DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP, WESTERN CANADA SEDIMENTARY BASIN

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Executive Summary

The Western Canada Sedimentary Basin contains several regionally-extensive salt deposits. The major part of these deposits is contained within the Devonian Elk Point Group. Five mappable salt units, reaching a maximum aggregate thickness of 380 m in one area of the basin, have been recognized within this stratigraphic interval. These are (from oldest to youngest) 1) the Lower Lotsberg, 2) the Upper Lotsberg, 3) the Cold Lake, 4) the Prairie Evaporite, and 5) the Hubbard Evaporite salts.

Stratigraphic data for the Elk Point salt units were checked and updated. Data processing and the application of mapping software resulted in the refinement of some of the salt boundaries and the production of basin-scale depth to, structure, and isopach maps for the Elk Point salt units. The lack of stratigraphic data in the area of Wood Buffalo National Park (northeastern Alberta) and the scarcity of stratigraphic data from the Northwest Territories did not allow confident subsurface mapping of the Cold Lake Salt deposits in these areas. Furthermore, available stratigraphic data for the Hubbard Evaporite Salts (Saskatchewan) were too scarce to warrant an improvement of previous work.

At this stage, only the total thickness of the individual salt units, including intervening non-soluble material (e.g., anhydrite and shale beds) has been considered. As a result of a history of repeated solution and redeposition, the Lower Lotsberg, Upper Lotsberg, and Cold Lake salt units are extraordinarily pure, hence, the reported thicknesses approximate the total brinable thickness. The Prairie Evaporite Salt unit, however, varies considerably in purity within the basin, reflecting 'normal' marine evaporite deposition, and only approximate ratios of brinable to non-brinable material are available. Detailed mapping of the total brinable thickness of the Prairie Evaporite Salt unit was beyond the scope of this study, but can be achieved using electrophysical log signatures.

The computer-generated isopach map of the Prairie Evaporite salt (where salt > 40%) in some cases closely mimics subsurface features, such as Winnipegosis reef build-ups and areas of local salt collapse. The combination of industry seismic data with stratigraphic data from wells would greatly improve the resolution of the subsurface maps for the Prairie Evaporite Salt.

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1.0 Introduction

During the Early and Middle Devonian the Western Canada Sedimentary Basin was the site of extensive deposition of evaporites. These contain minerals such as halite, potash salts, and gypsum, which are used as feedstock or as additives in a variety of industries. For example, halite is used to produce chlorine and caustic soda and is marketed for human consumption. Potash salt is essential to the fertilizer industry, and gypsum is widely used in the production of construction materials. Salt caverns are used for the storage of oil and natural gas (e.g., Crow, 1963; Allan, 1966; Tek, 1989; Crossley, 1998) and have been discussed as potential future disposal sites for industrial waste (e.g., Simpson and Dennison, 1975), nuclear waste (e.g, Meijer Drees, 1985), and carbon dioxide (Bradley et al., 1991; Bachu and Gunter, 1999). Furthermore, the evaporitic deposits of the Elk Point Group provide effective seals for hydrocarbon accumulations in underlying reservoir rocks (e.g., Winnipegosis/Keg River Formation) (Allan and Creany, 1991).

With an estimated total volume of rock salt of about $6x10^4$ km^3 (Zharkov, 1988), Elk Point Group strata contain the major amount of salt in the Western Canada Sedimentary Basin. Most of this salt is concentrated in four formations of the Elk Point Group: 1) the Lotsberg (Lower and Upper Lotsberg Salt), the Cold Lake (Cold Lake Salt), the Prairie Evaporite (Whitkow and Leofnard Salt), and the Dawson Bay (Hubbard Evaporite) (Figure 1). Publicly available information on the regional distribution and thickness of the Elk Point Group is given in Grayston et al. (1964), Hamilton (1971), and Meijer Drees (1986, 1994). The salt-bearing formations of the Elk Point Group were mapped by Hamilton (1971) in east-central Alberta and Meijer Drees (1986) in western Canada. Hamilton (1971) based his work mainly on well log data from more than 300 wells. Meijer Drees (1986) integrated some original work on the Devonian salt beds in the southern part of the District of Mackenzie and on the Prairie Evaporite Formation in northeastern Alberta and southwestern Saskatchewan, with published and unpublished data from various sources. Neither Hamilton (1971) nor Meijer Drees (1986) included stratigraphic picks in their reports.

Hundreds of new wells penetrating the Elk Point Group have been drilled in recent years. The corresponding stratigraphic picks were submitted by industry to the Alberta Energy and Utilities Board (formerly Energy Resources Conservation Board) and were added to the stratigraphic database. Hamilton’s (1971) stratigraphic picks, as well as picks from a study on the Lower Paleozoic in south-central Alberta (Nowlan, 1994; 1995), however, have not yet been added to the database of the Alberta Energy and Utilities Board.

The purpose of this report is to update the work by Hamilton (1971) and Meijer Drees (1986) by establishing a database for stratigraphic picks delineating the extent and thickness of the Lotsberg salts, Cold Lake Salt, and Prairie Evaporite Formation within the Western Canada Sedimentary Basin. The regional scale maps that are included in this report are compatible with those published in the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994) and represent an update and extension of the maps presented in Chapter 10 of the same (Meijer Drees, 1994).

2.0 Study area and regional geological setting

The study area extends from 96° to 126° W and 49° to 62° N, coinciding with that of the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994). The Western Canada Sedimentary Basin consists of a largely undisturbed succession of Phanerozoic sedimentary rocks overlying the crystalline rocks of the Precambrian basement and attaining a thickness of more than 6000 m in the southwestern part of the basin. The sedimentary succession can be divided into a Paleozoic to Jurassic platformal succession, dominated by carbonate rocks, and a mid-Jurassic to Paleocene foreland basin succession, dominated by clastic rocks. The nature and distribution of sediments of the platformal succession was greatly influenced by epeirogenic movements on various intracratonic arches, which episodically differentiated the region into sub-basins and areas of uplift. The sedimentation patterns of the foreland basin succession were profoundly influenced by the orogenic evolution of the Canadian Cordillera.

Lower to Middle Devonian clastics, red beds, evaporites and carbonates of the Elk Point Group (Figure 1) unconformably overlie Precambrian or lower Paleozoic rocks and accumulated in paleotopographic basins separated by paleotopographic highs (Figure 2). The formations of the Lower Elk Point subgroup onlap an irregular erosional surface of considerable relief. The formations of the Upper Elk Point subgroup are more widely distributed and extend from northeastern British Columbia and the District of Mackenzie southeastward into the Williston Basin of southern Saskatchewan, Manitoba and North Dakota. However, some of the paleotopographic highs (i.e., the Tathlina Uplift, the Western Alberta Ridge and the Peace River Arch) remained emergent during deposition of the Upper Elk Point subgroup. The top of the Elk Point Group is a relatively flat surface, indicating that the topographic relief (up to 1400 m) had been leveled out at the end of Elk Point Group deposition. The Elk Point Group is overlain by Upper Devonian beds, except along the eastern margin of the Western Canada Sedimentary Basin, where Elk Point Group strata are discontinuously exposed or unconformably overlain by Cretaceous sedimentary rocks. Here, and in the southern part of Saskatchewan, dissolution of halite from the salt-bearing formations of the Elk Point Group at various times has resulted in partial to complete removal of halite and collapse of the overlying strata.

3.0 Stratigraphy

In his report on the evaporitic deposits of Western Canada, Meijer Drees (1986) provided a detailed account of the stratigraphic succession and nomenclature of the Elk Point Group, which is summarized in the following (see also Figure 1).

McGehee (1949) introduced the term Elk Point Formation to describe the thick succession of evaporitic deposits in the subsurface of east-central Alberta between pre-Devonian rocks and the Upper Devonian. Belyea (1952) raised the unit to group status. Crickmay (1954) designated the interval between 867.5 m (2845 ft) and 1351 m (4430 ft) in the Anglo-Canadian Elk Point No. 11 well (2-11-57-5W4) as the type section for the

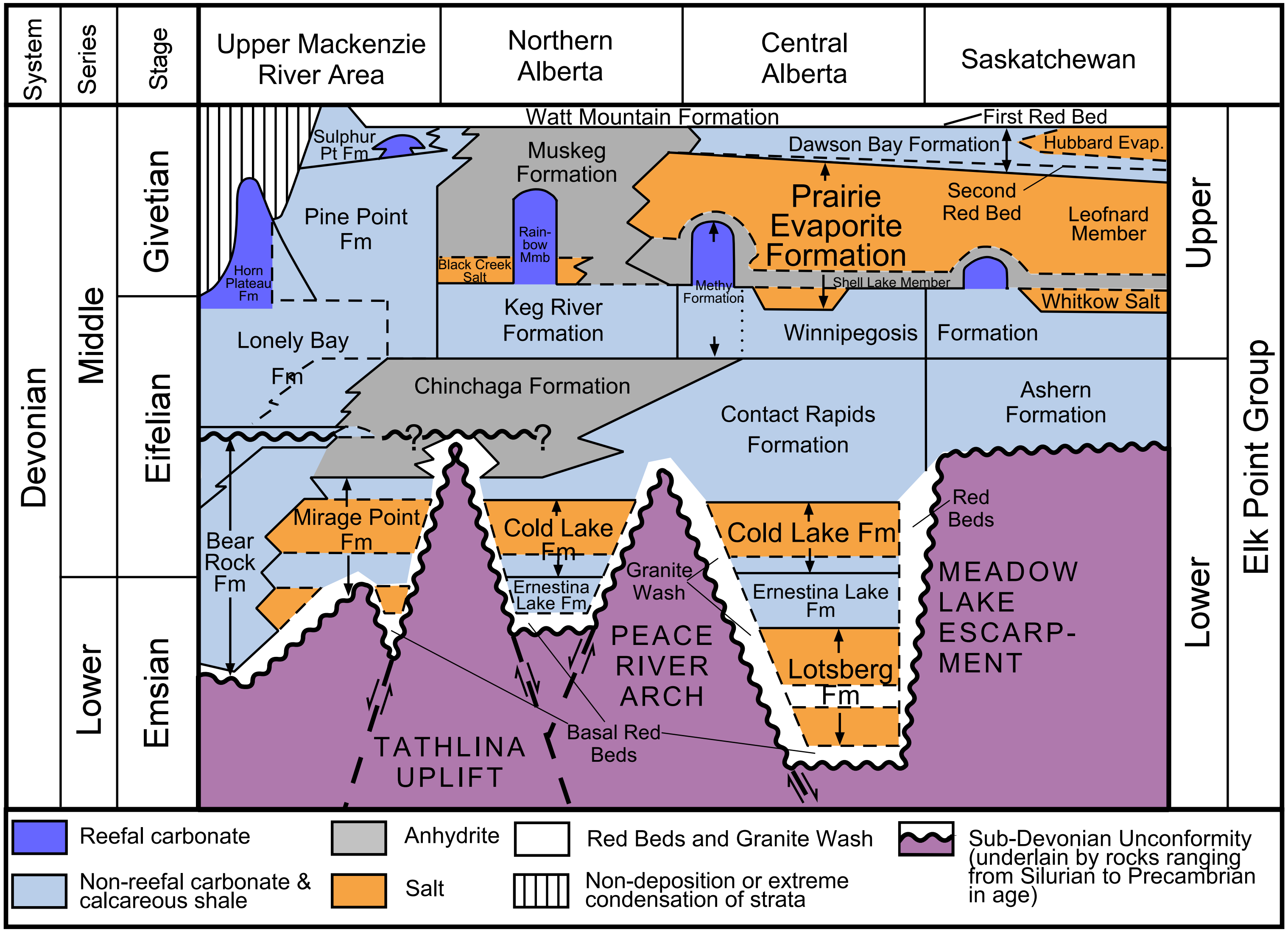

Figure 1: Table of formations of the Devonian Elk Point Group (modified after Meijer Drees, 1986).

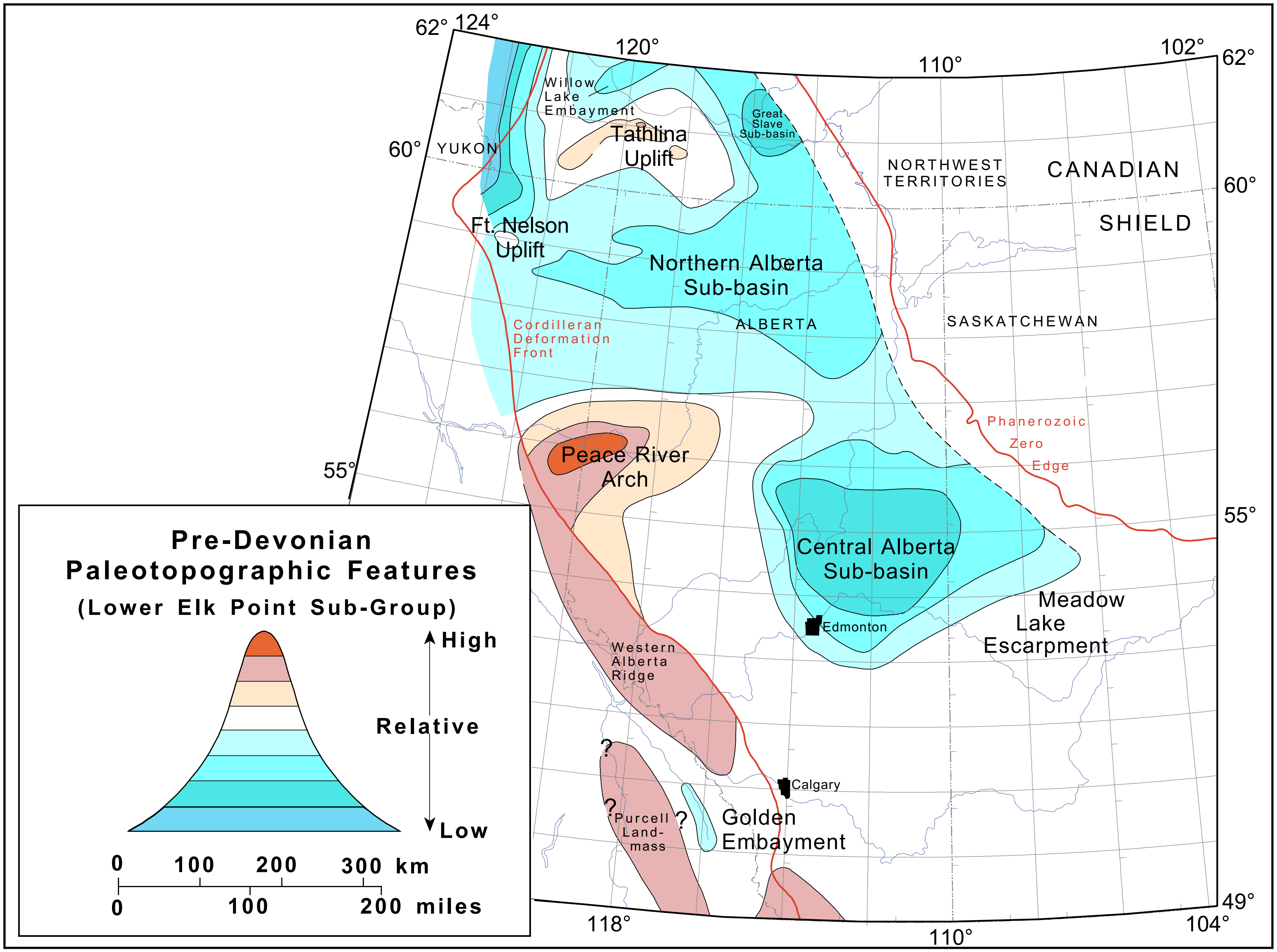

Figure 2: Pre-Devonian paleotopographic features for the Lower Elk Point subgroup (modified from Meijer Drees, 1994).

Elk Point Group, and subdivided the group into nine members. Sherwin (1962) divided the Elk Point Group into two subgroups (Lower and Upper Elk Point) using the Canadian Seaboard Ernestina Lake well (10-13-60-4W4) as a reference well, and elevated the individual members to formations (Figure 1). Grayston et al. (1964) established a stratigraphic framework for the Elk Point Group in Alberta and Saskatchewan, and Law (1955, 1971) recognized the group in northern Alberta and the Northwest Territories.

In central Alberta, the Lower Elk Point subgroup consists of, in ascending order, the “Basal Red Beds” unit, and the Lotsberg, Ernestina Lake, Cold Lake, and Contact Rapids formations (Figure 1). The Lotsberg and the Cold Lake formations are dominated by salt beds, which grade into red shale units near their depositional edges, where they become part of the informal “Basal Red Beds” unit. In Saskatchewan and Manitoba, the Lower Elk Point subgroup is represented by the Ashern Formation, which correlates with the Contact Rapids Formation of central Alberta. In the southern part of the District of Mackenzie, the Lower Elk Point subgroup consists of the salt-bearing Mirage Point Formation, followed by anhydrite and red beds of the Chinchaga Formation (Law, 1971). In northern Alberta, the Chinchaga Formation overlies the Cold Lake Formation (Law, 1955).

At the base of the Upper Elk Point subgroup, a regionally extensive fossiliferous carbonate unit is present (Figure 1). In Manitoba, Saskatchewan and the subsurface of central Alberta, this unit was mapped as the Winnipegosis Formation (Baillie, 1953; Walker, 1957; Jones, 1965; Holter, 1969; Reinson and Wardlaw, 1972; Sherwin, 1962; Grayston et al., 1964; Hamilton, 1971). For equivalent strata in the subsurface of northern Alberta, Law (1955) introduced the term Keg River Formation, whereas for equivalent rocks in the outcrop area of northeastern Alberta the term Methy Formation was used (Greiner, 1956; Norris, 1963). In the upper part of the Winnipegosis and Keg River Formations, reef buildups developed locally, which influenced subsequent deposition of the Prairie Evaporite and Muskeg formations. The interbedded anhydrite and halite of the Prairie Evaporite Formation in Manitoba, Saskatchewan and central Alberta grade into interbedded anhydrite and dolostone of the Muskeg Formation in northern Alberta and northern British Columbia. A salt-bearing unit at the base of the Muskeg Formation between reefal buildups in the Rainbow Lake area (northwestern Alberta) has been named the Black Creek Member (Hriskevich, 1966). To the north, carbonates of the Pine Point form the northern limit of the evaporite deposits of the Upper Elk Point subgroup. The Prairie Evaporite Formation in central Alberta, Saskatchewan, and Manitoba is overlain by red beds, carbonates and evaporites of the Dawson Bay Formation, which is stratigraphically equivalent to the upper part of the Muskeg Formation of northern Alberta. In Saskatchewan, the upper part of the Dawson Bay Formation contains the Hubbard Evaporite Member (Lane, 1959). The uppermost unit of the Elk Point Group in Alberta, northeastern British Columbia and the southern District of Mackenzie is the Watt Mountain Formation, which is stratigraphically equivalent to the First Red Beds in Saskatchewan (Grayston et al., 1964; Klingspor, 1969; Hamilton, 1971).

4.0 Methodology

A flow chart describing the work procedures used in this study is given in Figure 3. Stratigraphic picks of the units of the Elk Point Group were assembled from the files of the Alberta Energy and Utilities Board (EUB) and from previous studies by Hamilton (1971), Mossop and Shetsen (1994), and Nowlan (1995). Automated and manual culling resulted in a reduction of the number of picks from 10806 to 9598 and improved the quality of the data set. Procedures for automated culling were:

1) stratigraphic picks from deviated wells that did not give the true vertical depth were removed;
2) stratigraphic picks that had been checked and documented by previous workers (indicated by a quality code as a qualifier for the pick) took precedence over picks that had not been checked.

Manual culling involved removal of picks that could not be confirmed in spot checks of picks from wells that lay outside of the accepted boundaries of the salt-bearing units and from wells that were located in areas with anomalous contour patterns. In some cases, spot checks resulted in changes to the picks and/or new picks of other relevant stratigraphic horizons. Table 1 gives an overview over the database structure used to build the stratigraphic horizons from a variety of equivalent formations.

Cartographic software (AGSSYS) developed in-house (Lytviak and Wynne, 1988) was used to process stratigraphic picks data. The mapping software CPS-3™ developed by Radian Corporation was used for automated gridding and contouring. Depth to (overburden thickness), structure (elevation of unit top relative to sea-level), and isopach maps (unit thickness) were produced at a scale of 1:5,000,000 to match those in the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994) and were graphically enhanced in Canvas™. Hardcopies of the maps are included at the back of this report. The report, stratigraphic picks, CPS-3™ data files, surface grids and maps, as well as the final graphically enhanced maps are available in electronic format.

5.0 Distribution and thickness of salt-bearing units within the Elk Point Group

In the following, the distribution and thickness of the salt-bearing units within the Elk Point Group are presented in a series of maps (Map 1 to 13). Map 1 shows the boundaries of the Lower Lotsberg, Upper Lotsberg, Cold Lake, Prairie Evaporite (where halite > 40% of unit), and Hubbard salts. The salt limits are mainly depositional, except along the northeast margin (Upper Lotsberg, Cold Lake, and Prairie Evaporite salts) and in the south (Prairie Evaporite Salt), where salt was removed by dissolution, resulting in its abrupt termination. Only minor adjustments to the boundaries that are given in Hamilton (1971) and Meijer Drees (1994) had to be made. These changes will be addressed in the discussion of the individual salt-bearing units below.

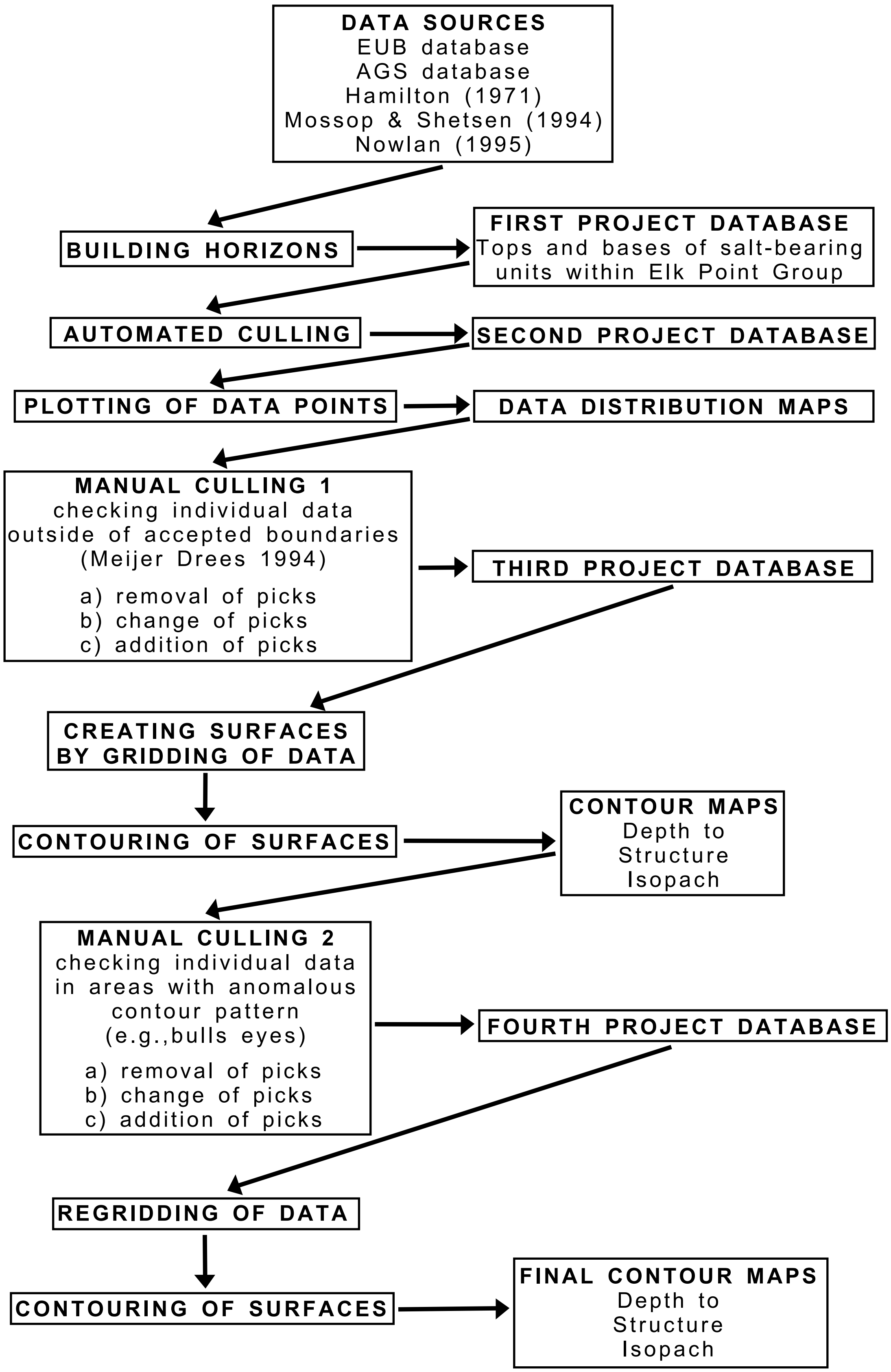

Figure 3: Flow chart of data processing procedures.

Interval	Horizon	formation name and equivalents	formation codes						(0)=Top (1)=Base	number of picks used for gridding	number of wells used for isopach
			EUB (AB)	n	AGS (AB)	n	AGS (SK)	n			
Hubbard Salt	Top of Hubbard Evaporite	Top of Hubbard					21120	7	0	0	0
	Base of Hubbard Evaporite	Base of Hubbard					21130	7	1	0	
Prairie Evaporite	Top of Prairie Evaporite	Prairie Evaporite	7860	295	17860	320	21140	747	0	1461	1003
		First Salt	7870	24					0		
		Black Creek Salt	7865	75					0		
	Base of Prairie Evaporite	Prairie Evaporite			17860	252	21140	12	1	6699	
		Keg River	7880	5475					0		
		Winnipegosis	7920	283			21150	677	0		
Cold Lake Salt	Top of Cold Lake Salt	Cold Lake	8000	259	18000	55			0	318	297
		Second Salt	8010	4					0		
	Base of Cold Lake Salt	Cold Lake			18000	112			1	460	
		Ernestina Lake	8020	343	18020	5			0		
Upper Lotsberg Salt	Top of Upper Lotsberg	Lotsberg	8040	122	18040	81			0	215	87
		Third Salt	8045	12					0		
	Base of Upper Lotsberg	Base of Upper Lotsberg			18046	87			1	87	
Lower Lotsberg Salt	Top of Lower Lotsberg	Fourth Salt	8056	4	18056	49			0	53	50
	Base of Lower Lotsberg	Lotsberg			18040	22			1	305	
		Base of Lotsberg			18056	42			1		
		Basal Red Beds	8060	241					0		
								Total number		9598	1437

Table 1: Database structure for mapping of Elk Point salt-bearing intervals and listing of formation codes with number of picks used in this study. EUB = Alberta Energy and Utilities Board; AGS = Alberta Geological Survey; AB = Alberta; SK = Saskatchewan.

The isopach maps represent the thickness of the salt units including intervening impurities, such as shale, red beds, and anhydrite. As a result of a history of repeated solution and redeposition, the Lower Lotsberg, Upper Lotsberg, and Cold Lake salt units are extraordinarily pure, hence, the reported thickness approximate the total brinable thickness (Hamilton, 1971). The Prairie Evaporite Salt unit, however, varies considerably in purity within the basin, reflecting 'normal' marine evaporite deposition. Hamilton (1971) mapped the total brinable thickness of the Prairie Evaporite in east-central Alberta by subtracting the thickness of intervening impurities from the thickness of salt layers in the thickest solution-brinable salt unit (i.e., a salt unit in which layers of impurities are less than 10 feet (3 m) thick). The resulting color-coded map gives only ranges of thickness in a quasi-logarithmic manner, and Hamilton (1971) stated that meaningful isopach patterns for the actual brinable salt thickness would be impossible to construct. Therefore, such an undertaking has not been attempted in the mapping presented in this report, but should be part of local site-specific studies.

5.1 Lower Lotsberg Salt (Maps 2, 3, and 4)

The Lower Lotsberg Salt is present in east-central Alberta and extends past the provincial border into Saskatchewan. The overburden thickness above the Lower Lotsberg Salt ranges from about 1050 m in the east to more than 2100 m in the west, with two positive anomalies which reflect present-day surface topography (Map 2): the Mostoos Upland in the east and the Pelican Mountains in the west. The structure map (Map 3) shows that the top of the Lower Lotsberg Salt is an even surface that dips gently to the southwest. The Lower Lotsberg Salt reaches a maximum thickness of over 60 m at its depocenter, and gradually thins to all sides, though more rapidly toward the southeast (Map 4). Since the limits and thickness variations are believed to be entirely depositional (Hamilton, 1971), the computer-generated zero-edge has been taken as the limit of the Lower Lotsberg Salt, where no well data were available to further delineate it. This resulted in small changes from the outline shown in Hamilton (1971), particularly in its northwestern and its southern part. In Meijer Drees (1994), the limits of the Lower Lotsberg Salt are only schematically shown, resulting in a relatively crude outline and an area smaller than it is in reality.

5.2 Upper Lotsberg Salt (Maps 5, 6, and 7)

The Upper Lotsberg Salt extends over a larger area than the Lower Lotsberg Salt in east-central Alberta and Saskatchewan. It is separated from the Lower Lotsberg Salt by an unnamed red shale interval ranging in thickness from 28 to 67 m. The overburden thickness above the Upper Lotsberg Salt ranges from about 750 m in the east to more than 2100 m in the west (Map 5). Anomalies in the overburden thickness again can be attributed to present-day surface topography. The structure map (Map 6) shows no major irregularities in the surface of the top of the Upper Lotsberg Salt, which is dipping toward the southwest (Map 7). Compared with the Lower Lotsberg Salt, the center of deposition moved eastward. The salt reaches a maximum thickness of more than 150 m and gradually thins toward the southwest, west and northwest (Map 7). The rather abrupt termination in the southeast results from depositional onlap against the pre-Devonian Meadow Lake Escarpment (Figures 1 and 2). Thinning of the salt and the linear termination in the northeast has been attributed almost entirely to removal of salt by subsurface dissolution (Hamilton, 1971). The limits of the Upper Lotsberg Salt have been refined compared to those given in Hamilton (1971) and Meijer Drees (1994), particularly in the northwest.

In the well Triad Berny 6-25-66-16W4, the stratigraphic equivalent of the overlying Ernestina Lake Formation consists of salt and is in mappaple continuity with the Upper Lotsberg Salt. According to Hamilton, a north-trending channel scoured in sediments underlying the Cold Lake Formation was filled with salt. While Hamilton (1971) has mapped the "Ernestina Lake salt" as part of the Cold Lake formation, it is mapped in this report as part of the Upper Lotsberg Salt. This is because 1) its relationship to the Cold Lake Salt is uncertain (Hamilton, 1971); 2) this anomaly is only of local stratigraphic significance; and 3) in terms of brinability, the "Ernestina Lake salt" would be considered part of the Upper Lotsberg Salt.

5.3 Cold Lake Salt (Maps 8, 9, and 10)

The Cold Lake Salt is present in two areas separated by a paleotopographic high, which is part of the Peace River Arch (figures 1 and 2): 1) a southern area in east-central Alberta and west-central Saskatchewan, and 2) a northern area in northern Alberta and northeastern British Columbia. According to Meijer Drees (1986), equivalents of the Cold Lake Salt have been mapped in the southern part of the Mackenzie District as the Cold Lake salt member of the Mirage Point Formation (Figure 1). The distribution of control wells on Maps 8, 9, and 10 shows that available stratigraphic data from northeastern British Columbia and the Northwest Territories are scarce and are lacking completely from the area of Wood Buffalo National Park, thus not allowing confident mapping in these areas.

The overburden thickness above the Cold Lake Salt in east-central Alberta and west-central Saskatchewan ranges from about 550 m in the east to 1600 m in the southwest. In northern Alberta and northeastern British Columbia it ranges from less than 700 m at the western and southern boundaries of Wood Buffalo National Park to more than 2400 m in northeastern British Columbia. Anomalies in overburden thickness reflect present-day surface topography. There are no irregularities in the structure map (Map 9), which shows the surface of the top of the Cold Lake Salt dipping gently toward the southwest. The depositional center in the southern area of the Cold Lake Salt deposit remained in the same location as it was during deposition of the Upper Lotsberg Salt, and a maximum thickness of 60 m was attained (Map 10). In the northern area, at least two depositional centers can be recognized within the Northern Alberta Sub-basin. Maximum thickness of the Cold Lake Salt in northwestern Alberta reaches 60 m, and in northeastern Alberta probably more than 80 m in the area below Wood Buffalo National Park. A basement high (drilled in well Amoco Pitchimi 10-5-116-5W5) divides the depositional center in northeastern Alberta into smaller sub-basins. Unfortunately, the configuration of these sub-basins could not be mapped due to the lack of data in the area of Wood Buffalo National Park. All boundaries are depositional in origin, except for the northeastern boundaries in Alberta and the Northwest Territories, where removal of salt by subsurface dissolution resulted in the abrupt thinning of the Cold Lake Salt. Toward the south, the southern Cold Lake Salt deposit onlaps against the Meadow Lake escarpment. Westward thinning of the salt primarily is the result of a gradual facies change (shale-out) from salt into red beds, and northward thinning is due mainly to bedding convergence (Hamilton, 1971). The thinning of the limits of the northern Cold Lake Salt deposit also is mainly the result of depositional onlap and gradational facies changes (Meijer Drees, 1986). Only minor changes of the salt boundaries compared to those given in Meijer Drees (1994) were made, e.g. in northwestern Alberta, between Townships 117 and 119 and Ranges 5 and 12 west of the 6^{th} Meridian. In this area, Meijer Drees (1994) showed an outlier of salt, which in this present report has been connected to the main salt deposit, based on identification of Cold Lake Salt on well logs.

5.4 Prairie Evaporite Formation where halite > 40% (Maps 11, 12, and 13)

The Prairie Evaporite Formation is an interbedded succession of halite, sylvite, bedded anhydrite, red beds, and minor anhydritic dolostone. It has been informally divided into the Whitkow Salt, the Shell Lake, and the Leofnard Salt members (Meijer Drees, 1986) (Figure 1). The Leofnard Salt Member contains several potash beds in Saskatchewan and Manitoba (Holter, 1969; 1972). For the purpose of this report, the subsurface mapping of the Prairie Evaporite Formation was limited to the area where halite constitutes more than 40% of the formation, as shown in Meijer Drees (1994). This area stretches from eastern Alberta to southern Saskatchewan and southeastern Manitoba. For reasons outlined above, it was neither attempted to map the individual members nor the total brinable thickness of the Prairie Evaporite Formation.

Along the southwestern margin of the Elk Point Basin, the salt beds grade into a nearshore siliciclastic/clastic-mixed facies (Map 11), which onlaps the Western Alberta Ridge and the southeastern part of the Peace River Arch. To the northwest, the lithology changes to anhydrite (Muskeg Formation) and then into carbonates, which include reefal beds (Presqu’ile Barrier) (Meijer Drees, 1994). Along its eastern edge and in southern Saskatchewan, the Prairie Evaporite Formation has been subject to removal of salt by subsurface dissolution, resulting in collapse breccias. Areas of complete salt removal are shown on the maps.

In the mapped area (halite > 40%), the overburden thickness ranges from 200 m in northeastern Alberta to about 2300 m in central Alberta, and from about 700 m in central Saskatchewan to 2700 m at the Saskatchewan/USA border (Map 11). Anomalies in overburden thickness are the combined result of present-day topography and subsurface dissolution in the areas where subsurface dissolution took place. The influence of subsurface dissolution on the position of the top of the Prairie Evaporite Formation is indicated by the irregularity of the structure contours along the eastern and northeastern margin of the mapped area (Map 12). The structure map shows that, in the areas not affected by subsurface dissolution, the top of the Prairie Evaporite Formation in Alberta dips gently towards the southwest, whereas in Saskatchewan it dips more steeply toward the south. The axis of inflection trends about SSW-NNE and is an expression of the influence of the Sweetgrass Arch on Middle Devonian sedimentation (Kent and Christopher, 1994). Uplift of the arch during the Permo-Triassic also facilitated the selective removal of halite (and associated potash beds) from the Prairie Evaporite Formation in southern Saskatchwan.

The thickness of the Prairie Evaporite in the area where it consists of more than 40% halite is very variable and ranges from less than 25 m in southern Alberta, along the northern and northeastern limits in central Saskatchewan and southwestern Manitoba, to more than 300 m in northeastern Alberta. Centers of maximum deposition are located in northeastern Alberta, whereas the evaporite basin centre is in central Saskatchewan. Variations in thickness are the combined result of differences in subsidence, the occurrence of reefal buildups of the underlying Winnipegosis Formation, and the removal of salt by subsurface dissolution. Many of the Winnipegosis reefs are too small to be recognized in regional-scale mapping, with only a few exceptions, where the thinning of the Prairie Evaporite coincides with the location of a Winnipegosis reef (e.g., Township 35, Range 10 west of the 2nd Meridian; Township 24, Range 5 west of the 2nd Meridian; Township 17, Range 28 west of the 1st Meridian) (Map 13). The computer-generated contours roughly mimic some of the areas of salt dissolution (e.g., Township 30, Range 15 west of the 3rd Meridian; Township 44, Range 7 west of the 3rd Meridian; Township 12, Range 2 west of the 2nd Meridian).

5.5 Hubbard Evaporite Member of the Dawson Bay Formation

The Dawson Bay Formation overlies the Prairie Evaporite Formation in east-central Alberta, southern Saskatchewan, and southwestern Manitoba (Figure 1). It includes a lower redbed member, a middle carbonate member, and an upper salt member named the Hubbard Evaporite (Lane, 1959). The limits of the Hubbard Evaporite Member are taken from Meier Drees (1994) and are shown on Map 1. Only seven wells with stratigraphic picks for the top and bottom of the Hubbard Evaporite were available at the time of the preparation of this report; therefore, mapping of this unit was not attempted. According to Lane (1959), the thickness of salt varies between 0 and 18.9 m and the limit of the salt is depositional, except in the northeast where the edge is due to dissolution.

6.0 Conclusions and recommendations

This report contains the first complete set of regional maps of overburden thickness, structure, and thickness of the four major salt bearing units of the Devonian Elk Point Group in the Western Canada Sedimentary Basin - the Lower and Upper Lotsberg, the Cold Lake, and the Prairie Evaporite Salt -. Maps and data provide an update and an extension of the work of Hamilton (1971) and Meijer Drees (1986, 1994) and are a useful supplement to the Geological Atlas of the Western Canada Sedimentary Basin.

Usage of the maps is limited by: 1) the scarcity of available stratigraphic data from northeastern British Columbia and the Northwest Territories, and 2) the lack of data from Wood Buffalo National Park in northeastern Alberta. Furthermore, the depositional complexity of the Prairie Evaporite Formation makes it difficult to establish meaningful maps with respect to salt distribution and thickness on a regional scale. To evaluate the potential of the subsurface salt beds of the Elk Point Group for disposal or storage of industrial waste, nuclear waste, and CO_2, local site-specific studies of the distribution, thickness, depth, purity and stability of the salt beds and the overlying rocks need to be conducted. The integration of industry seismic data showing the locations and dimensions of Winnipegosis reefs (e.g., Gendzwill, 1978), and salt dissolution features would greatly improve the resolution of the subsurface maps, particularly for the Prairie Evaporite Salt.

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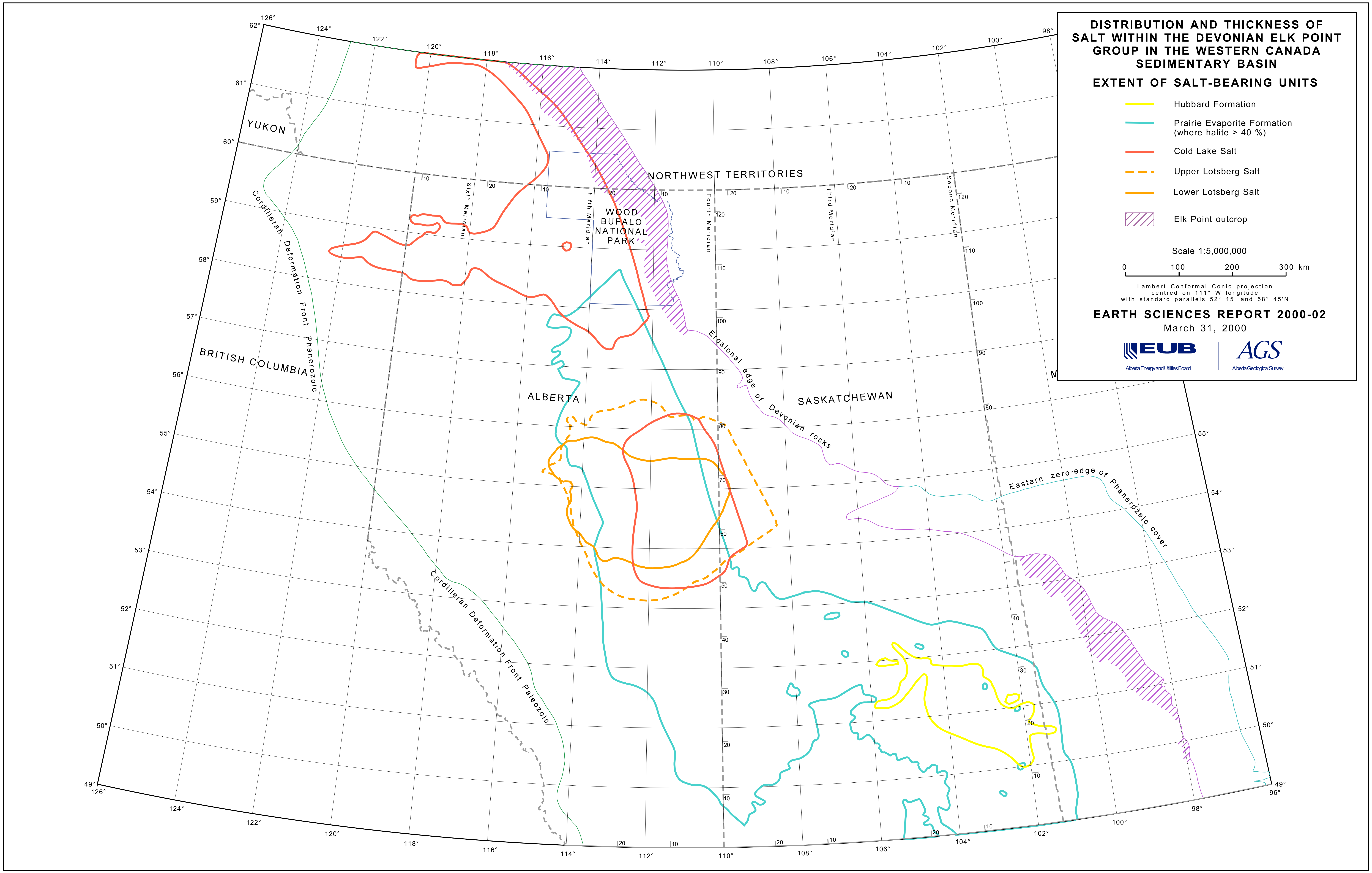
Map 1



DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
EXTENT OF SALT-BEARING UNITS
Hubbard Formation
Prairie Evaporite Formation (where halite > 40 %)
Cold Lake Salt
Upper Lotsberg Salt
Lower Lotsberg Salt
Elk Point outcrop
Scale 1:5,000,000
0
100
200
300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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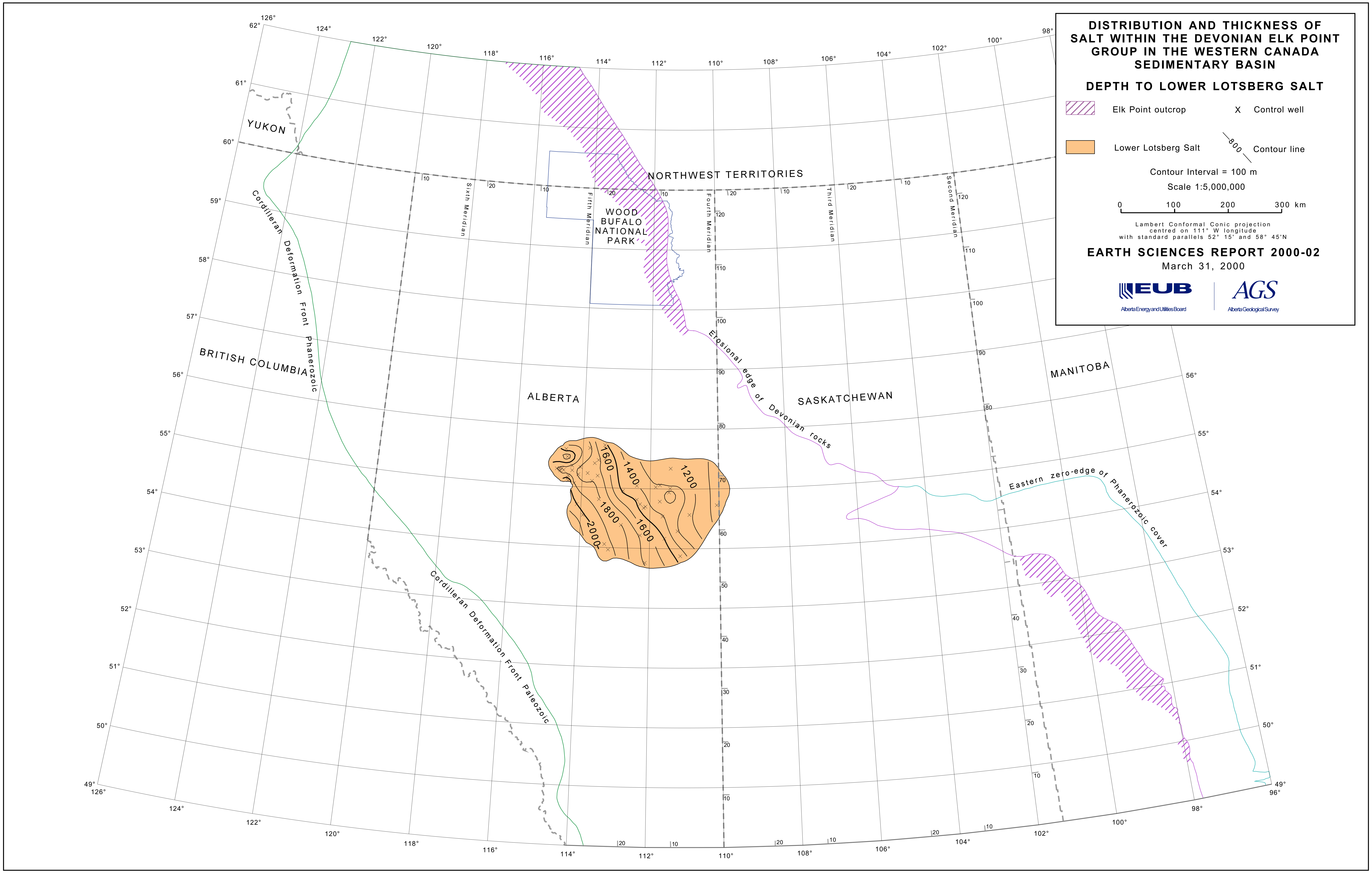
WOOD BUFALO NATIONAL PARK
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian

Map 2



DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
DEPTH TO LOWER LOTSBERG SALT
Elk Point outcrop
X Control well
Lower Lotsberg Salt
800
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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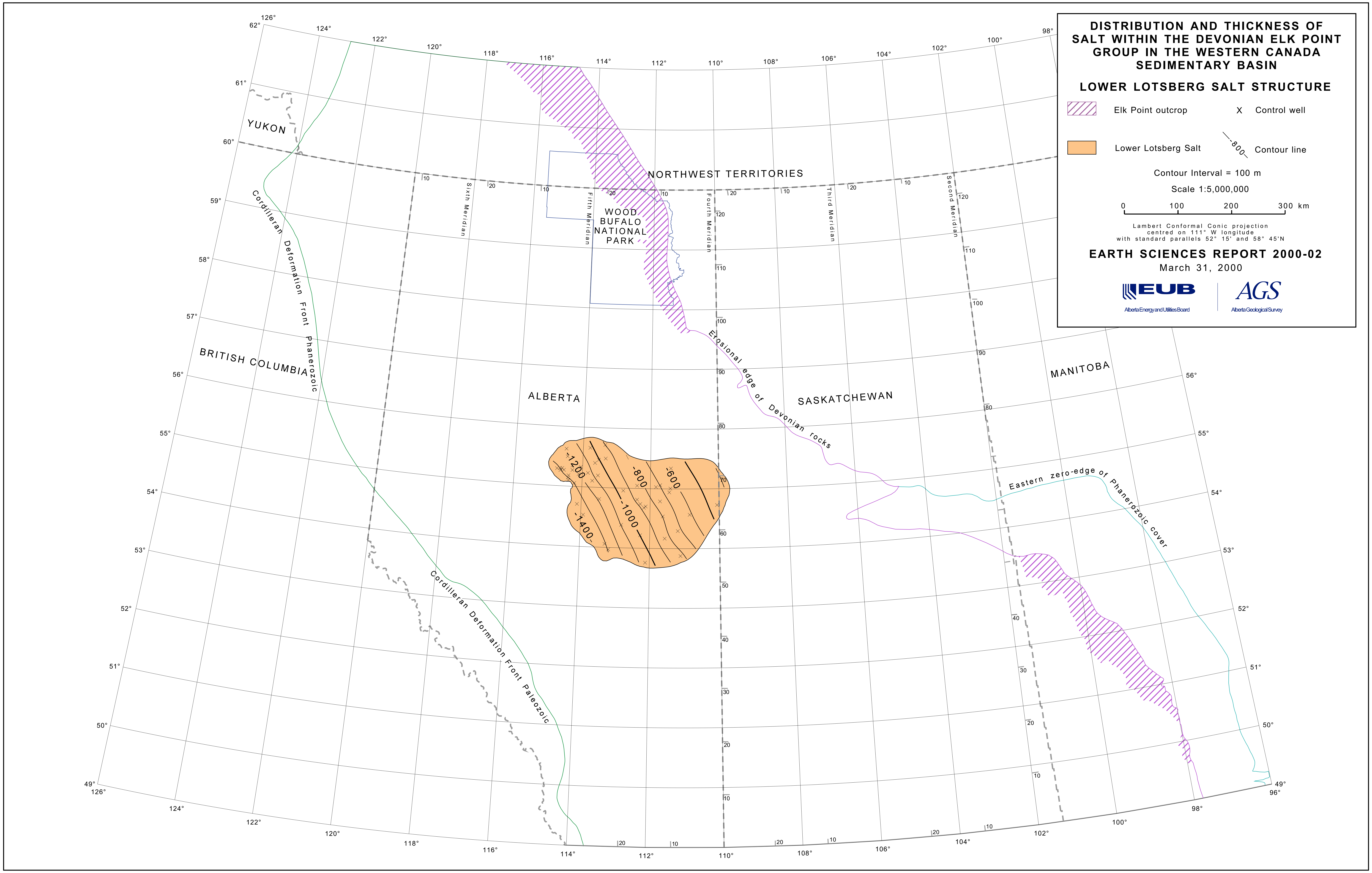
SASKATCHEWAN
MANITOBA
WOOD BUFALO NATIONAL PARK
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
1200
1400
1600
1800
2000

Map 3


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
LOWER LOTSBERG SALT STRUCTURE
Elk Point outcrop
X Control well
Lower Lotsberg Salt
-800 Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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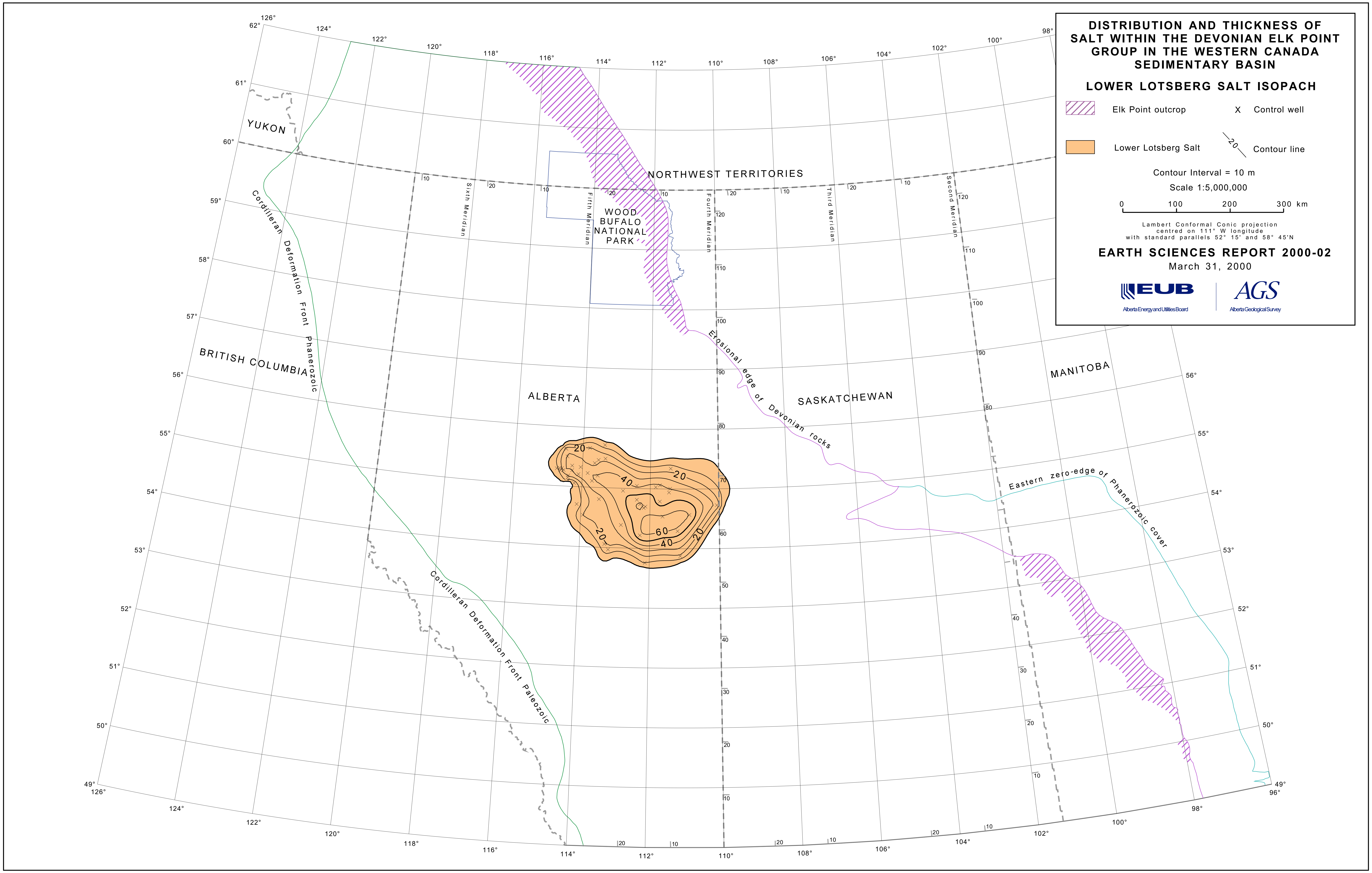
SASKATCHEWAN
MANITOBA
WOOD BUFALO NATIONAL PARK
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
-600
-800
-1000
-1200
-1400
62°
61°
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
50°
49°
126°
124°
122°
120°
118°
116°
114°
112°
110°
108°
106°
104°
102°
100°
98°
96°

Map 4


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
LOWER LOTSBERG SALT ISOPACH
Elk Point outcrop
X Control well
Lower Lotsberg Salt
20
Contour line
Contour Interval = 10 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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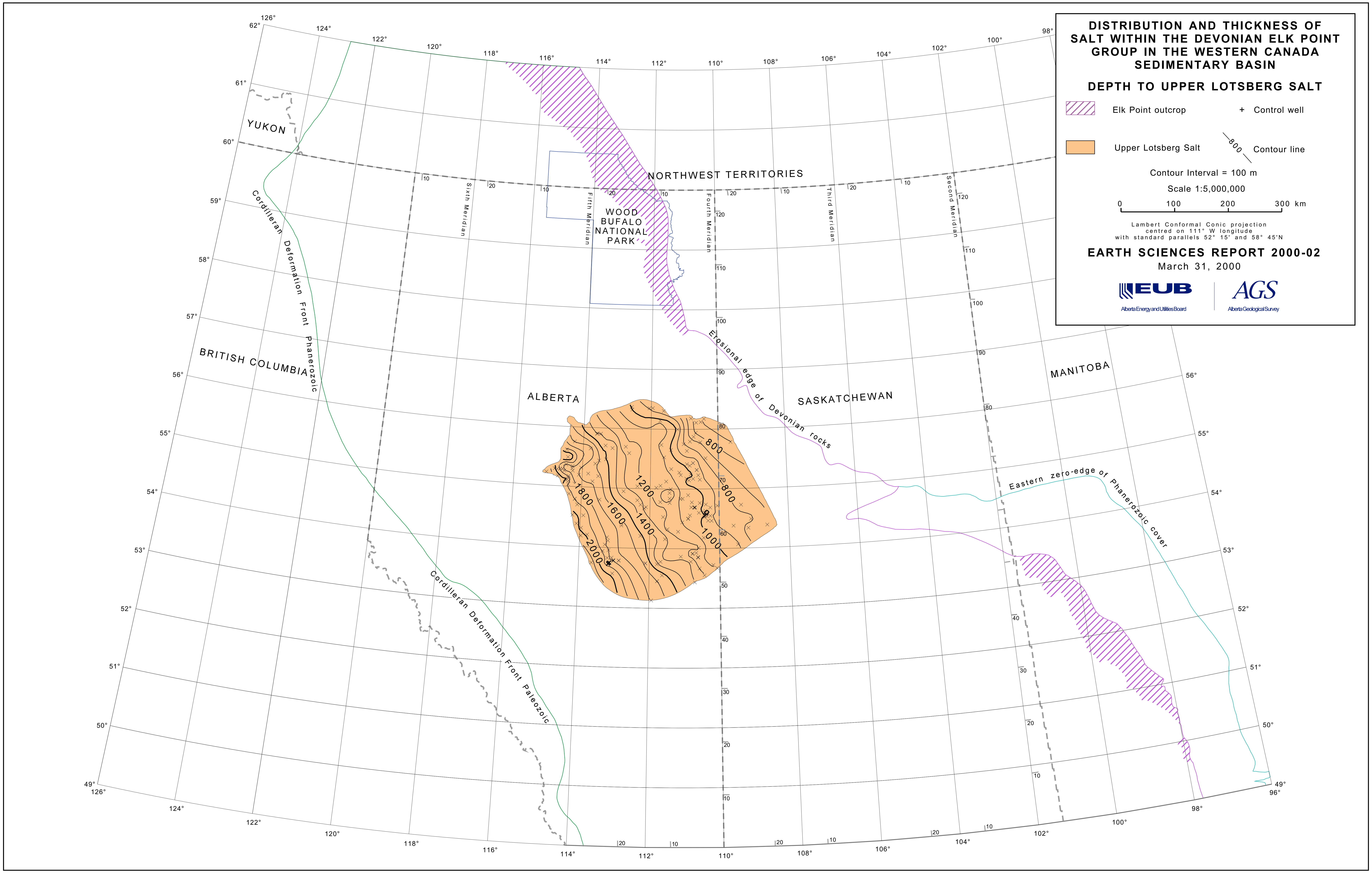
ALBERTA
SASKATCHEWAN
MANITOBA
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
20
40
60
40
20
20

Map 5



DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
DEPTH TO UPPER LOTSBERG SALT
Elk Point outcrop
+ Control well
Upper Lotsberg Salt
800
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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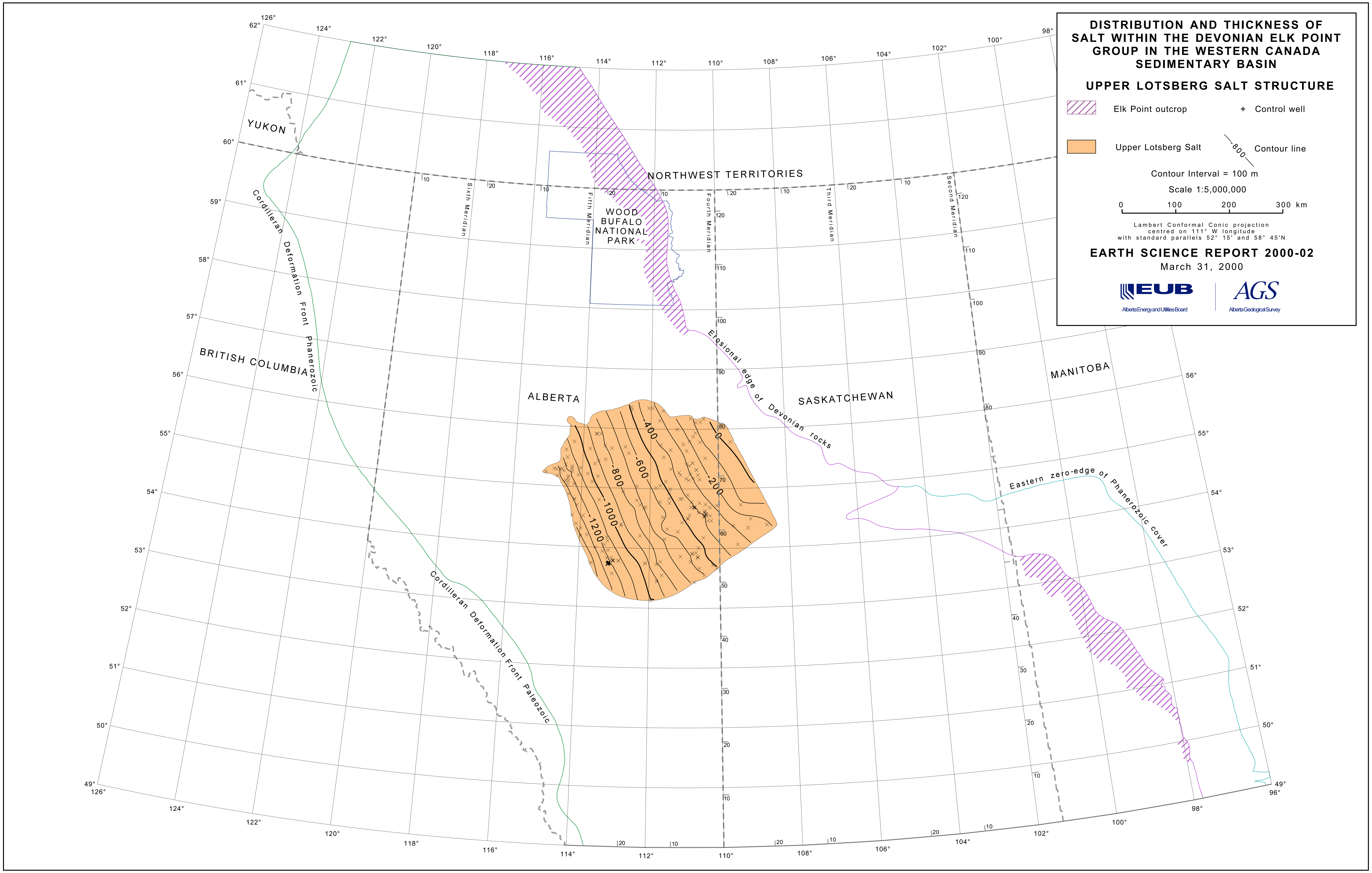
SASKATCHEWAN
MANITOBA
WOOD BUFALO NATIONAL PARK
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
800
1000
1200
1400
1600
1800
2000

Map 6


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
UPPER LOTSBERG SALT STRUCTURE
Elk Point outcrop
Control well
Upper Lotsberg Salt
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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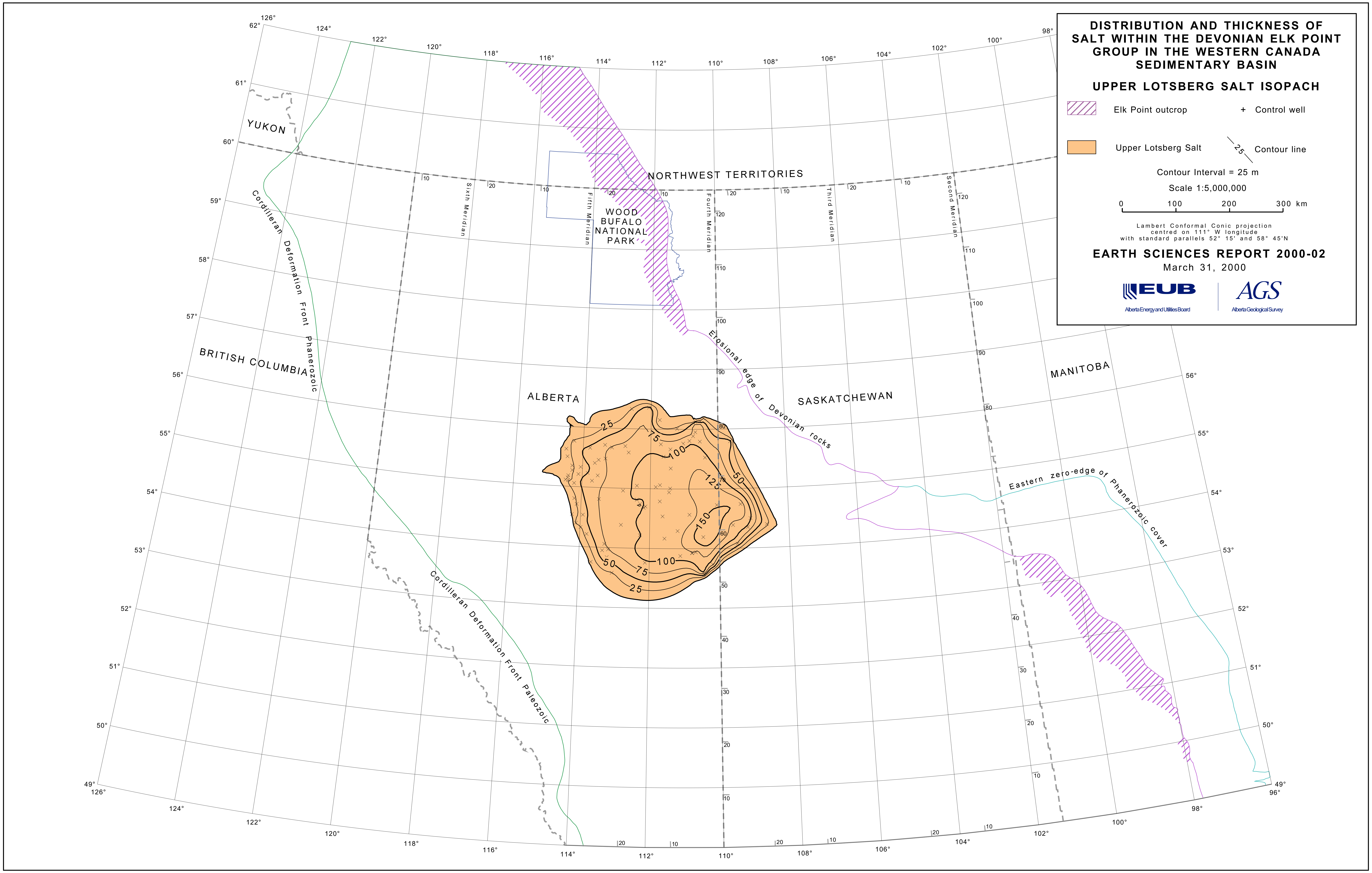
SASKATCHEWAN
MANITOBA
WOOD BUFALO NATIONAL PARK
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
0
-200
-400
-600
-800
-1000
-1200


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
UPPER LOTSBERG SALT ISOPACH
Elk Point outcrop
+ Control well
Upper Lotsberg Salt
Contour line
Contour Interval = 25 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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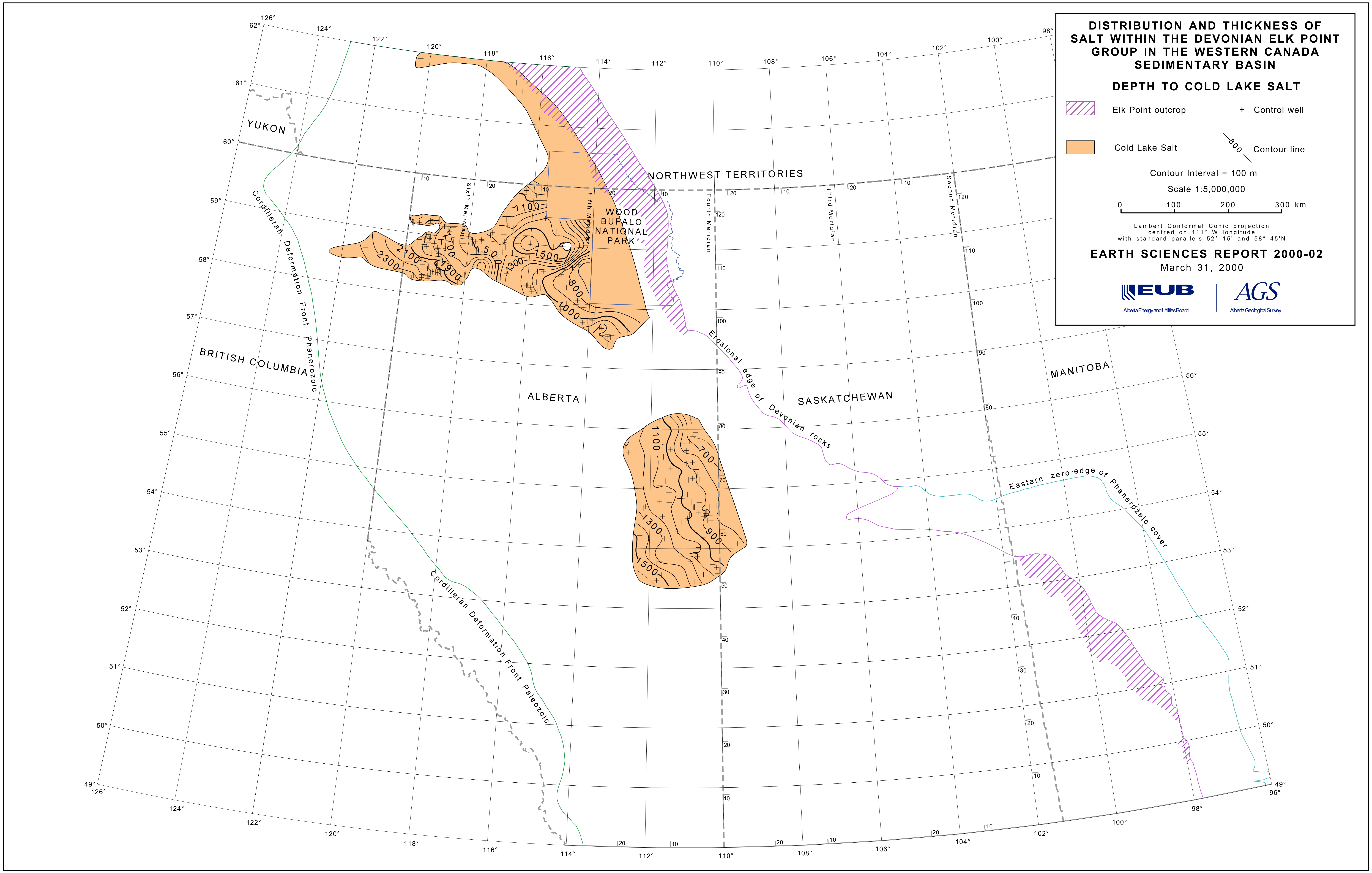
WOOD BUFALO NATIONAL PARK
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
25
50
75
100
125
150

Map 8


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
DEPTH TO COLD LAKE SALT
Elk Point outcrop
+ Control well
Cold Lake Salt
800
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0
100
200
300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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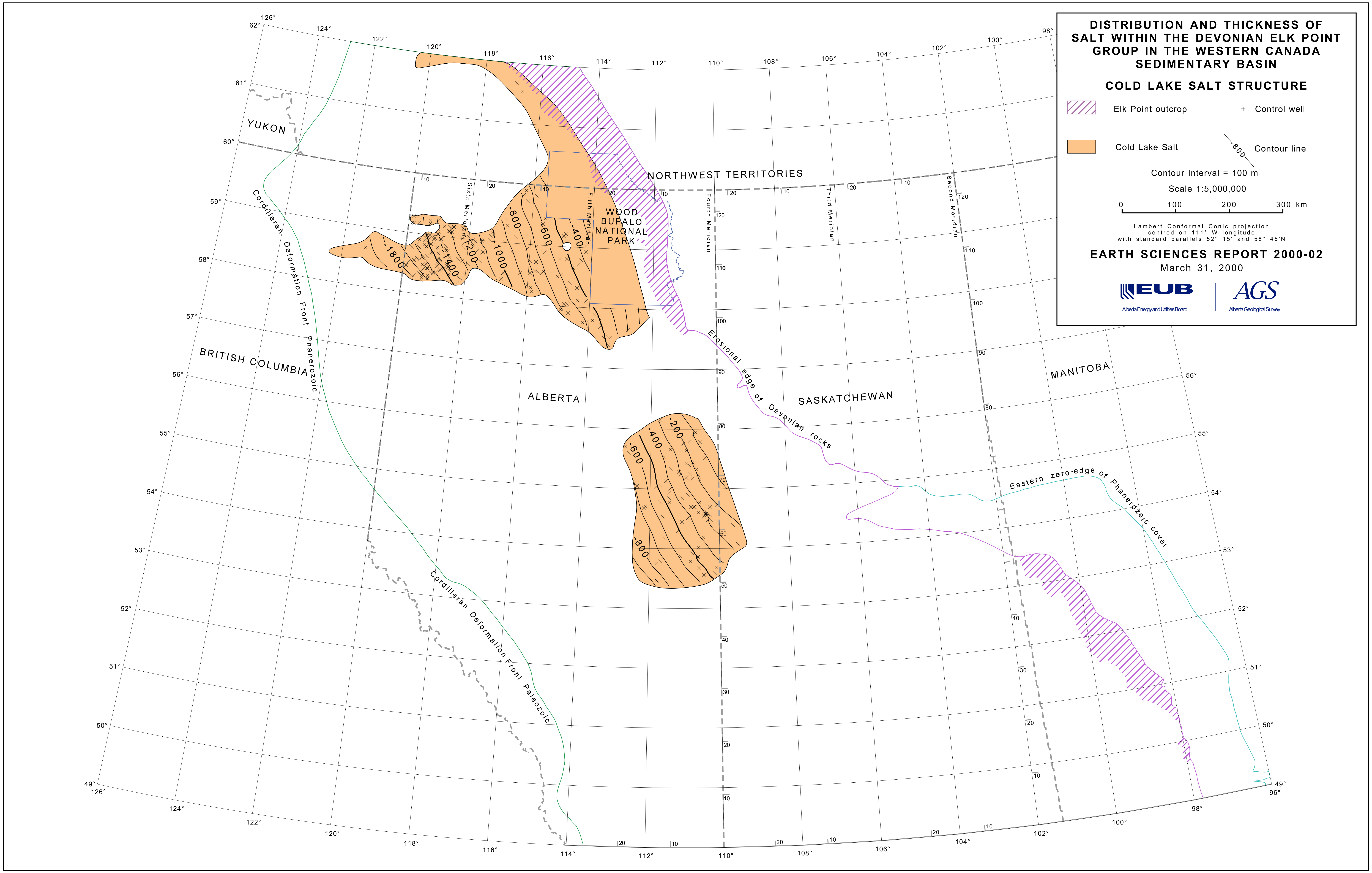
WOOD BUFALO NATIONAL PARK
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
1100
2100
2300
1700
1900
1500
1300
800
1000
700
900

Map 9



DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
COLD LAKE SALT STRUCTURE
Elk Point outcrop
+ Control well
Cold Lake Salt
800
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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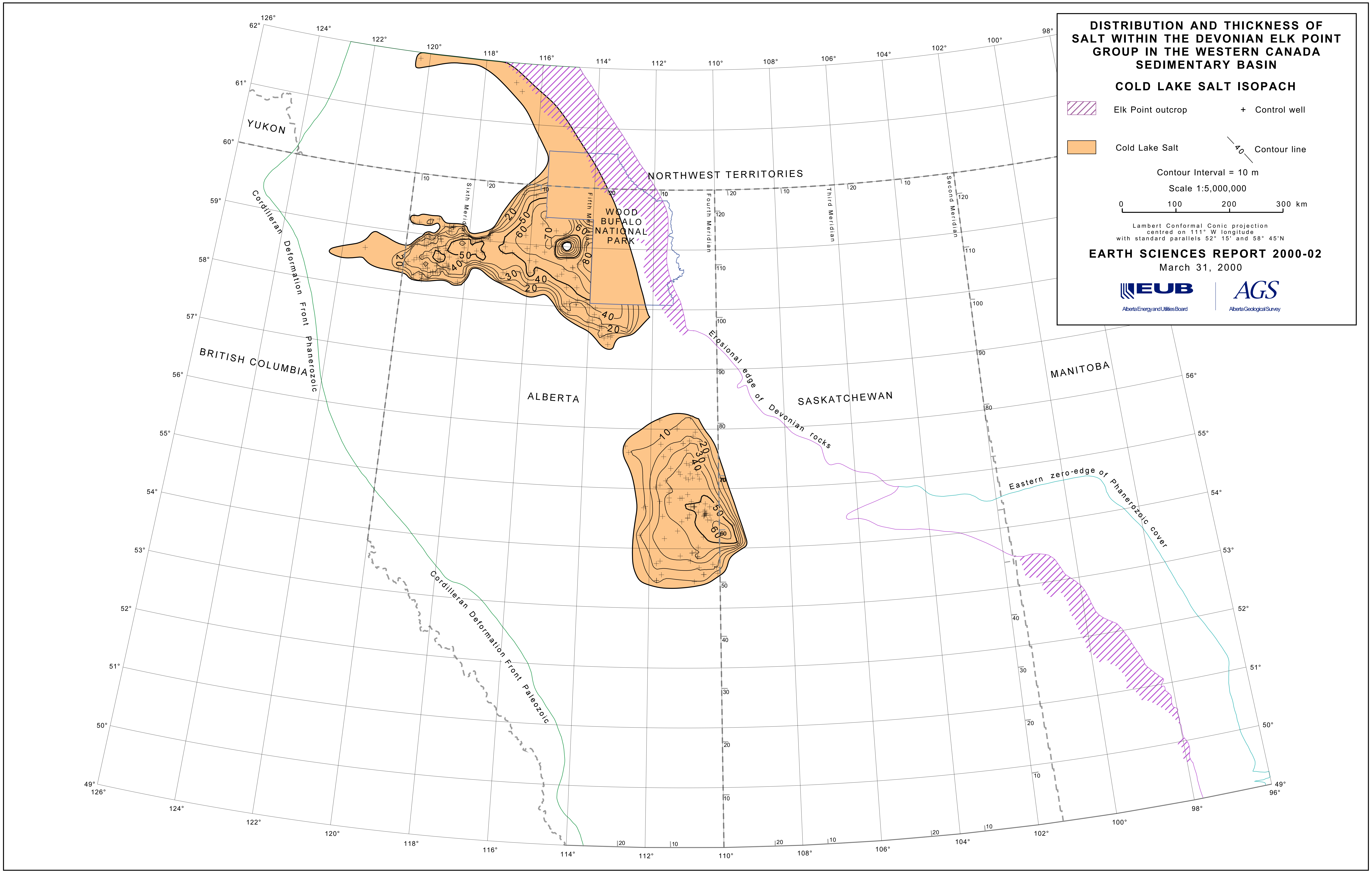
MANITOBA
WOOD BUFALO NATIONAL PARK
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
-1800
-1400
-1200
-1000
-800
-600
-400
-200


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
COLD LAKE SALT ISOPACH
Elk Point outcrop
+ Control well
Cold Lake Salt
Contour line
Contour Interval = 10 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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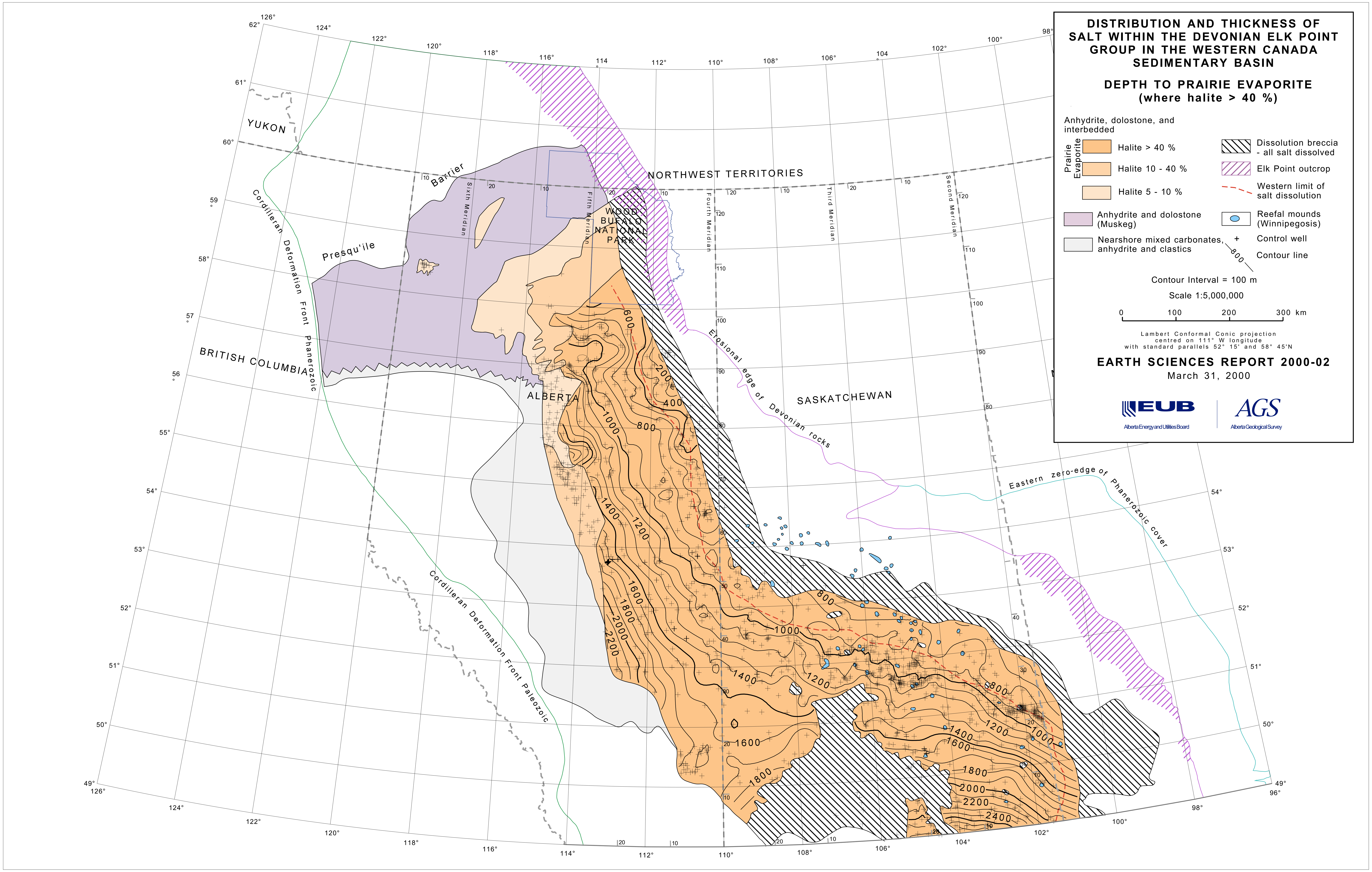
MANITOBA
WOOD BUFALO NATIONAL PARK
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
DEPTH TO PRAIRIE EVAPORITE (where halite > 40 %)
Anhydrite, dolostone, and interbedded
Prairie Evaporite
Halite > 40 %
Halite 10 - 40 %
Halite 5 - 10 %
Anhydrite and dolostone (Muskeg)
Nearshore mixed carbonates, anhydrite and clastics
Dissolution breccia - all salt dissolved
Elk Point outcrop
Western limit of salt dissolution
Reefal mounds (Winnipegosis)
Control well
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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SASKATCHEWAN
WOOD BUFALO NATIONAL PARK
Barrier
Presqu'ile
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian
600
400
800
1000
1200
1400
1600
1800
2000
2200
2400
126°
124°
122°
120°
118°
116°
114°
112°
110°
108°
106°
104°
102°
100°
98°
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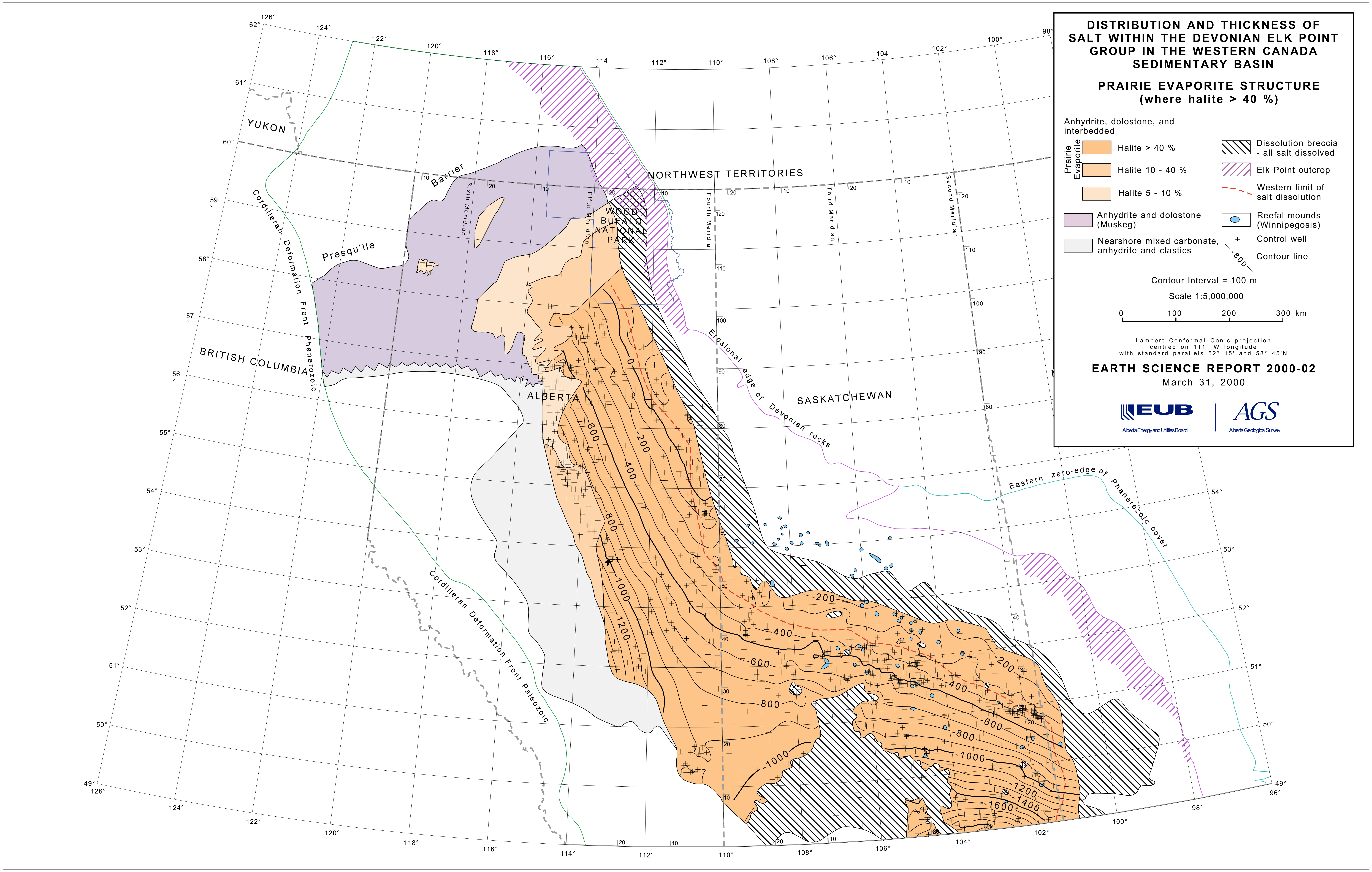
52°
51°
50°
49°



DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
PRAIRIE EVAPORITE STRUCTURE (where halite > 40 %)
Anhydrite, dolostone, and interbedded
Prairie Evaporite
Halite > 40 %
Halite 10 - 40 %
Halite 5 - 10 %
Anhydrite and dolostone (Muskeg)
Nearshore mixed carbonate, anhydrite and clastics
Dissolution breccia - all salt dissolved
Elk Point outcrop
Western limit of salt dissolution
Reefal mounds (Winnipegosis)
Control well
Contour line
Contour Interval = 100 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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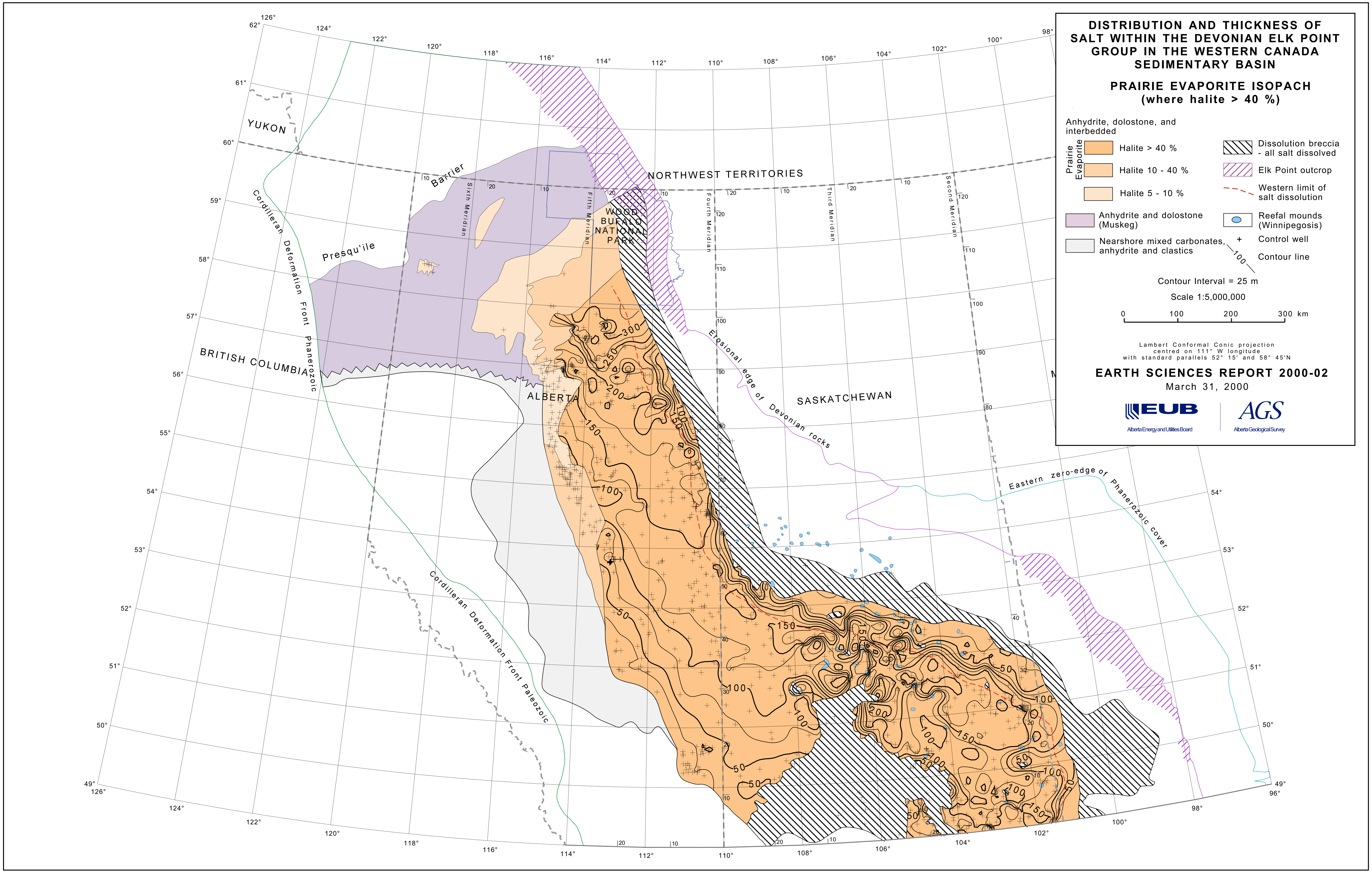
SASKATCHEWAN
WOOD BUFALO NATIONAL PARK
Presqu'ile Barrier
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian

Map 13


DISTRIBUTION AND THICKNESS OF SALT WITHIN THE DEVONIAN ELK POINT GROUP IN THE WESTERN CANADA SEDIMENTARY BASIN
PRAIRIE EVAPORITE ISOPACH (where halite > 40 %)
Anhydrite, dolostone, and interbedded
Prairie Evaporite
Halite > 40 %
Halite 10 - 40 %
Halite 5 - 10 %
Anhydrite and dolostone (Muskeg)
Nearshore mixed carbonates, anhydrite and clastics
Dissolution breccia - all salt dissolved
Elk Point outcrop
Western limit of salt dissolution
Reefal mounds (Winnipegosis)
Control well
Contour line
Contour Interval = 25 m
Scale 1:5,000,000
0 100 200 300 km
Lambert Conformal Conic projection centred on 111° W longitude with standard parallels 52° 15' and 58° 45'N
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WOOD BUFFALO NATIONAL PARK
Barrier
Presqu'ile
Cordilleran Deformation Front Phanerozoic
Cordilleran Deformation Front Paleozoic
Erosional edge of Devonian rocks
Eastern zero-edge of Phanerozoic cover
Sixth Meridian
Fifth Meridian
Fourth Meridian
Third Meridian
Second Meridian

Data sets

Control point data

The following files of isopach data contain the unique well identifier, location (in latitude and longitude) of the wells that were used to create the grids for the contour maps associated with the report, as well as the thickness values for those wells where the top and bottom of the salt units were identified. These files are in ASCII " comma separated value" format. Note that some spreadsheet software will attempt to convert the unique identifier field to scientific resolution. Such a conversion will result in modifications such that the well ID will become incorrect.

- COLDLAKE_ISO.CSV - Cold Lake Salt
- LOTSBERG_ISO.CSV - Lotsberg Salt
- PREVAP_ISO.CSV - Prairie Evaporite

Polygon & Polyline data

The following files contain polygon and polyline data in the Atlas ASCII format. Data in this format consist of a header record followed by vertex coordinate records. The header line consists of a 16-column polyline name followed by an 8 column, right-justified number. The number gives the count of vertices to follow. The vertex records contain a 12-column longitude, followed by four blanks, followed by a 12-column latitude. Both longitude and latitude are given in decimal degrees.

- CLDLK_CP.DEG - Cold Lake clipping polygon
- CLDLK_PG.DEG - Zero outline of Cold Lake Salt modified from Atlas boundaries
- ELKSOUTCROP_PG.DEG - Outlines of Elk Point Group outcrop in WCSB
- ELKSSALT_PG.DEG - Areas of salt dissolution of Prairie Evaporite
- ELKS_CPG.DEG - Elk Point Group outline in WCSB
- LI_COL_BREC.DEG - Areas of salt dissolution of Cold Lake Salt
- LLOTS_PG.DEG - Zero outline of Lower Lotsberg Salt, also serves as clipping polygon
- PREVAP_0_PG.DEG - Zero edge of Prairie Evaporite
- PREVAP_40_100_CP.DEG - Prairie Evaporite where halite >40% clipping polygon
- PREVAP_40_100_PG.DEG - Prairie Evaporite where halite >40%
- PREVAP_DIS_E_PG.DEG - Prairie Evaporite dissolution edge
- ULOTS_PG.DEG - Zero edge of Upper Lotsberg Salt, also serves as clipping polygon

Surface Grid Data

The following files contain surface grids as X, Y, Z triplets. These were derived by inverting the engineering transform and then the cartographic projection used in gridding data when constructing the maps. The coordinate of every grid node, which was associated with a non-null value, was inverted. The two additional values in each record give the column and row number of the node within the original grid (this is primarily of administrative interest). The files are in ASCII fixed format. Each record contains a 12-column longitude, followed by four blanks, followed by a 12-column latitude followed by four blanks, followed by a 16 column "Z" value (isopach or depth). Both longitude and latitude are given in decimal degrees; "Zs" are in metres.

- B_CLDLK_D_CPTS.DAT - Depth to base of Cold Lake Salt
- B_CLDLK_E_CPTS.DAT - Elevation grid of base of Cold Lake Salt

- B_LOTS_E_CPTS.DAT - elevation of base of Lotsberg Formation
- B_PREVAP_E_CPTS.DAT - Elevation of base of Prairie Evaporite
- B_ULOTS_D_CPTS.DAT - Depth to Upper Lotsberg Salt
- B_ULOTS_E_CPTS.DAT - Elevation of base of Lotsberg Formation
- CLDLK_I_CPTS.DAT - Isopach of Cold Lake Salt
- CLDLK_I_CP_CPTS.DAT - Isopach of Cold Lake Salt including zero outline data
- LLOTS_D_CPTS.DAT - Depth to Lower Lotsberg Salt
- LLOTS_E_CPTS.DAT - Elevation of Lower Lotsberg Salt
- LLOTS_I_CPTS.DAT - Isopach of Lower Lotsberg Salt
- LOTS_I_CPTS.DAT - Isopach of Lotsberg Formation
- MLOTS_I_CPTS.DAT - Isopach of shale interval between Lower and Upper Lotsberg salts
- PREVAP_I_CPTS.DAT - Isopach of Prairie Evaporite
- PREVAP_I_TOT_CPTS.DAT - Isopach of Prairie Evaporite, unclipped
- T_CLDLK_CHECK_I_CPTS.DAT - Elevation of top of Cold Lake Formation derived by adding isopach grid to elevation grid of base of Upper Lotsberg Salt
- T_CLDLK_D_CPTS.DAT - Depth to top of Cold Lake Salt
- T_CLDLK_E_CPTS.DAT - Elevation of top of Cold Lake Salt
- T_LLOTS_CHECK_I_CPTS.DAT - Elevation of top of Lotsberg Formation derived by adding isopach grid to elevation grid of base of Lotsberg Formation
- T_LOTS_CHECK_I_CPTS.DAT - Elevation of top of Lower Lotsberg Salt derived by adding isopach grid to elevation grid of base of Lotsberg Formation
- T_PREVAP_D_CPTS.DAT - Depth to top of Prairie Evaporite, clipped to PREVAP_40_100_CP
- T_PREVAP_D_TOT_CPTS.DAT - Depth to top of Prairie Evaporite, unclipped
- T_PREVAP_E_CPTS.DAT - Elevation of top of Prairie Evaporite, clipped to PREVAP_40_100_CP
- T_PREVAP_E_TOT_CPTS.DAT - Elevation of Prairie Evaporite unclipped
- T_ULOTS_CHECK_I_CPTS.DAT - elevation of top of Upper Lotsberg Salt derived by adding isopach grid to elevation grid of base of Upper Lotsberg Salt
- T_ULOTS_D_CPTS.DAT - Depth to Upper Lotsberg Salt
- T_ULOTS_E_CPTS.DAT - Elevation of top of Upper Lotsberg Salt
- ULOTS_I_CPTS.DAT - Isopach of Upper Lotsberg Salt