 | 1.24 |
| 8.73 | 8170.0 | 149 | 2950 | 12.0 | 16.90 | 2240.0 | 17.0 | 3230 | 179 | 1500.0 | 1570.00 | 3.71 | 1.01 | 5.72 |
| 8.40 | 22000.3 | | 229 | 82.0 | 122.00 | 5525.0 | 26.7 | 266 | 10 | 8600.0 | | | | 1106.00 |
| 8.90 | 26700.1 | | 553 | 22.0 | 149.00 | 6688.0 | 48.3 | 556 | 65 | 11200.0 | | | | 9.50 |
| 8.30 | | | | 34.0 | 46.00 | 2075.0 | 18.8 | 383 | 0 | 3180.0 | | | | 52.00 |
| 8.30 | 13900.1 | | 687 | 11.8 | 62.00 | 3638.0 | 8.3 | 859 | 0 | 5200.0 | | | | 3.80 |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

**Appendix D, Table 9. Lower Cretaceous - Wabiskaw and McMurray Formation Water Chemistry**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |
| 1010.00 | 25200 | 2.9 | 645.0 | <6 | <2 | 158.0 | <0.10 | 0.200 | <0.050 | 15.1000 | <0.0050 | <0.070 | 9.990 | <0.0050 |
| 194.00 | 8680 | -4.6 | <1 | <2 | <0.5 | 467.0 | <0.01 | <0.008 | <0.005 | 0.4800 | <0.0005 | 0.010 | 6.020 | <0.0005 |
| 99.00 | 5560 | 2.3 | | | | | <0.10 | 0.170 | <0.050 | 0.1400 | <0.0050 | <0.070 | 5.310 | <0.0050 |
| | 15016 | -2.8 | | | | | | | | | | | | |
| | 18136 | -3.1 | | | | | | 0.040 | | | | | | |
| | 5434 | -0.4 | | | | | | | | | | | | |
| | 9518 | 1.0 | | | | | | 0.080 | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

## Appendix D, Table 9. Lower Cretaceous - Wabiskaw and McMurray Formation Water Chemistry

| 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) | $SiO_2$ (mg/L) | Extractable Silica (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <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 | 19.45 |  | 41.65 |
| <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 | 13.70 |  | 29.35 |
| <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 | 19.80 |  | 42.35 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3.60 |
|  |  | 0.000 | 0.100 | 0.020 |  | 0.080 | 0.0003 |  |  |  |  |  |  |  | 1.00 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 42.00 |
|  |  | 0.004 | 0.000 | 0.006 |  | 0.000 | 0.0005 |  |  |  |  |  |  |  | 3.20 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

## Appendix D, Table 9. Lower Cretaceous - Wabiskaw and McMurray Formation Water Chemistry

| Ag (mg/L) | Sr (mg/L) | S (mg/L) | Tl (mg/L) | Ti (mg/L) | V (mg/L) | Zn (mg/L) |
|---|---|---|---|---|---|---|
| <0.010 | 27.3000 | 0.890 | <0.040 | <0.0040 | <0.010 | <0.0060 |
| <0.001 | 3.3800 | 0.413 | <0.004 | <0.0004 | 0.002 | 0.0006 |
| <0.010 | 1.6200 | 1.910 | <0.040 | <0.0040 | 0.013 | <0.0060 |

## Appendix D, Table 10. Lower Cretaceous - Wabiskaw and McMurray Formation Water Isotope Chemistry

| Key | Site ID | UWI | Latitude | Longitude | UTM Easting | UTM Northing | Ground Elevation (m) | Formation or Member | Completion Depth Top (m) | Completion Depth Bottom (m) | Sample Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 106636 | 00/07-27-071-21W4-0 | 55.174896 | 113.143097 | 363517.3 | 6116349.7 | 598.00 | Wabiskaw | 500 | 517 | January 12, 2001 |
| 52 | 142706 | 00/05-04-078-05W4-0 | 55.726726 | 110.723283 | 517379.9 | 6175700.4 | 585.90 | McMurray | 338 | 340.5 | February 6, 2001 |
| 53 | 179024 | 00/02-08-084-17W4-0 | 56.264247 | 112.650671 | 397760.1 | 6236715.2 | 530.80 | Wabiskaw | 251 | 254 | April 13, 2001 |
| 56 | 2000052 | 08-27-088-09W4 | 56.660206 | 111.336723 | 479358.8 | 6279613.3 | 372.16 | McMurray | 131.3 | 136.3 | August 2, 2000 |

| Key | Site ID | $^{87}Sr/^{86}Sr$ | $\delta^{13}C$ (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 | 106636 | 0.709109 | -12.7 | -16.7 | -118 | | | 37 |
| 52 | 142706 | 0.708156 | 24.2 | -20.3 | -149 | | 6.4 | 50 |
| 53 | 179024 | 0.707647 | 16.2 | -20.3 | -151 | | 8.2 | |
| 56 | 2000052 | | 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

# Appendix E. Quality Control

## Quality Control

Blank, duplicate, split and standard samples were included with the formation water samples to provide a measure of possible sources of error and to validate the sampling method. The results of the chemical analyses are provided in Tables 11 and 12.

The data from the quality control sampling show reproducibility of results between split and duplicate samples. They indicated a problem with the initial decontamination procedures used to clean the field equipment. These procedures were changed and subsequent blank samples displayed a marked improvement. Results from the analysis of the standard sample showed deviation from the values provided by the manufacturer. The laboratory that performed the chemical analyses of the samples was consulted, and their calibration records were scrutinized. These records were deemed acceptable and the results of the analyses are believed to be of high quality.

## Appendix E, Table 11. Quality Control Standard Chemistry Data

| UID | Sample Name | AGS Site Id | Sample Type | Sample Date | Al-s | Al | Sb-s | Sb | As-s | As | Ba-s |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Tubing and Filter Blank | 9000001 | System Blank | 20000711 | + | 0.028 | < | 0.005 | < | 0.01 | + |
| 2 | Tubing and Filter Blank | 9000006 | System Blank | 20000718 | + | 0.029 | < | 0.005 | < | 0.01 | + |
| 3 | Tubing and Filter Blank | 9000010 | System Blank | 20000724 | + | 0.011 | < | 0.005 | < | 0.01 | + |
| 4 | System Blank | 2000045 | System Blank | 20000802 | < | 0.008 | < | 0.005 | < | 0.01 | + |
| 5 | 11-130 duplicate | 2000046 | Serial Duplicate | 20000803 | + | 0.024 | < | 0.005 | < | 0.01 | + |
| 6 | 11-130a split | 2000046 | Split Sample | 20000803 | + | 0.020 | < | 0.005 | < | 0.01 | + |
| 7 | 11-130b split | 2000046 | Split Sample | 20000803 | + | 0.020 | < | 0.005 | < | 0.01 | + |
| 8 | PW1CAQ1 | 232669 | Serial Duplicate | 20000824 | + | 0.920 | < | 0.200 | < | 0.50 | + |
| 9 | PW1CAQ2 | 232669 | Split Sample | 20000824 | + | 0.900 | < | 0.200 | < | 0.50 | + |
| 10 | PW1CT | 232669 | Serial Duplicate after 1 week | 20000831 | + | 0.750 | < | 0.100 | < | 0.20 | + |
| 11 | PW1ST | 12000097 | Standard Analytical Results | 20000914 | + | 0.361 | + | 0.023 | + | 0.04 | + |
| 12 | Trace Metals Sample | 12000097 | Standard Analytical Results from Manufacturer | 20000914 | + | 0.300 | + | 0.020 | + | 0.04 | + |
| 13 | PWIHB | 12000097 | HPLC Grade Water Blank | 20000915 | + | 0.052 | < | 0.005 | < | 0.01 | + |
| 14 | PWAQ23 | 219663 | System Blank | 20010123 | + | 0.023 | < | 0.005 | < | 0.01 | + |
| 15 | PWAQ24 | 219663 | Distilled Water Blank | 20010123 | + | 0.033 | < | 0.005 | < | 0.01 | + |
| 16 | PWAQ25 | 105768 | Serial Duplicate | 20010124 | + | 0.130 | < | 0.050 | < | 0.10 | + |
| 17 | PWAQ26 | 105768 | Split Sample | 20010124 | + | 0.190 | < | 0.050 | < | 0.10 | + |
| 18 | PWAQ27 | 116495 | Serial Duplicate | 20010206 | + | 0.014 | < | 0.005 | < | 0.01 | + |
| 19 | PWAQ28 | 116495 | Split Sample | 20010206 | + | 0.012 | < | 0.005 | < | 0.01 | + |
| 20 | System Blank | 2001008 | System Blank | 20010427 | < | 0.008 | < | 0.005 | < | 0.01 | + |
| 21 | WR 99-1-230-Duplicate | 2001004 | Serial Duplicate | 20010524 | < | 0.008 | < | 0.005 | + | 0.02 | + |
| 22 | WR 99-1-230-Split | 2001004 | Split Sample | 20010524 | < | 0.008 | < | 0.005 | + | 0.02 | + |

**Appendix E, Table 11. Quality Control Standard Chemistry Data**

| Ba | Be-s | Be | Bi-s | Bi | B-s | B | Cd-s | Cd | Cr-s | Cr | Co-s | Co | Cu-s | Cu | Pb-s | Pb | Li-s | Li | Mo-s | Mo | Ni-s | Ni | P-s | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0022 | < | 0.0005 | < | 0.007 | + | 0.009 | < | 0.0005 | < | 0.0008 | < | 0.0007 | + | 0.004 | < | 0.002 | < | 0.001 | < | 0.001 | < | 0.001 | < | 0.03 |
| 0.0075 | < | 0.0005 | < | 0.007 | + | 0.011 | < | 0.0005 | < | 0.0008 | < | 0.0007 | + | 0.005 | < | 0.002 | + | 0.002 | + | 0.001 | < | 0.001 | < | 0.03 |
| 0.0014 | < | 0.0005 | < | 0.007 | + | 0.008 | < | 0.0005 | < | 0.0008 | < | 0.0007 | + | 0.002 | < | 0.002 | < | 0.001 | < | 0.001 | < | 0.001 | < | 0.03 |
| 0.0004 | < | 0.0005 | < | 0.007 | + | 0.019 | < | 0.0005 | < | 0.0008 | < | 0.0007 | < | 0.001 | < | 0.002 | < | 0.001 | < | 0.001 | < | 0.001 | < | 0.03 |
| 0.0466 | < | 0.0005 | < | 0.007 | + | 1.02 | < | 0.0005 | < | 0.0008 | + | 0.0012 | < | 0.001 | < | 0.002 | + | 0.076 | < | 0.001 | + | 0.001 | + | 0.03 |
| 0.0465 | < | 0.0005 | < | 0.007 | + | 1.02 | < | 0.0005 | < | 0.0008 | + | 0.0011 | < | 0.001 | < | 0.002 | + | 0.076 | < | 0.001 | < | 0.001 | + | 0.05 |
| 0.0461 | < | 0.0005 | < | 0.007 | + | 1.01 | < | 0.0005 | < | 0.0008 | + | 0.0013 | < | 0.001 | < | 0.002 | + | 0.076 | < | 0.001 | < | 0.001 | + | 0.09 |
| 24.40 | < | 0.0300 | < | 0.400 | + | 4.78 | < | 0.0300 | < | 0.0400 | + | 0.0850 | < | 0.050 | < | 0.100 | + | 2.61 | < | 0.050 | < | 0.050 | + | 2.70 |
| 24.30 | < | 0.0300 | < | 0.400 | + | 4.76 | < | 0.0300 | < | 0.0400 | + | 0.0650 | < | 0.050 | < | 0.100 | + | 2.61 | < | 0.050 | < | 0.050 | + | 2.50 |
| 25.70 | < | 0.0100 | < | 0.100 | + | 5.60 | < | 0.0100 | < | 0.0200 | + | 0.0420 | + | 0.022 | < | 0.040 | + | 2.72 | < | 0.020 | < | 0.020 | + | 2.20 |
| 0.3530 | + | 0.0410 | < | 0.007 | + | 0.298 | + | 0.0348 | + | 0.5560 | + | 0.8840 | + | 0.396 | + | 0.349 | < | 0.001 | + | 0.110 | + | 0.231 | < | 0.03 |
| 0.3000 | + | 0.0400 |  |  | + | 0.250 | + | 0.0300 | + | 0.5000 | + | 0.7500 | + | 0.350 | + | 0.300 |  |  | + | 0.100 | + | 0.200 |  |  |
| 0.0018 | < | 0.0005 | < | 0.007 | + | 0.009 | + | 0.0014 | < | 0.0008 | < | 0.0007 | + | 0.008 | < | 0.002 | < | 0.001 | < | 0.001 | < | 0.001 | < | 0.03 |
| 0.0169 | < | 0.0005 | < | 0.007 | + | 0.009 | + | 0.0006 | + | 0.0008 | < | 0.0007 | + | 0.018 | < | 0.002 | + | 0.004 | < | 0.001 | + | 0.002 | < | 0.03 |
| 0.0085 | < | 0.0005 | < | 0.007 | + | 0.007 | < | 0.0005 | + | 0.0014 | + | 0.0008 | + | 0.023 | < | 0.002 | + | 0.004 | < | 0.001 | + | 0.002 | < | 0.03 |
| 12.30 | < | 0.0050 | + | 0.070 | + | 9.12 | < | 0.0050 | + | 0.0080 | < | 0.0070 | + | 0.011 | < | 0.020 | + | 3.56 | < | 0.010 | < | 0.010 | < | 0.30 |
| 12.30 | < | 0.0050 | + | 0.075 | + | 9.11 | + | 0.0055 | + | 0.0170 | + | 0.0110 | < | 0.010 | < | 0.020 | + | 3.54 | < | 0.010 | + | 0.021 | < | 0.30 |
| 2.02 | < | 0.0005 | + | 0.007 | + | 3.05 | < | 0.0005 | < | 0.0008 | + | 0.0026 | < | 0.001 | < | 0.002 | + | 1.22 | < | 0.001 | + | 0.002 | + | 0.29 |
| 2.02 | < | 0.0005 | + | 0.007 | + | 3.05 | < | 0.0005 | < | 0.0008 | + | 0.0026 | < | 0.001 | < | 0.002 | + | 1.21 | + | 0.002 | + | 0.002 | + | 0.27 |
| 0.0002 | < | 0.0005 | < | 0.007 | + | 0.005 | < | 0.0005 | + | 0.0009 | < | 0.0007 | < | 0.001 | < | 0.002 | < | 0.001 | < | 0.001 | + | 0.001 | < | 0.03 |
| 0.0959 | < | 0.0005 | < | 0.007 | + | 0.361 | < | 0.0005 | < | 0.0008 | + | 0.0013 | + | 0.002 | < | 0.002 | + | 0.065 | + | 0.009 | < | 0.001 | + | 0.18 |
| 0.0958 | < | 0.0005 | < | 0.007 | + | 0.360 | < | 0.0005 | < | 0.0008 | + | 0.0009 | + | 0.001 | < | 0.002 | + | 0.065 | + | 0.008 | < | 0.001 | + | 0.19 |

**Appendix E, Table 11. Quality Control Standard Chemistry Data**

| Se-s | Se | Si-s | Si | Ag-s | Ag | Sr-s | Sr | S-s | S | Tl-s | Tl | Ti-s | Ti | V-s | V | Zn-s | Zn | Hg-s | Hg | SiEx-s | SiEx | SIO2Ex-s | SIO2Ex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| < | 0.004 | + | 0.03 | < | 0.001 | + | 0.001 | + | 0.10 | < | 0.004 | < | 0.0004 | + | 0.002 | + | 0.001 | < | 1E-04 | | | | |
| + | 0.006 | + | 1.07 | < | 0.001 | + | 0.002 | + | 13.60 | < | 0.004 | < | 0.0004 | + | 0.001 | < | 0.001 | < | 1E-04 | | | | |
| < | 0.004 | + | 0.03 | < | 0.001 | + | 0.001 | + | 0.23 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.004 | < | 1E-04 | | | | |
| < | 0.004 | + | 0.01 | < | 0.001 | + | 0.000 | + | 0.08 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.003 | < | 1E-04 | | | | |
| < | 0.004 | + | 6.11 | < | 0.001 | + | 0.609 | + | 10.50 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.001 | < | 1E-04 | | | | |
| < | 0.004 | + | 6.15 | < | 0.001 | + | 0.606 | + | 10.50 | < | 0.004 | < | 0.0004 | < | 0.001 | < | 0.001 | < | 1E-04 | | | | |
| < | 0.004 | + | 6.10 | < | 0.001 | + | 0.606 | + | 10.40 | < | 0.004 | < | 0.0004 | < | 0.001 | < | 0.001 | < | 1E-04 | | | | |
| + | 0.910 | + | 2.71 | < | 0.050 | + | 55.7 | + | 1.50 | < | 0.200 | < | 0.0200 | < | 0.050 | + | 0.040 | < | 1E-04 | + | 3.27 | + | 6.99 |
| + | 0.250 | + | 2.43 | < | 0.050 | + | 55.8 | + | 1.90 | < | 0.200 | < | 0.0200 | < | 0.050 | < | 0.030 | < | 1E-04 | | | | |
| < | 0.080 | + | 2.90 | < | 0.020 | + | 56.9 | + | 2.91 | < | 0.080 | < | 0.0080 | + | 0.042 | + | 0.074 | < | 1E-04 | + | 2.85 | + | 6.10 |
| + | 0.112 | + | 0.43 | + | 0.057 | + | 0.315 | + | 0.02 | + | 0.146 | + | 0.0215 | + | 0.388 | + | 0.833 | | | | | | |
| + | 0.100 | | | + | 0.050 | + | 0.300 | | | + | 0.100 | | | + | 0.350 | + | 0.750 | + | 0.014 | | | | |
| + | 0.015 | + | 0.06 | < | 0.001 | + | 0.002 | + | 0.05 | + | 0.006 | + | 0.0007 | + | 0.002 | + | 0.005 | | | | | | |
| < | 0.004 | + | 2.76 | < | 0.001 | + | 0.073 | + | 24.40 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.009 | < | 1E-04 | + | 2.35 | + | 5.02 |
| < | 0.004 | + | 2.75 | + | 0.001 | + | 0.070 | + | 24.70 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.012 | < | 1E-04 | + | 2.34 | + | 5.00 |
| < | 0.040 | + | 2.13 | + | 0.011 | + | 22.7 | + | 0.22 | < | 0.040 | < | 0.0040 | < | 0.010 | + | 0.025 | < | 1E-04 | + | 1.95 | + | 4.18 |
| + | 0.071 | + | 2.20 | + | 0.012 | + | 22.6 | + | 0.13 | + | 0.067 | < | 0.0040 | < | 0.010 | < | 0.006 | < | 1E-04 | | | | |
| < | 0.004 | + | 3.04 | < | 0.001 | + | 2.240 | + | 2.77 | < | 0.004 | < | 0.0004 | + | 0.002 | + | 0.002 | < | 1E-04 | + | 2.56 | + | 5.47 |
| < | 0.004 | + | 3.11 | < | 0.001 | + | 2.270 | + | 2.75 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.003 | < | 1E-04 | | | | |
| < | 0.004 | < | 0.00 | < | 0.001 | + | 0.001 | + | 0.04 | < | 0.004 | < | 0.0012 | + | 0.001 | + | 0.007 | < | 1E-04 | | | | |
| < | 0.004 | + | 11.70 | < | 0.001 | + | 0.540 | + | 12.80 | < | 0.004 | < | 0.0004 | < | 0.001 | < | 0.001 | < | 1E-04 | + | 3.73 | + | 7.99 |
| < | 0.004 | + | 11.70 | < | 0.001 | + | 0.514 | + | 12.80 | < | 0.004 | < | 0.0004 | < | 0.001 | + | 0.006 | < | 1E-04 | | | | |

**Appendix E, Table 11. Quality Control Standard Chemistry Data**

| AA-s | Acetic Acid | BuA-s | Butyric Acid | FA-s | Formic Acid | PA-s | Propionic Acid | pH-s | pH | Cond-s | Cond | Ca-s | Ca | Mg-s | Mg | Na-s | Na | K-s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | + | 6.00 | + | 2.90 | < | 0.20 | < | 0.05 | + | 0.4 | < |
| | | | | | | | | + | 8.16 | + | 187.00 | < | 0.20 | + | 0.06 | + | 46.6 | < |
| | | | | | | | | + | 6.29 | + | 3.80 | < | 0.20 | + | 0.06 | + | 1.0 | + |
| | | | | | | | | + | 8.27 | + | 2.70 | + | 0.30 | + | 0.25 | + | 0.5 | < |
| | | | | | | | | + | 7.80 | + | 1080.00 | + | 47.30 | + | 16.40 | + | 210.0 | + |
| | | | | | | | | + | 8.07 | + | 1060.00 | + | 46.90 | + | 16.30 | + | 209.0 | + |
| | | | | | | | | + | 8.06 | + | 1060.00 | + | 46.80 | + | 16.40 | + | 210.0 | + |
| < | 0.20 | < | 0.30 | < | 0.10 | + | 13 | + | 6.92 | + | 47200.00 | + | 536.00 | + | 253.00 | + | 11000.0 | + |
| | | | | | | | | + | 7.12 | + | 46400.00 | + | 536.00 | + | 253.00 | + | 10900.0 | + |
| < | 0.20 | < | 0.30 | < | 0.10 | + | 18 | + | 7.16 | + | 45900.00 | + | 529.00 | + | 265.00 | + | 12200.0 | + |
| | | | | | | | | | | | | + | 0.20 | < | 0.05 | + | 0.4 | < |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | + | 0.20 | < | 0.05 | + | 0.6 | < |
| + | 0.20 | < | 0.30 | < | 0.10 | + | 64 | + | 8.34 | + | 397.00 | + | 9.00 | + | 7.26 | + | 66.5 | < |
| + | 0.30 | < | 0.30 | < | 0.10 | + | 64 | + | 8.23 | + | 386.00 | + | 9.10 | + | 7.32 | + | 66.9 | < |
| < | 4.00 | < | 6.00 | < | 2.00 | + | 153 | + | 7.62 | + | 30300.00 | + | 228.00 | + | 128.00 | + | 7570.0 | + |
| | | | | | | | | + | 7.67 | + | 29600.00 | + | 227.00 | + | 128.00 | + | 7460.0 | + |
| + | 1.10 | < | 2.00 | < | 0.50 | + | 798 | + | 8.08 | + | 9880.00 | + | 21.90 | + | 23.50 | + | 2610.0 | + |
| | | | | | | | | + | 8.16 | + | 9980.00 | + | 22.00 | + | 23.40 | + | 2550.0 | + |
| | | | | | | | | + | 6.34 | + | 1.60 | < | 0.20 | < | 0.05 | < | 0.4 | < |
| | | | | | | | | + | 7.78 | + | 747.00 | + | 65.60 | + | 19.10 | + | 99.8 | + |
| | | | | | | | | + | 7.98 | + | 740.00 | + | 65.20 | + | 18.90 | + | 99.9 | + |

**Appendix E, Table 11. Quality Control Standard Chemistry Data**

| K | Fe-s | Fe | Mn-s | Mn | Cl-s | Cl | ClNAA-s | Cl by NAA | BrNAA-s | Br by NAA | INAA-s | I by NAA | NO3+NO2-s | NO3+NO2 | SO4-s | SO4 | OH-s | OH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.40 | + | 0.018 | + | 0.0006 | < | 0.50 | | | | | | | < | 0.006 | + | 0.31 | < | 5 |
| 0.40 | + | 0.010 | + | 0.0011 | + | 2.40 | | | | | | | + | 0.272 | + | 40.70 | < | 5 |
| 0.80 | < | 0.003 | + | 0.0006 | < | 0.50 | | | | | | | < | 0.006 | + | 0.68 | < | 5 |
| 0.40 | < | 0.003 | + | 0.0008 | < | 0.50 | | | | | | | + | 0.014 | + | 2.05 | < | 5 |
| 2.90 | + | 0.044 | + | 0.0385 | + | 74.70 | | | | | | | + | 0.010 | + | 31.50 | < | 5 |
| 3.00 | + | 0.148 | + | 0.0390 | + | 74.20 | | | | | | | + | 0.009 | + | 31.50 | < | 5 |
| 2.30 | + | 0.146 | + | 0.0388 | + | 73.90 | | | | | | | < | 0.006 | + | 31.20 | < | 5 |
| 50.00 | + | 0.350 | + | 0.7300 | + | 17100 | + | 20200 | + | 68.20 | + | 10.60 | + | 0.660 | + | 4.60 | < | 5 |
| 50.00 | + | 0.360 | + | 0.7100 | + | 18000 | | | | | | | < | 0.300 | + | 5.70 | < | 5 |
| 53.00 | + | 0.140 | + | 0.7960 | + | 19700 | | | | | | | < | 0.300 | + | 8.74 | < | 5 |
| 0.04 | + | 0.251 | + | 0.5590 | | | | | | | | | | | + | 0.07 | | |
| | + | 0.200 | + | 0.5000 | | | | | | | | | | | | | | |
| 0.40 | + | 0.011 | + | 0.0005 | | | | | | | | | | | + | 0.16 | | |
| 0.40 | < | 0.003 | + | 0.0012 | + | 1.70 | + | 3.58 | < | 0.01 | < | 0.01 | + | 0.304 | + | 73.20 | < | 5 |
| 0.40 | < | 0.003 | + | 0.0008 | + | 1.30 | + | 3.44 | + | 0.01 | < | 0.01 | < | 0.328 | + | 74.10 | < | 5 |
| 40.10 | < | 0.030 | + | 0.8480 | + | 11800 | + | 12800 | + | 38.50 | + | 7.94 | < | 0.100 | + | 0.66 | < | 5 |
| 40.90 | < | 0.030 | + | 0.8400 | + | 11800 | | | | | | | < | 0.100 | + | 0.38 | < | 5 |
| 21.90 | + | 0.004 | + | 0.0765 | + | 2120 | + | 2460 | + | 5.85 | + | 1.34 | < | 0.060 | + | 8.30 | < | 5 |
| 21.80 | + | 0.003 | + | 0.0762 | + | 2130 | | | | | | | < | 0.060 | + | 8.25 | < | 5 |
| 0.40 | + | 0.003 | + | 0.0003 | < | 0.50 | | | | | | | < | 0.006 | + | 0.12 | < | 5 |
| 5.40 | + | 0.056 | + | 0.0956 | < | 0.50 | | | | | | | < | 0.006 | + | 38.30 | < | 5 |
| 5.40 | + | 0.057 | + | 0.0961 | < | 0.50 | | | | | | | < | 0.006 | + | 38.30 | < | 5 |

## Appendix E, Table 11. Quality Control Standard Chemistry Data

| CO3-s | CO3 | HCO3-s | HCO3 | P-Alk-s | P-Alk | T-Alk-s | T-Alk | TDS-s | TDS | Hard-s | Hard |
|---|---|---|---|---|---|---|---|---|---|---|---|
| < | 6 | < | 5 | < | 5 | < | 5 | < | 1 | < | 0.7 |
| < | 6 | + | 60 | < | 5 | + | 50 | + | 120 | + | 0.2 |
| < | 6 | < | 5 | < | 5 | < | 5 | + | 2 | + | 0.2 |
| < | 6 | < | 5 | < | 5 | < | 5 | + | 3 | + | 1.7 |
| < | 6 | + | 599 | < | 5 | + | 491 | + | 677 | + | 186.0 |
| < | 6 | + | 602 | < | 5 | + | 494 | + | 678 | + | 184.0 |
| < | 6 | + | 608 | < | 5 | + | 498 | + | 680 | + | 184.0 |
| < | 6 | + | 124 | < | 5 | + | 102 | + | 28900 | + | 2380.0 |
| < | 6 | + | 121 | < | 5 | + | 100 | + | 29800 | + | 2380.0 |
| < | 6 | + | 128 | < | 5 | + | 105 | + | 32800 | + | 2410.0 |
|  |  |  |  |  |  |  |  |  |  | + | 0.6 |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | + | 0.6 |
| < | 6 | + | 164 | < | 5 | + | 135 | + | 239 | + | 52.4 |
| < | 6 | + | 161 | < | 5 | + | 132 | + | 238 | + | 52.8 |
| < | 6 | + | 206 | < | 5 | + | 169 | + | 19900 | + | 1100.0 |
| < | 6 | + | 206 | < | 5 | + | 169 | + | 19800 | + | 1090.0 |
| < | 6 | + | 3550 | < | 5 | + | 2910 | + | 6550 | + | 152.0 |
| < | 6 | + | 3530 | < | 5 | + | 2900 | + | 6480 | + | 151.0 |
| < | 6 | < | 5 | < | 5 | < | 5 | < | 1 | < | 0.7 |
| < | 6 | + | 477 | < | 5 | + | 391 | + | 463 | + | 242.0 |
| < | 6 | + | 480 | < | 5 | + | 394 | + | 464 | + | 241.0 |

**Appendix E, Table 12. Quality Control Isotope Chemistry Data**

| UID | Sample Name | AGSSitd | Sample Type | Sample Date | d180-s | d18O | d2H-s | d2H | d13C-s |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Tubing and Filter Blank | 9000001 | System Blank | 20000711 | | | | | |
| 2 | Tubing and Filter Blank | 9000006 | System Blank | 20000718 | | | | | |
| 3 | Tubing and Filter Blank | 9000010 | System Blank | 20000724 | | | | | |
| 4 | System Blank | 2000045 | System Blank | 20000802 | | | | | |
| 5 | 11-130 duplicate | 2000046 | Serial Duplicate | 20000803 | | | | | |
| 6 | 11-130a split | 2000046 | Split Sample | 20000803 | | | | | |
| 7 | 11-130b split | 2000046 | Split Sample | 20000803 | | | | | |
| 8 | PW1CAQ1 | 232669 | Serial Duplicate | 20000824 | - | 15.4 | - | 126 | |
| 9 | PW1CAQ2 | 232669 | Split Sample | 20000824 | | | | | |
| 10 | PW1CT | 232669 | Serial Duplicate after 1 week | 20000831 | - | 15.4 | - | 123 | - |
| 11 | PW1ST | 12000097 | Standard Analytical Results | 20000914 | | | | | |
| 12 | Trace Metals Sample | 12000097 | Standard Analytical Results from Manufacturer | 20000914 | | | | | |
| 13 | PWIHB | 12000097 | HPLC Grade Water Blank | 20000915 | | | | | |
| 14 | PWAQ23 | 219663 | System Blank | 20010123 | - | 20.6 | - | 155 | - |
| 15 | PWAQ24 | 219663 | Distilled Water Blank | 20010123 | - | 20.5 | - | 154 | - |
| 16 | PWAQ25 | 105768 | Serial Duplicate | 20010124 | - | 16.3 | - | 123 | |
| 17 | PWAQ26 | 105768 | Split Sample | 20010124 | | | | | |
| 18 | PWAQ27 | 116495 | Serial Duplicate | 20010206 | - | 20.5 | - | 150 | + |
| 19 | PWAQ28 | 116495 | Split Sample | 20010206 | | | | | |
| 20 | System Blank | 2001008 | System Blank | 20010427 | | | | | |
| 21 | WR 99-1-230-Duplicate | 2001004 | Serial Duplicate | 20010524 | | | | | |
| 22 | WR 99-1-230-Split | 2001004 | Split Sample | 20010524 | | | | | |

**Appendix E, Table 12. Quality Control Isotope Chemistry Data**

| d13C | d34S-sulphate-s | d34S-sulphate | d34S-sulphide-s | d34S-sulphide | d11B-s | d11B | 87Sr/86Sr-s | 87Sr/86Sr | U-s | U |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | + | 1.80 | | | | | + | 0.70910 | < | 0.088 |
| | | | | | | | | | | |
| 12.8 | + | 6.30 | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| 17.1 | + | 12.40 | + | 11.9 | | | + | 0.70911 | < | 0.001 |
| 17.2 | + | 12.40 | | | | | + | 0.70837 | < | 0.001 |
| | | | | | | | + | 0.70905 | < | 0.047 |
| | | | | | | | | | | |
| 23.9 | | | | | | | + | 0.70770 | < | 0.013 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |