GEO-NOTE 2000-04

Quaternary Geology Northern Alberta: Information Sources and Implications for Diamond Exploration

Alberta Energy and Utilities Board
Alberta Geological Survey

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Purpose

The purpose of this Geo-Note is to briefly draw the reader's attention to some of the more significant aspects, with respect to mineral exploration, of the Quaternary and related geology; and to record the sources where preexisting data can be obtained.
This is not a comprehensive document dealing thoroughly with all aspects of the Quaternary geology, rather, it hits some highlights.

Summary

This Geo-Note briefly presents some aspects of Quaternary geology of interest to mineral exploration. It is not a comprehensive document. Information is provided on the physiography, bedrock topography, drift thickness, Quaternary stratigraphy, surficial geology, features which differs significantly from other areas of exploration such as the Lac De Gras region. Types and sources of surface and subsurface data are also discussed.

Northern Alberta consists of a number of highlands separated by major drainage ways, many of which were essentially cut prior to the first glaciation. All of northern Alberta was covered by a number of glacial advances. The region is blanketed by drift, which may be up to 300 m thick in buried preglacial valleys. The stratigraphy of this drift is not well known due to a paucity of subsurface data. However drift includes, in places at least, multiple till sheets with intertill and subtill glaciolacustrine and glaciofluvial sediment.

Introduction

Knowledge of the Quaternary geology and history of a particular target area can help maximize the return from mineral exploration throughout the Interior Platform including northern Alberta.

This document focuses only on a few aspects of the Quaternary age and related sediment that would be of interest to an explorationist starting work in the region. It is drawn from the text and figures used in a presentation during the Mineral Exploration Group Meeting, April 1998, Calgary, Alberta.

The assumption is that the reader has some experience with drift prospecting in the Canadian Shield and is familiar with the variety of glaciogenic deposits of importance to mineral exploration in glaciated terrain.

Northern Alberta, presently the focus of extensive exploration for diamonds, differs from other areas such as Lac De Gras, in a number of ways of importance for mineral exploration, including: physiography, drift thickness, Quaternary stratigraphy, and surficial and bedrock geology.

Physiography

Northern Alberta consists of a number of highlands: the Swan Hills, Pelican Mountains, Saddle Hills, Clear Hills, Naylor Hills, Milligan Hills, Buffalo Head Hills, Birch Mountains, Caribou Mountains, Cameron Hills, Bootis Hills and Elsa Hills. The Caribou Mountains are the highest feature, rising to just over 1000 m. above sea level (asl). Separating these highlands are major drainage ways such as the Peace, Wabasca and Athabasca Rivers. The last river falls to about 240 m. asl. in the northeast near Lake Athabasca (Figure l). Comprehensive information on the physiography of Alberta can be found in Pettapiece, 1986.

Bedrock Topography

The bedrock topography (Figure 2) is drawn on the surface of the bedrock underlying the unconsolidated sediment of Quaternary age and also, mainly in the deep portions of the preglacial channels, unconsolidated sediment of late Tertiary age.

The bedrock topography resembles the surface topography (Figure 1) to some degree with the high and lows in the bedrock surface being reflected in the surface topography. The bedrock topography map shows two basic topographic elements: the broad generally northward and eastward trending valleys, and intervening uplands formed by eroded bedrock remnants.

The bedrock topography map reveals that most of the uplands shown on the physiographic map (Figure 1) are bedrock controlled. Bedrock highlands contribute significantly to the Swan Hills, Pelican Mountains, Saddle Hills, Clear Hills, Naylor Hills, Milligan Hills, Buffalo Head Hills, Birch Mountains, and the Caribou Mountains. Note however, that in the vicinity of the Cameron, Bootis and Elsa Hills in northwestern Alberta, the bedrock high is lower and less extensive than the surface expression of these hills.

The topographic lows are primarily the major preglacial valleys; the thalwegs of which are shown on Figure 2. The valleys in the southern half of the area are well defined and known to contain preglacial sediment at their base. The valleys in the north half are not as well defined due to a lack of subsurface data when the map was compiled. Most of these valleys were likely eroded in preglacial time; however, the existence of preglacial sediment at the base of these valleys is needed to confirm this assumption. The primary indicator of preglacial sediment is the absence of Precambrian crystalline and Paleozoic clasts because these lithologies were transported into the area by westward and southward flowing Laurentide glaciers. Whereas the preglacial sediments contain lithologies from the Cordillera that were transported easterly by fluvial systems.

Not shown on Figure 2 are numerous smaller preglacial channels that act as tributaries to the major channels. Also absent are narrow steep sided channels that contain, at their base, sediment with glacially transported Precambrian and Paleozoic clasts. The steep channels are interpreted to have been formed after the first glacier advanced into the region.

As well, closely spaced drilling associated with petroleum and more recently mineral exploration, has shown that the bedrock surface elevation may change more than 10 m over short distances. Some explanations for this are small channels, collapse structures and glaciotectonic excavation of bedrock masses.

The preglacial valleys include, for example, the Beverly system that passes through Edmonton and extends northeastward to and across the Alberta Saskatchewan border. North of this system, on the east side of the province, is the Wiau valley; this large valley has been filled by about 300 m of sediment. In the northern half of the area are preglacial valleys occupied, in part, by the present day Peace and Athabasca Rivers. A preglacial valley may also underlie the low between the Birch Mountains and Buffalo Head Hills. Pawlowicz and Fenton (1995) show the location and the names of other preglacial valleys.

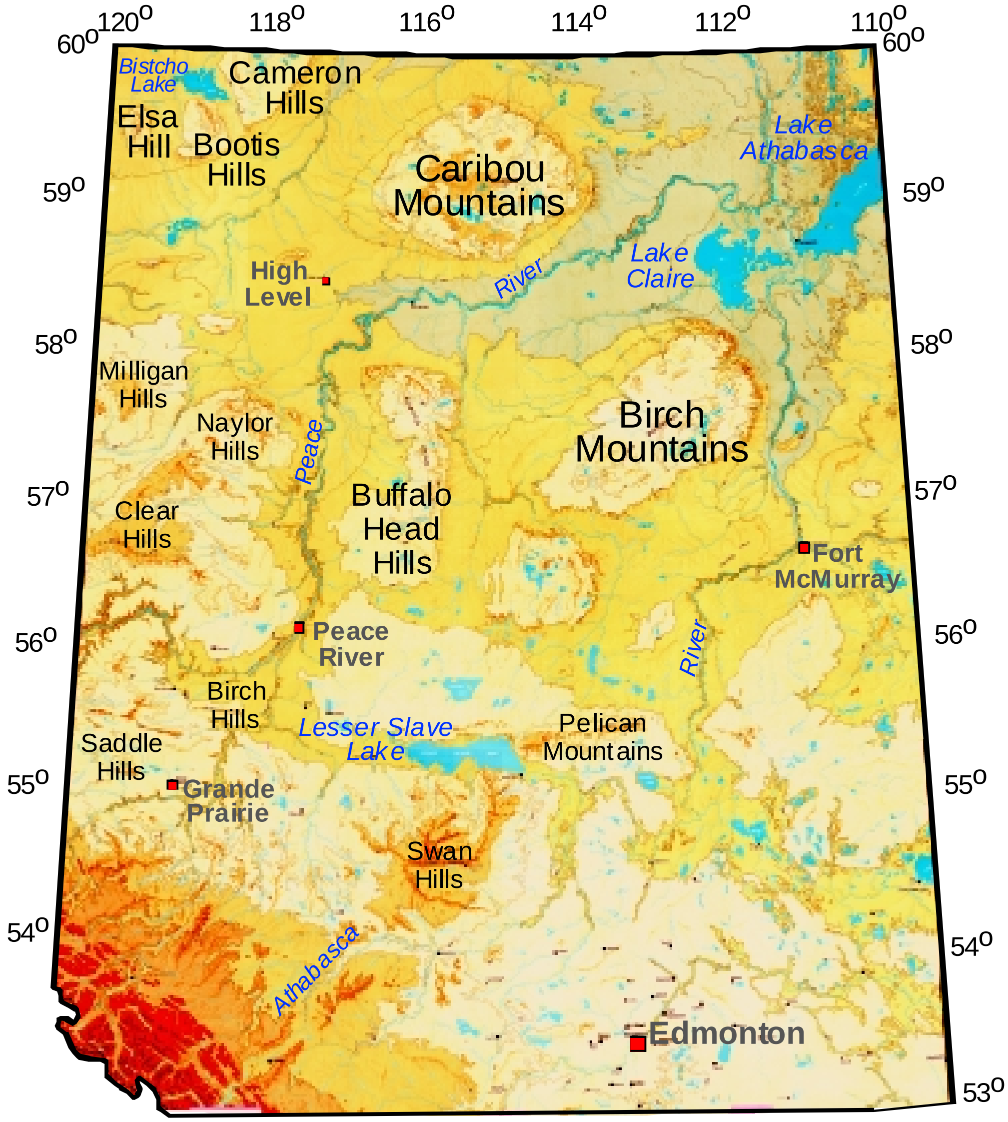

Figure 1. Physiography map Northern Alberta

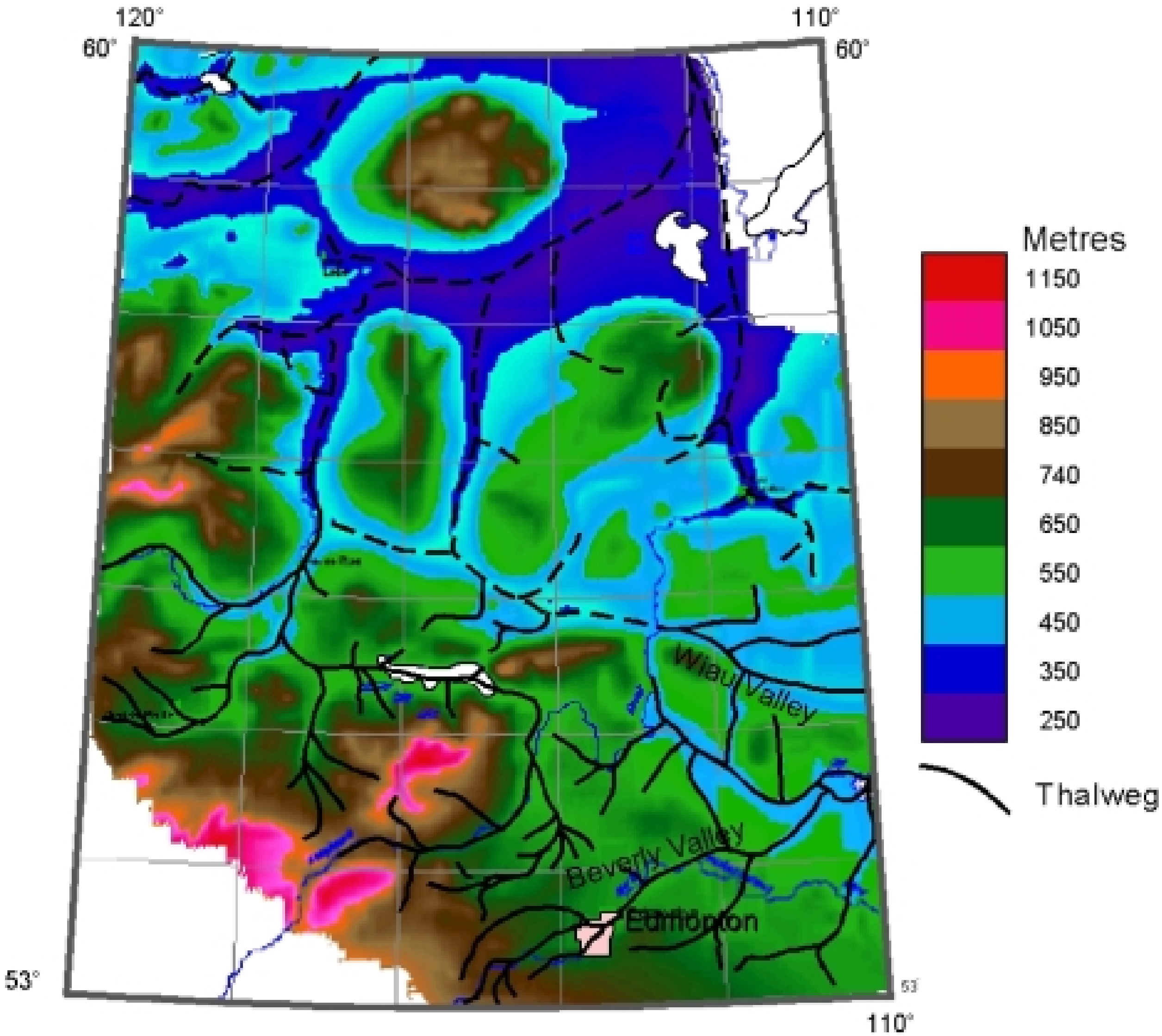

Figure 2. Bedrock topography map derived from Pawlowicz and Fenton 1995. Northern half of the map based on very limited data.

Drift Thickness

A drift thickness map is an isopach map from the top of bedrock to land surface. This map is very generalized in the northern half of the area because of the small amount of subsurface data available during its preparation.

The drift thickness for the entire Prairies was discussed by Fenton and others, (1994). The conditions in the northern Alberta portion of this area are typical of this region. That is, drift thickness varies from 0 m in a few areas to 300 m in the Wiau channel on the Alberta - Saskatchewan boarder. The drift is generally thick in the valleys, but in places it can also thicken on the uplands. The lows, primarily the preglacial channels, have been partially filled, thus lowering the local relief on the present land surface.

The drift thickness map (Figure 3) shows the thickness of unconsolidated sediment overlying the bedrock and includes sediment of both Late Tertiary and Quaternary age; although Quaternary sediment forms the major proportion of the sequence. The Tertiary sediment is confined largely to the lower portions of the preglacial channels.

Deposition of this map unit within the valleys was more or less continuous from the close of the Tertiary into the Quaternary. The deposition of nonglacial fluvial sediment continued until the preglacial drainageways were first blocked by the earliest glacial advance to reach a particular region. The first stratigraphic marker positively identifying Quaternary sediment, at any particular site, is the stratigraphically lowest appearance of till and/or stratified sediment that contains material transported westward and/or southward by the advancing Laurentide glaciers - typically material from the Precambrian Shield and/or the adjacent Paleozoic carbonate outcrop belt.

The stratigraphy of these channels fills in the north half are not as well defined due to a lack of data when the map was compiled. (See previous section for more information).

Factors influencing the location of thick accumulations of sediment in northern Alberta are: (1) the preglacial valleys, (2) bedrock highlands and remnants, (3) areas of ice marginal still-stands and (4) bedrock contacts or scarps (Fenton and others, 1994). An example of thick sediment accumulation in a preglacial channel is the east-west trending Wiau preglacial channel (described previously in the bedrock topography section), which exists along the Alberta-Saskatchewan boarder between 55 and 56 degrees. (Figures 2 and 3). The Wiau is filled with about 300 m of sediment. These valleys influenced deposition in a number of ways: (1) they acted as sediment traps, accumulating thick sequences of stratified sediment as the advancing or retreating glaciers dammed the eastward flowing streams, (2)they influenced glacial dynamics and contributed to the accumulation and preservation of comparatively thick sequences of till within them, (3) during the nonglacial intervals, they formed lows favorable to initial erosion and channel formation, and this led to subsequent infilling of these channels by nonglacial stratified sediment, and (4) because of their low position in the landscape, they tended to preserve the existing sediment from erosion during subsequent glacial advances.

Bedrock uplands may also include areas of thick drift accumulation. An example is the northern portion of the Birch Mountains where one petroleum well intersected drift to a depth of 165 m. These areas may be the result of a thick, comparatively widespread, accumulation of glaciogenic sediment (till, and glaciofluvial and/or glaciolacustrine sediment) or the infilling of comparatively narrow preglacial or interglacial channels.

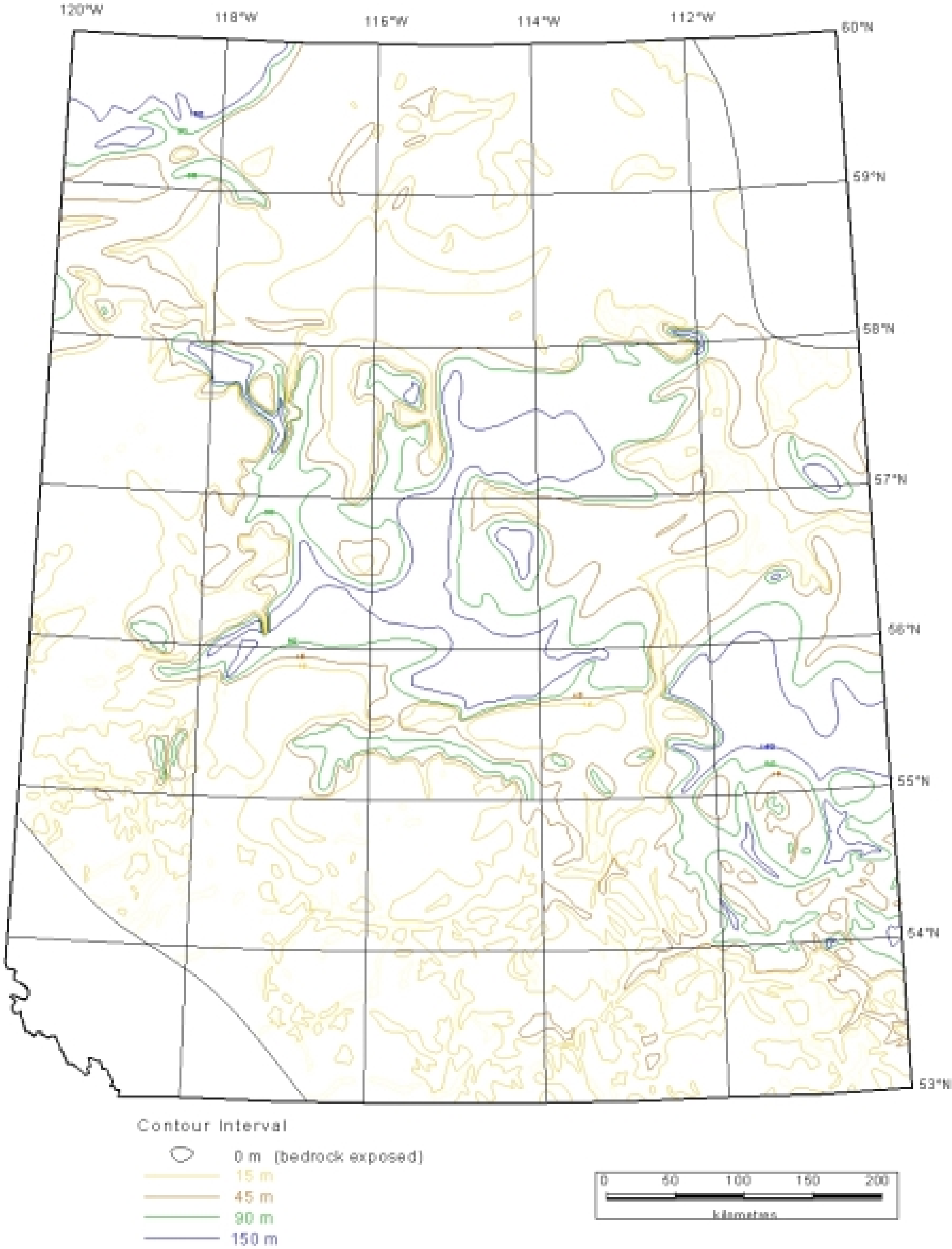

Figure 3. Drift thickness map, reduced from Pawlowicz and Fenton 1995. Northern half of the map based on very limited data.

The effect of deposition at an ice marginal stillstand is shown by the Cameron, Bootis and Elsa Hills region in northwestern Alberta. The limited subsurface data indicated these uplands are composed primarily of a thick sequence of Quaternary sediment deposited during one or more intervals when the ice margin was stationary in the region long enough to deposit the sediment.

Bedrock contacts or scarps are areas where glaciers deformed the bedrock and stacked comparatively thick accumulations of thrusted bedrock and glacial sediment. So far, no major glaciotectonic features have been recognized in northern Alberta, but, minor deformation has been recognized in a number of areas, including the Birch Mountains (Figure 4), on the northeastern flank of the Caribou Mountains, south of Rock Island Lake, at Fawcett Lake and Muskwa Lake, and in the Fort McMurray region. It is probable that other glacially deformed sediment will be recognized as the Alberta Geological Survey program continues to map the surficial geology in northern Alberta.

The Cooking Lake Erratic, an area east of Edmonton in which the Grand Rapids Sandstone is exposed in many roadcuts, indicates that the glacial ice was capable of transporting rafts or slabs of the Grand Rapids Sandstone, more or less intact, from its subcrops south of Fort McMurray (Figures 5a and 5b). The Neutral Hills, Misty Hills and Mud Buttes in central eastern Alberta, as shown in Green (1972), also are Alberta examples of glaciotectonism affecting major accumulations of sediment, primarily preexisting bedrock and till.

Quaternary Stratigraphy

The Quaternary stratigraphy is poorly understood over much of the region. Geological investigations are however underway to correct this. Presently, multiple tills have been recognized in most of the regions where information does exist. Examples include those from the Firebag River north east of Fort McMurray (Dufresne, and others 1994), the Sand River map area (Andriashek and Fenton 1989), and the Peerless Lake map area (Pawlowicz and Fenton, 1998).

The Sand River map area is southeast of Fort McMurray 54°N to 55°N latitude and 110°W to 112°W longitude (Figure 1). In this area, Andriashek and Fenton (1989) demonstrated the presence of a number of glacial and nonglacial units (Figure 6). This sedimentary sequence records the advance and melt back of a number of glaciations which moved through this area. As well, the nonglacial intervals, local river erosion produced narrow channels that were subsequently filled with fluvial and lacustrine sediment (Figure 6, cross section BB', unit 2).

During each glacial advance, ice flowed over the soft, poorly consolidated Mesozoic bedrock, and/or the tills, which previously were deposited and derived from that bedrock. This, together with the well developed relief, allowed each glacial advance to incorporate considerable quantities of debris, both as finely divided sediment and large masses incorporated through glaciotectonism. Subsequent melting of the ice released this debris as relatively clay-rich till and associated glaciofluvial and glaciolacustrine sediment.

Other areas of northern Alberta that contain over 50 m of unconsolidated Quaternary sediment may contain a similar multiple unit sequence. There are insufficient data to be certain of this at this time.

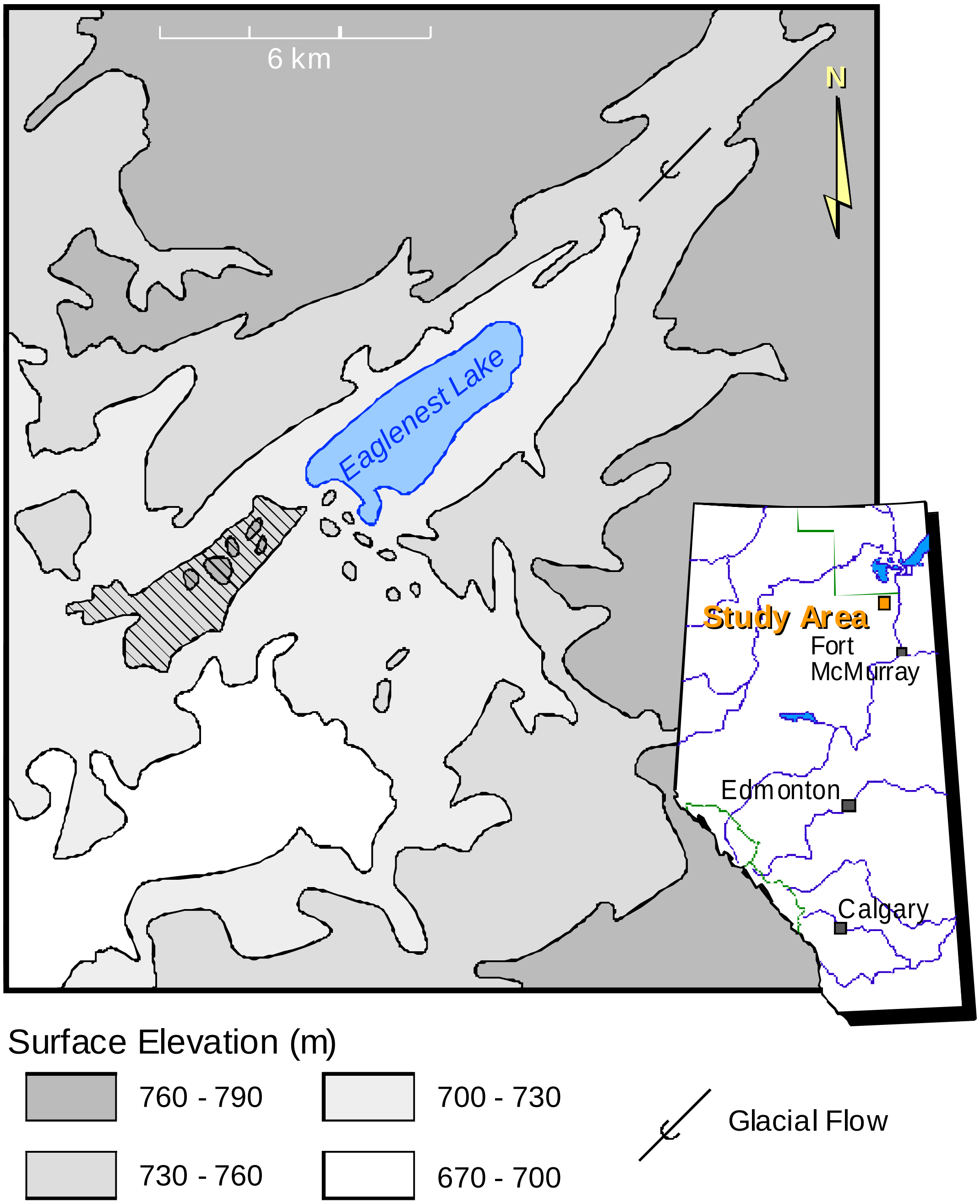

Figure 4. Glacial thrustmass down glacier from source depression occupied by Eaglenest Lake, Birch Mountains.

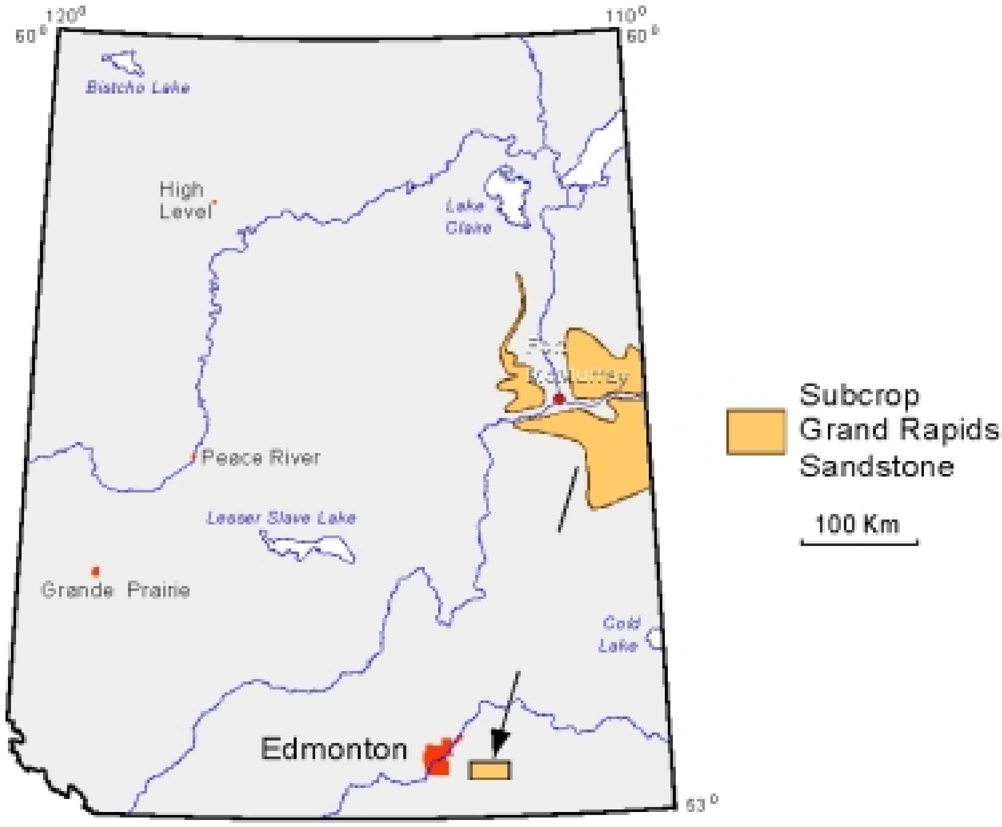

Figure 5a. Source and transport of the Cooking Lake Erratic.

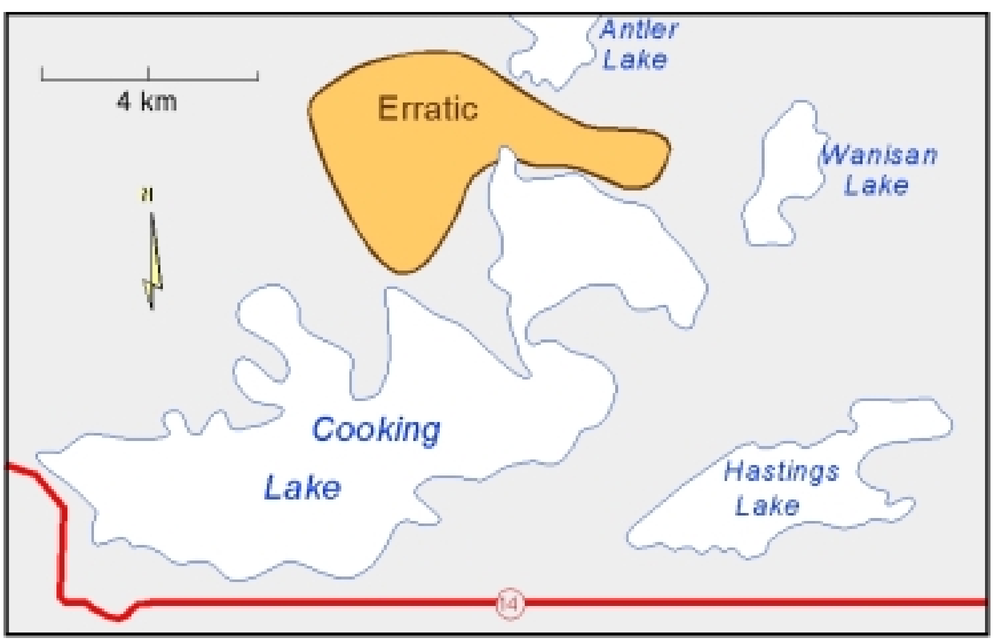

Figure 5b. Area where the Cooking Lake Erratic is visible in road cuts.

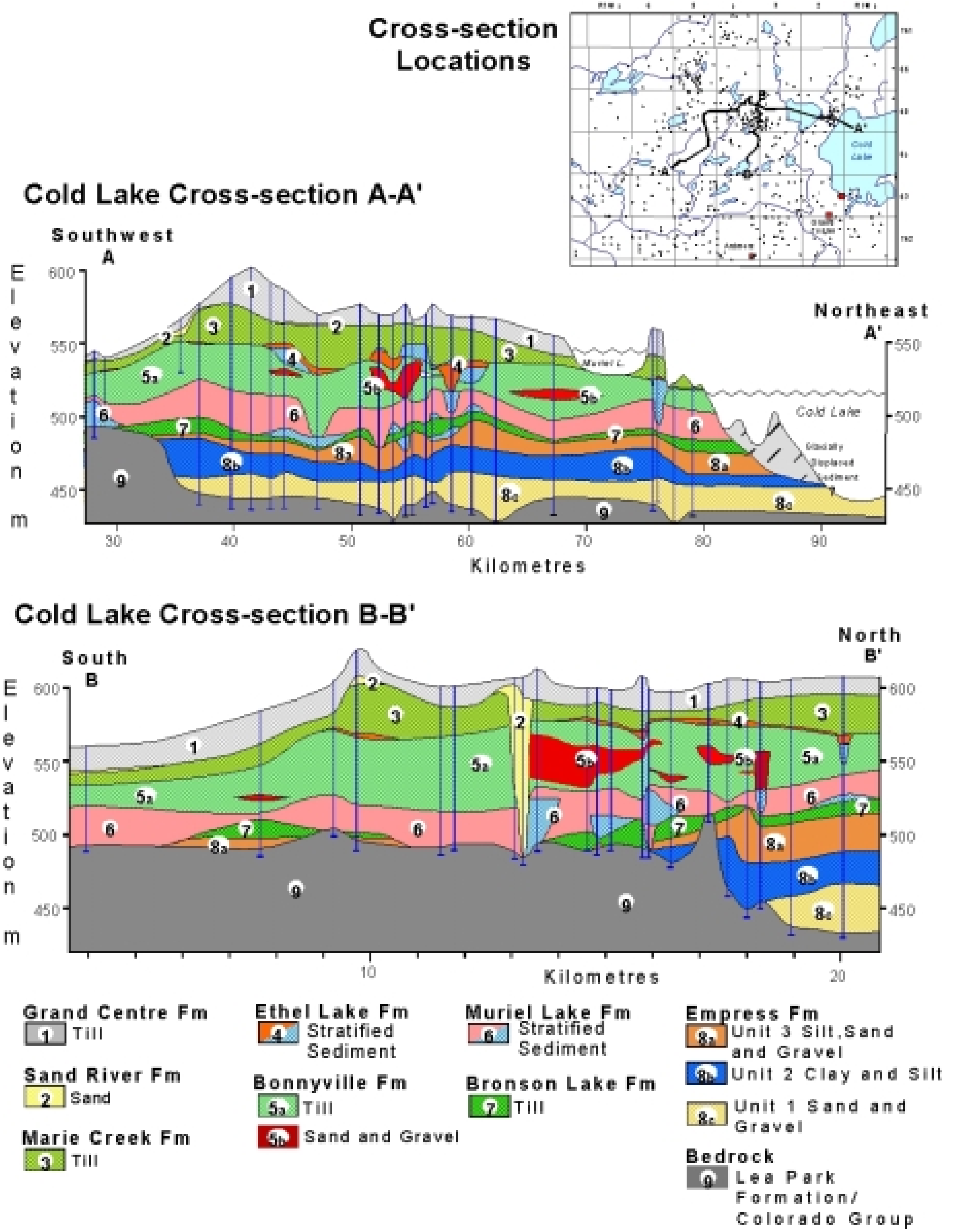

Figure 6. Cross sections through the Sand River map sheet area showing the presence of multiple units. Some of the units can be correlated over the entire map area and beyond. Modified from Andriashek and Fenton 1989.

Surficial and Quaternary Geology

Quaternary sediment is of glacial, fluvial, lacustrine, aeolian, colluvial and organic origin. The major proportion of this sediment is diamicton (till) deposited either directly or indirectly by the glaciers. One of the most noticeable properties of this sediment is the Precambrian Shield and Paleozoic clasts that were glacially transported from the east. The till is generally clay rich (30-60%) because the glaciers moved over Mesozoic bedrock, or over earlier tills which were also derived from that bedrock. Only in the northeast where the glaciers had just flowed off the Precambrian crystalline rocks or the Athabasca sandstone, are the till units generally sandy.

The glacial terrain can be divided into a number of terrain types, including streamlined terrain, hummocky stagnant ice terrain, deformation terrain, palimpsest terrain and low relief terrain. All of these types can be recognized on air photographs; some easily, others with less certainty. The report by Andriashek and Fenton (1989) for the Sand River map area describes the various terrain types to be expected over much of northern Alberta. A simple subdivision of the glacial terrain is shown in Table 1. Other subdivisior examples are in Prest (1970) and Clayton and others (1980 a, b).

Table 1. Examples of major glacial terrain types.

Major Terrain Type	Sediment type
Streamlined terrain	Basal till &/or pre-existing sediment
Hummocky stagnant ice terrain	Superglacial minor basal
Deformation terrain	Subglacial drift and bedrock
Palimpsest terrain	Basal-superglacial
Low relief terrain	Variety of basal-superglacial

Permafrost terrain types can also be expected in the Caribou Mountains, and the Cameron, Bootis and Elsa Hills. Permafrost is also present in portions of the wetlands, south of these uplands (Vitt and others, 1998).

Although a discussion of terrain types is beyond the scope of this paper, some comments on deformation terrain are needed. First, being absent from the Shield, this terrain type is most likely new to an explorationist moving operations onto the Interior Platform. Second, and more importantly, the sediment forming this unit is always highly variable and failure to recognize it would have serious ramifications for drift prospecting and associated stratigraphic studies.

Deformation terrain, or glaciotectonic terrain, is masses of pre-existing sediment, bedrock and/or drift that have been transported more or less intact by glaciers; also included, where present, are the associated depressions up-glacier of the thrust features. Glaciotectonic features are widespread, having been recognized in Alberta, Saskatchewan, Manitoba, North Dakota, Minnesota and South Dakota (Andriashek and Fenton, in prep.; Bluemle and Clayton, 1984; Byers, 1960; Christiansen and Whitaker, 1976; Fenton, 1987 a,b; Fenton and others, 1986; Hopkins, 1923; Kupsch, 1962; Moran 1971; Moran and others, 1980; and Slater, 1926, 1927). Morphologically, the terrain can consist of a single hill or ridge situated down-glacier of a source depression, or a series of smaller hills, called rubble terrain, extending down-glacier from a broad source depression. Large scale folding or faulting may be present. Syngenetic till or diamicton may be included, particularly in the rubble terrain. Long distance transport of thrust slabs is possible: for example the Cooking Lake erratic which was discussed in the preceding section on drift thickness (Figures 5a and 5b).

Andriashek and Fenton (1989) described deformation terrain in the Sand River map area. This terrain can be recognized using air photographs, where the morphologic expression has not been removed or buried by subsequent glacial action.

Glacially deformed sediment can also be recognized by surface geophysical and downhole geophysical techniques and drilling (Fenton and others,1986 and 1992; Sartorelli and others, 1986; Green and others, 1988). Lastly high resolution seismic surveys have revealed both the maximum depth of deformation and the internal structure of the thrust masses (Andriashek and others, 1999).

Data Types and Sources

There are a number of existing data types and data sources for northern Alberta available to the explorationist. The primary sources of subsurface data include reports and maps; and the lithologs and geophysical logs created during petroleum and water exploration. The principal sources of surface information come from reports and maps, and from remote sensing data, such as air photography and satellite imagery. Table 2 lists some of the sources for these data.

Table 2. Some sources of information (as of mid 2000)

Data type	Office source	Phone/FAX
Alberta digital topographic data files	Resource Data Division 1:20,000 - 10 m contours	780-427-7374 ph. Alberta Environment
NTS topographic maps (federal) 1:250,000 1:50,000	Canada map office	1-800-465-6277 ph. 1-800-661-6277 fax
Alberta topographic maps 1:250,000	Map Town (Edmonton)	780-429-2600 ph.
Oil well data	Alberta Energy Utilities Board	403-297-8190 ph.
Water well data	Groundwater data bank Alberta Environment	780-427-2612 ph. Dave Cable
Air photos and digital air photo data	Air photo services Alberta Environment	780-422-9683 ph.
Remote sensing data, LandSat	RadarSat (Vancouver)	604-231-4972 ph. www.rsc.ca
Geologic maps/reports, hydrogeologic reports bedrock topography and drift thickness maps, mineral assessment reports	Alberta Geological Survey	780-422-3767 ph. 780-422-1918 fax www.ags.gov.ab.ca
Regional geophysical data, geologic maps/reports	Geological Survey of Canada (Calgary)	403-292-7030 ph.
Soil survey maps and reports	Alberta Agriculture Publications office	780-427-0391ph. 1-800-292-5697 780-427-2861 fax

Subsurface

1) Reports and maps

Information on bedrock topography ,drift thickness and stratigraphy can be found in reports and maps on surficial geology and Quaternary stratigraphy, groundwater, and the bedrock topography. Drift thickness here commonly refers to the thickness of the sediment lying between the top of the bedrock and the land surface. These are available primarily from the Alberta Geological Survey (AGS).

Reports on the Quaternary and surficial geology often include sections on the drift thickness and the stratigraphy of this unit. The bedrock topography map series includes a map showing the bedrock topography and two smaller scale maps: a shaded contour map indicating the drift thickness and one showing the density of the data used to make the maps.

Reports on the surficial geology and Quaternary stratigraphy are presently available for only a small portion of northern Alberta, as are those from the bedrock topography map series. The reconnaissance hydrogeological maps (AGS) cover all of northern Alberta except the extreme northeast. These reports are useful in that they each include a hydrogeological map which has four cross sections that provide some information on drift thickness.

2) Drill Hole data.

Through a combination of petroleum, coal and water well exploration, there have been many hundreds of thousands of test holes drilled in Alberta. All of the petroleum test holes, most of the coal test holes, and some of those drilled for groundwater, have been geophysically logged. A wide variety of logs have been run in petroleum and coal holes, including: natural gamma, focused electric, caliper, density (gamma-gamma), sonic (interval transit time), neutron, dipmeter (3 pad microresistivity), resistivity and self potential. The geophysical logs from groundwater holes include primarily self-potential and resistivity, with natural gamma being run in a few. Geophysical logs are the main tools used in correlating bedrock units. Both the lithologs and the geophysical logs from many of these test holes are available through provincial agencies and private industry.

Information on the holes drilled for petroleum and coal include databases that summarize information on each well, such as the location, elevation, total hole depth, the different formations intersected, and the suite of geophysical logs run in the hole. These data are available from a variety of sources, some of which are listed in Table 2. Most useful are the geophysical logs that have been run to the shallowest depth. In some wells, the casing, which decreases or eliminates the geophysical signal recorded by the logging tool, was set from the surface to many metres into the bedrock before the hole was geophysically logged. This procedure results in the log suite stopping below the drift bedrock contact.

The number of petroleum test holes with geophysical logs extending to within a particular distance of the surface increases as this “cut-off depth”, depth increases. For example in one area in north central Alberta these are 1348 holes with geophysical logs extending to within 2 m of the land surface and 2480 holes with geophysical logs extending to within 100 m of the land surface (Figure. 7). As the depth from surface of the geophysical log top increases, the number of wells available also increases (Figure 8). Not all of these wells may be useful: some may not have logs that are the correct type to be useful for picking the bedrock top and in some areas there will be a relative "overabundance" of wells confined to a particular oil or gas field.

In Alberta, water well drillers are required to submit a lithology for each hole they drill. Some also submit a copy of any geophysical logs, usually E-logs, they run. These data are available from Alberta Environmental (Table 2). This department also provides summary data for any particular area. This includes information such as well location, total hole depth, and whether an E-log was run and if the department has it on file. Figure 9 shows the data density and variety for a sample area

Surficial Geology Information

The principal sources of surface data come from reports and maps, and remote sensing data such as air photography and satellite imagery. The most comprehensive information can be found in maps and reports on the surficial geology and Quaternary stratigraphy. However, as mentioned previously, the reports on the surficial geology and Quaternary stratigraphy are presently available for only a small portion of the area. To rectify this lack of mapping, the Alberta Geological Survey has begun a program to complete the surficial geology maps for in northern Alberta.

One alternate source that provides information on some aspects of the surficial geology is the series of reports and maps describing the sand and gravel (aggregate) resources. Another type of information is the soil survey reports. These include the small scale exploratory soil survey series and the larger scale reconnaissance soil survey series. The soil reports contain descriptions of the shallow (~1m) parent material. Almost all of northern Alberta has been covered by either exploratory or reconnaissance soil surveys. These maps and reports are available through Alberta Agriculture (Table 2.)

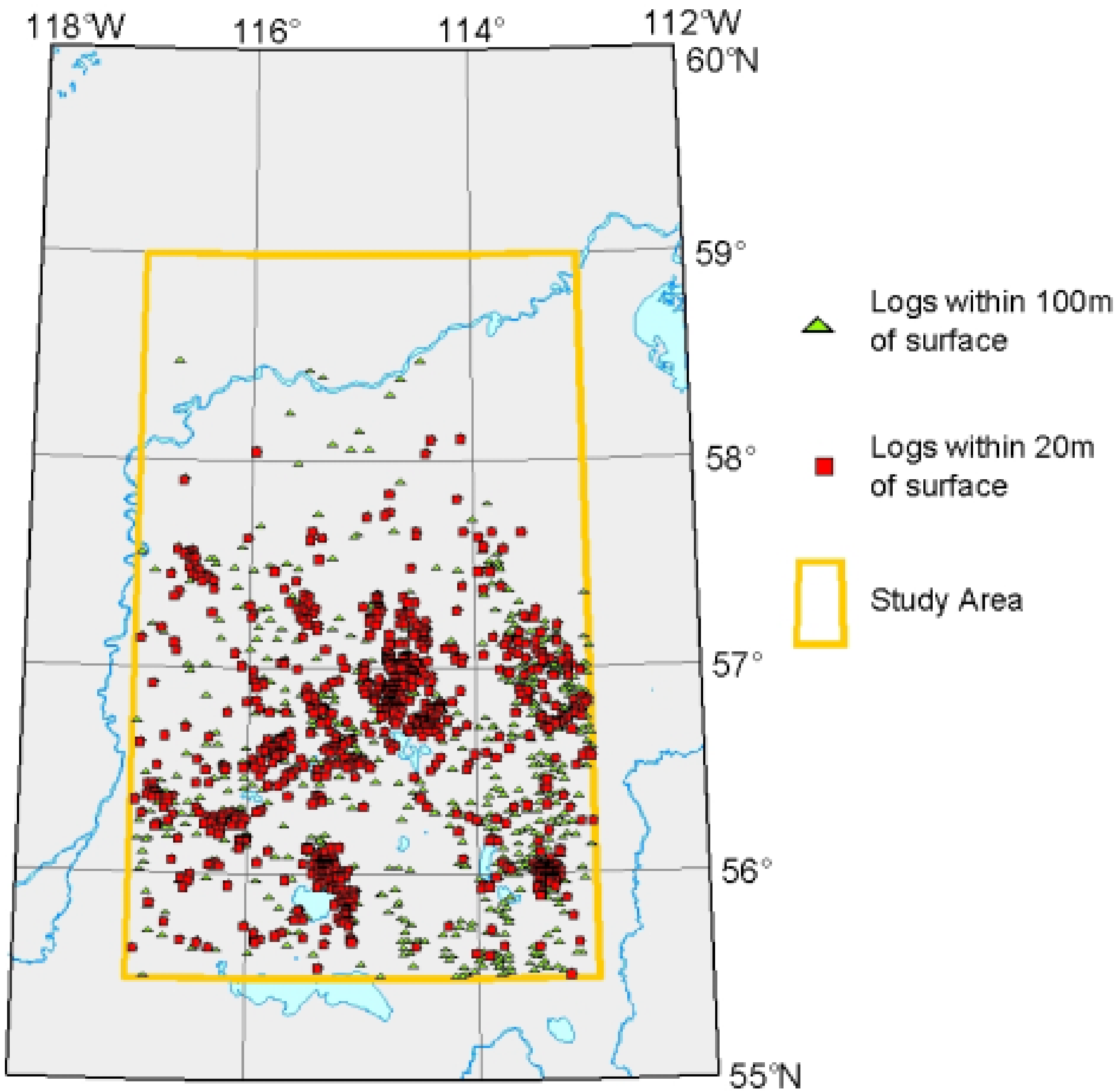

Figure 7. Map showing the number of wells with geophysical logs extending to within 20 m and to within 100 m the land surface.

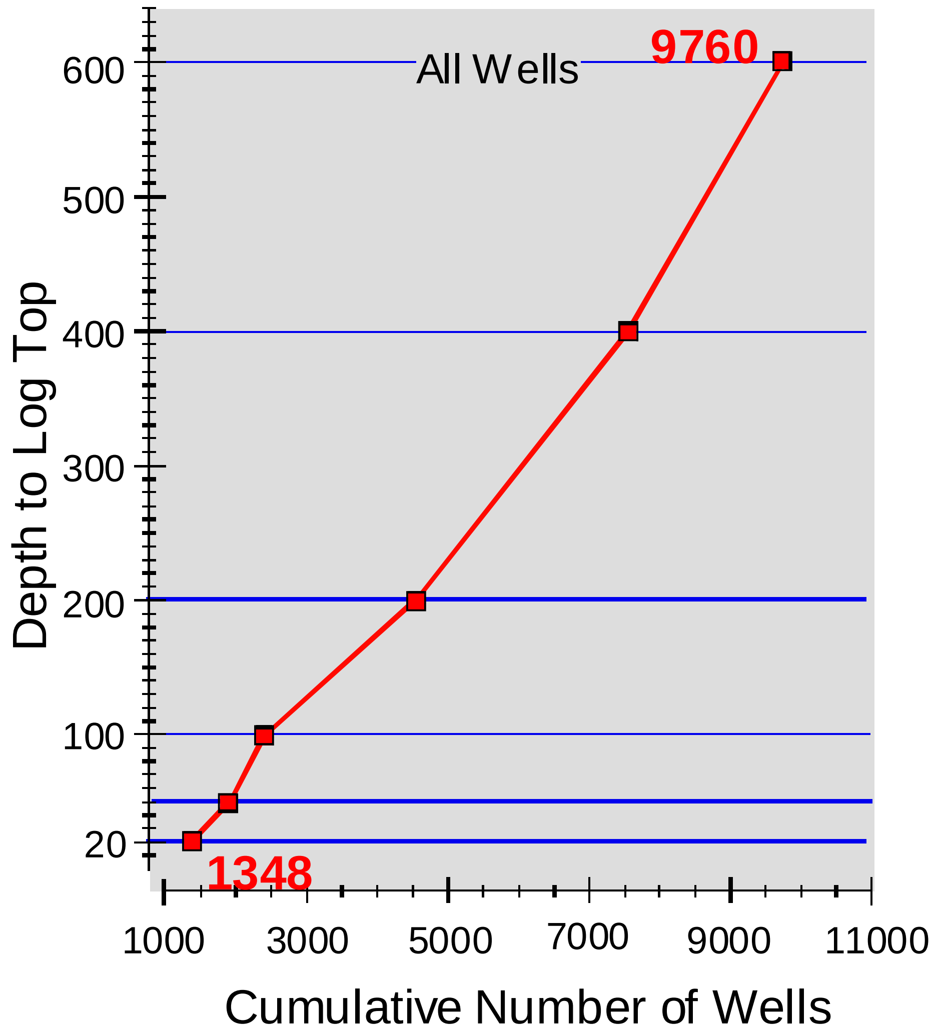

Figure 8. Cross plot of depth to log top versus the number of petroleum wells.

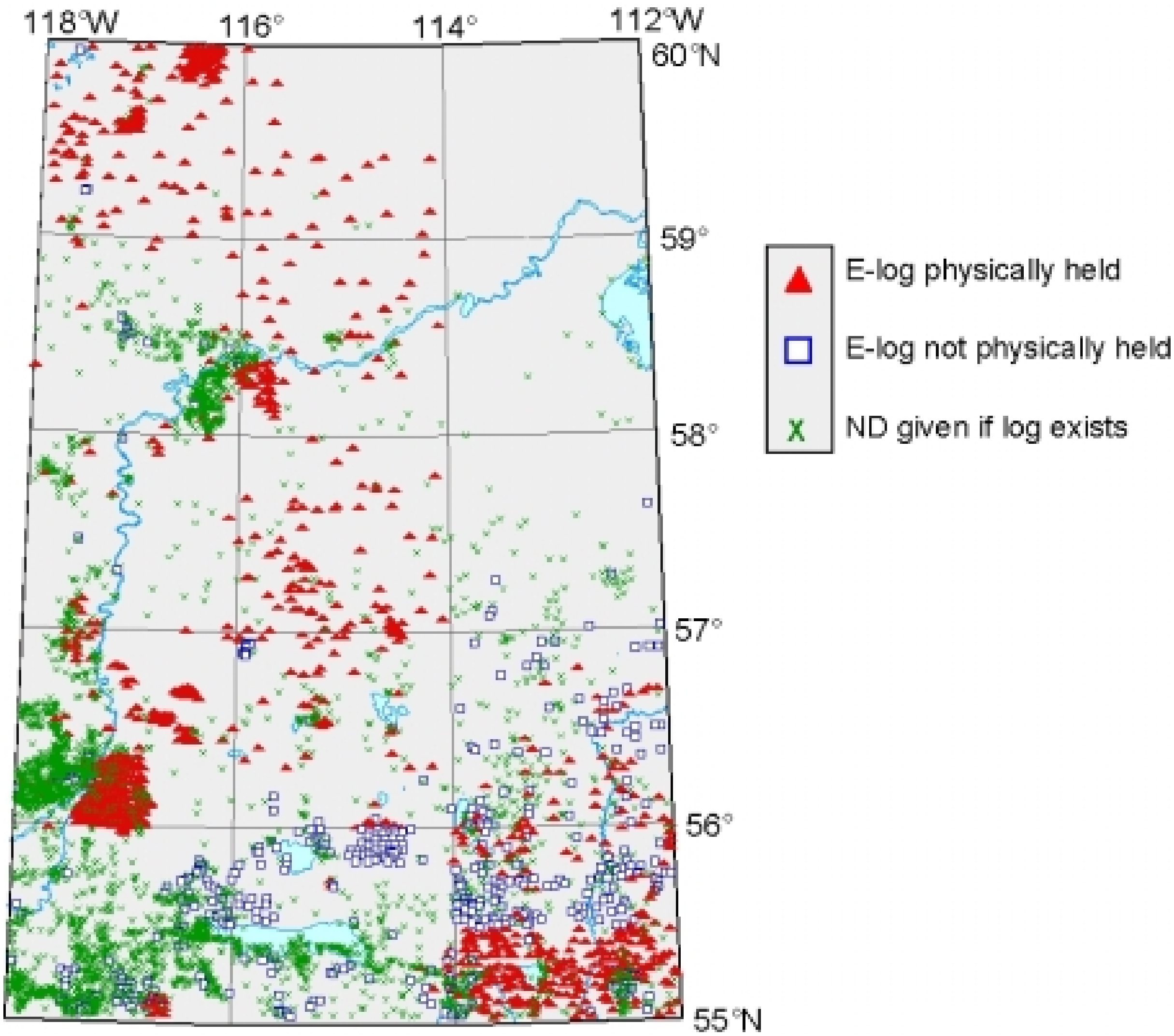

Figure 9. Map showing the spacial density and variety of water well data.

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