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Quaternary Stratigraphy of the Buried Birch and Willow Bedrock Channels, NE Alberta

Alberta Energy and Utilities Board

Alberta Geological Survey

AGS

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Acknowledgments

This study benefited greatly from the contributions of a number of Alberta Geological Survey staff. The smooth and seamless field operations, including organizing of the drilling and installation of water-wells at temperatures near -40^0 C, is a testimony to Gordon Jean's technical and field managerial capabilities. Sheila Stewart is credited with the interpretation of many of the geophysical well logs, particularly the bedrock stratigraphic sequences. Jessica Meeks assisted in the preparation of many of the graphics figures and Maryanne Protz prepared the manuscript. Dianne Goulet conducted most of the laboratory analyses, including preparation of samples submitted to external laboratories. Much appreciation is extended to Dr. Mark Fenton who provided geological expertise and many enlightening discussions on the outcrop.

The drill crew of Elk Point Water-Well Drilling are to be commended for their efficiency and high quality of drilling and installation of waterwells under extreme winter weather conditions.

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1. Introduction

As the development of Alberta's oil sands extends into the non-surface mineable areas of northeastern Alberta that are covered by thick overburden, steam assisted oil recovery processes become increasingly more important in the development of those resources. One requirement for a successful steam assisted recovery process is the availability of large volumes of high quality water to generate steam, at least 3 barrels of water for every barrel of recovered oil. Increasing importance is being placed on groundwater supplies to meet the water needs of the heavy oil and oil sand producing industries.

The Alberta Geological Survey (AGS) has long recognized the importance that Quaternary aquifer systems can play in providing groundwater for local heavy oil and oil sand producers. More than 20 years ago the AGS mapped major Tertiary and Quaternary aquifer units that lie in buried bedrock channels in the Cold Lake area (Andriashek and Fenton, 1989). A number of these units, particularly the Empress Formation, continue to supply the Cold Lake area oil producers with water for Cyclic, and Steam Assisted Gravity Drainage (SAGD) steam recovery methods.

In 1996 the Alberta Geological Survey (EUB) conducted a study of a Quaternary aquifer system that supplied groundwater to the Alberta Oil Sand Technology and Research Authority (AOSTRA) Underground Test Facility (UTF) to generate steam for an experimental SAGD method of bitumen extraction. Existing stratigraphic information was supplemented with helicopter reconnaissance and drilling of four test sites located above or adjacent to the buried Birch Channel, which is located about 1.5 kilometres south of the UTF site (Figure 1). This study presents the bedrock topography, drift thickness, and Quaternary stratigraphy in the buried Birch Channel, and briefly discusses the stratigraphic succession in an outcrop of the buried Willow Channel (Figure 1) near the Dover River.

2. Methods

2.1 Sources of Information

Interpretations regarding the bedrock topography and Quaternary stratigraphic sequences in the buried channels are derived from a number of sources. The majority of the bedrock top picks are from the Alberta Energy Utilities Board (EUB) database; others are from petrophysical log interpretations of AOSTRA oil exploration logs. The elevations from more than 700 well-log picks were plotted on maps and examined to determine if there were any anomalous data values. In addition to a review of the pick values, a number of well logs were printed and previously-made interpretations were checked against the log signatures. A random evaluation of wells showed that, in many cases, the top of the bedrock surface was chosen at the base of surface casing. A review of logs run through casing, specifically gamma and neutron porosity and density logs, revealed that the bedrock top could be picked at elevations above the base of casing. Bedrock-top values were subsequently revised for a number of wells, especially in areas of thick drift. An exhaustive review of the bedrock picks was not done for all of the logs.

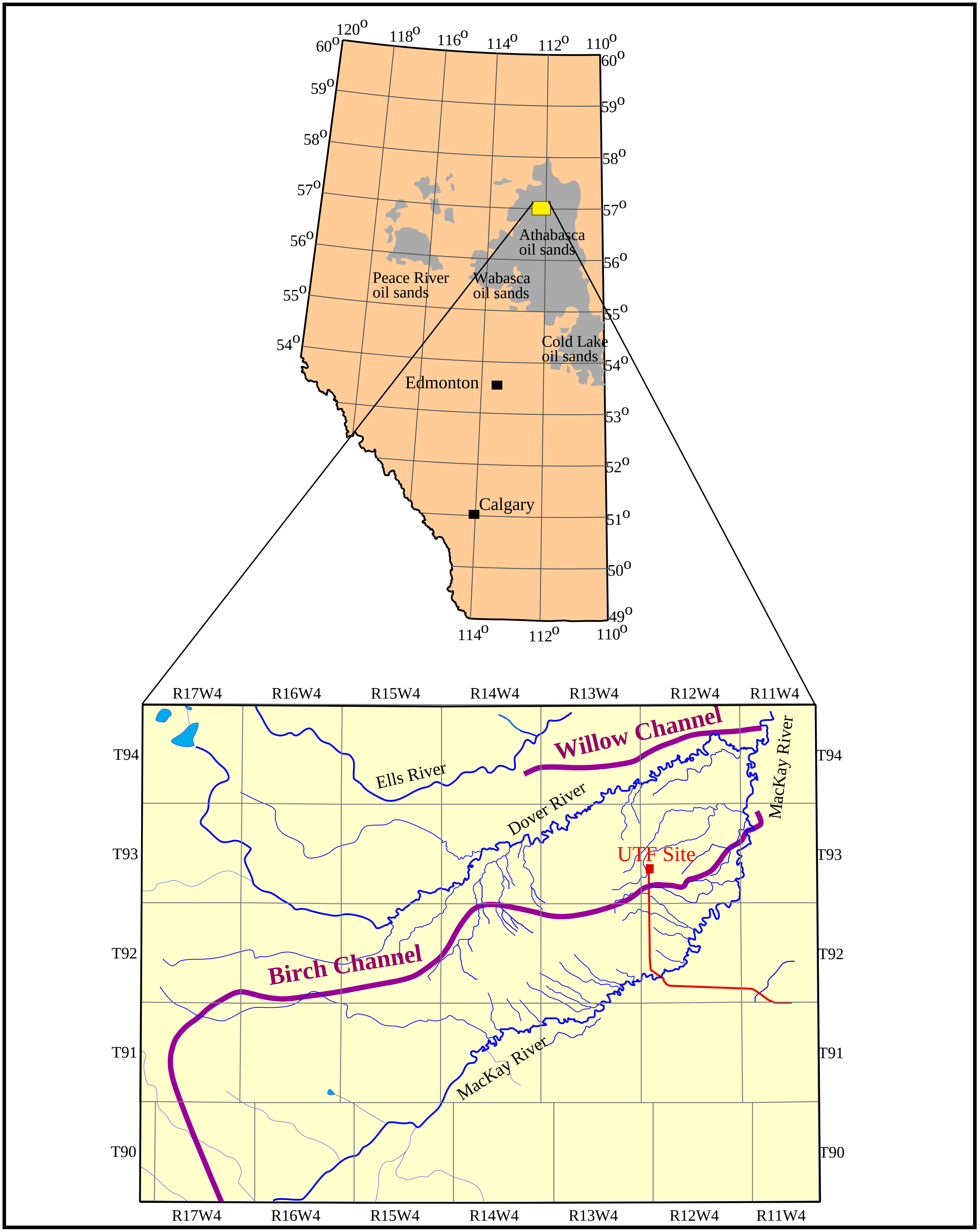

Figure 1. Location of the study area showing the buried Birch and Willow bedrock channels, Athabasca oil sands region.

Because of casing depths that extended into the bedrock surface in about 150 of the 700 plus wells, actual bedrock top picks were made for approximately 550 sites. However, it was possible to establish that the bedrock top was at least higher than the casing depth in those 150 deeply-cased wells.

In addition to petroleum exploration logs, a search was conducted for water-well logs in Alberta Environmental Protection's groundwater resources information files. A small number of logs were available for the study area, primarily logs for the UTF water-supply wells.

New bedrock surface and Quaternary stratigraphic information was collected in a helicopter survey and during a water-well drill program conducted by AGS staff, as part of this study. The data consist of descriptions of drill cuttings, petrophysical log picks (gamma, short and long focussed resistivity, caliper, neutron density, sandstone porosity, and sonic logs) from four drill locations, and descriptions of two outcrops along the MacKay and Dover rivers. Rotary borehole samples were collected at roughly 1.5 m intervals and submitted to the AGS laboratory for a suite of analyses. Borehole lithologs and outcrop descriptions of these sites are included in Appendices 1 and 2.

Interpretations of the Quaternary stratigraphic succession above the bedrock surface were hampered by a lack of data. Sources of high quality information, such as lithological descriptions of geological materials, could only be derived from outcrop examinations and rotary drill cuttings collected in this study. This information was augmented by analytical data from samples sent to the AGS laboratory and to outside laboratories.

2.2 Laboratory Procedures

A number of analytical techniques have been successfully applied in Alberta to characterize Quaternary sediments for the purposes of differentiating and correlating units, particularly tills (Andriashek and Fenton, 1989). The main of these include: grain-size analysis, matrix carbonate content, and geochemical analysis. These data are presented in both graphic and tabular form (Figures A2-3, A2-4, A2-6, and A2-10 to A2-15 in Appendix 2, and Table A3-1 in Appendix 3).

2.2.1 Grain Size Analysis

Field samples of the glacial sediments (tills) were dried, manually disaggregated using mortar and pestle, and passed through a 2 mm sieve to yield at least 50 grams of sample for grain-size analysis. A combination of hydrometer and dry-sieving methods was used to determine the bulk percentages of sand, silt and clay in the less-than-2 mm fraction of the till samples. Percentages of sand, silt, and clay were calculated using both geological (.063 mm sand/silt, .004 mm silt/clay) and engineering (.050 mm sand/silt, .002 mm silt/clay) grain-size boundary classifications.

2.2.2 Matrix Carbonate Content

The carbonate content of the silt-clay fraction of fine-grained glacial sediments (till, glacial lacustrine clay) was determined using the Chittick apparatus. This process involves the addition of 10% HCL acid to the <.063mm (silt-clay) fraction of the sediment, and the measurement of the volume of CO_2 gas released. The percentage by weight of carbonate is calculated, and by measuring the volume of gas released as a function of time, the rate of reaction can be determined. This enables the ratio of calcite to dolomite to be calculated.

2.2.3 Till Geochemistry

Approximately 30 to 40 grams of the <0.063 mm fraction were recovered from each till sample and further subdivided to provide a subset for flame atomic absorption spectrophotometry (AA), and for instrumental neutron activation analysis (NA). The AA analyses were done by CanTech Laboratories Inc., using a "total digestion" procedure. This procedure involves dissolving a 1-gram subsample in a fuming HF-$HClO_4$-HNO_3 mixture and analyzing for the concentrations of elements listed in Table A3-2 (Appendix 3).

The instrumental neutron activation analysis (NA) uses subsamples of about 10 grams to determine the concentrations of elements listed in Table A3-1 (Appendix 3). The Becquerel Laboratories Inc. procedure involves irradiating an encapsulated sample with a neutron flux in a 2 megawatt (MW) pool type reactor. Following a 7 day decay period to remove transient decay products, the gamma radiation from the samples is counted for approximately 500 seconds using a high resolution Ge detector system.

The detection limits for all of the analyzed elements are listed in Table A3-2. Geochemistry values for samples from each of the boreholes were: 1) formatted in a spreadsheet (EXCEL™); 2) imported into a log generation program (Logger™) to produce a strip litholog and series of curves; and, 3) imported into a graphics package (Canvas™) for presentation and printing.

The results of the analyses from the two procedures are depicted in Figures A2-11 to A2-16, Appendix 2, and included in Table A3-1, Appendix 3. Sample depth locations are shown in each borehole litholog strip as a filled black circle. Only those elements which have values above minimum detection limits are plotted, and for this reason a number of the rare earth elements are omitted. Samples in which the value is below the detection limit are assigned a ‘0’ value for the purposes of generating the plot diagrams.

2.3 Mapping Methods

Bedrock surface topography maps were generated using the MCadContour™ mapping software developed for the Macintosh computer. Bedrock contours were computer-generated initially, and later modified by hand to conform to the geologist’s conceptual model of the surface. Aerial photographs were examined to locate outcrops along streams and to evaluate bedrock topographic features that may be expressed at the surface, such as thalwegs of buried channels. The surface topography was derived from a combination of digitized 1:50, 000 scale NTS maps and Digital Elevation Model (DEM) data of the area. Geological cross-sections were generated using Rockware software products, specifically Logger™ and MacSection™.

3. Physiography and Regional Topography

The study area spans parts of the Dover Plain district of the McMurray Lowland section, and the MacKay Plain district of the Wabasca Lowland in the Northern Alberta Lowlands region of the Interior Plains of Canada (Figure 2). The elevation within this region ranges from about 275 m to as much as 600 m, and the landforms are described as level to inclined glacial lacustrine and morainal plains.

The MacKay and Dover rivers are the major physiographic features within the study area (Figure 3). Both rivers flow north and eastward to ultimately join with the Athabasca River. The UTF bitumen extraction site is located on a northeast to southwest trending upland, referred to here as the Dover Upland, which forms the interfluve between these rivers. Elevation within the study area ranges from a high of more than 510 m in the western part of the upland, to a low of about 300 m along the floors of the Dover and MacKay rivers. An air photo examination shows that much of the landscape west of the UTF site is generally level to undulating and mantled by wet fen and bog peatlands. Numerous ephemeral streams drain the perimeter of the peatlands in a radiating pattern northward, eastward and southeastward from the upland toward the Dover and MacKay rivers (Figure 2). Although not apparent at ground level, there is a relatively abrupt break in slope east of the UTF site where the elevation decreases by approximately 50 m along a 2 to 3 km distance.

4. Bedrock Topography and Channels

On a regional scale, the topography of the underlying bedrock approximates that of the present-day land surface (Figure 4). The bedrock surface rises westward from the MacKay and Athabasca rivers, increasing in elevation from 290 m along the MacKay River to a high of about 500 m at the western and southern boundaries of the study area. Present-day erosion has exposed the bedrock surface along the Dover and MacKay rivers, outcrops of which are depicted in Figure 4.

The most prominent bedrock-surface features consist of two deeply eroded glacial meltwater channels, herein named the Birch Channel and the Willow Channel (Figure 4). The Birch Channel lies directly south of the UTF site. Although data are sparse, the western end of the channel has been mapped as far as Tp 90, Rg 17 W4M. Borehole data east of the UTF site indicate that the channel continues eastward then northward, subparallel to the MacKay River. The total length of the channel mapped in this study is about 80 km. The Birch Channel exhibits a form that is characteristic of many channels interpreted to have been eroded by glacial meltwater. That is, it has a relatively straight to poorly sinuous form, and has a relatively small width to depth ratio.

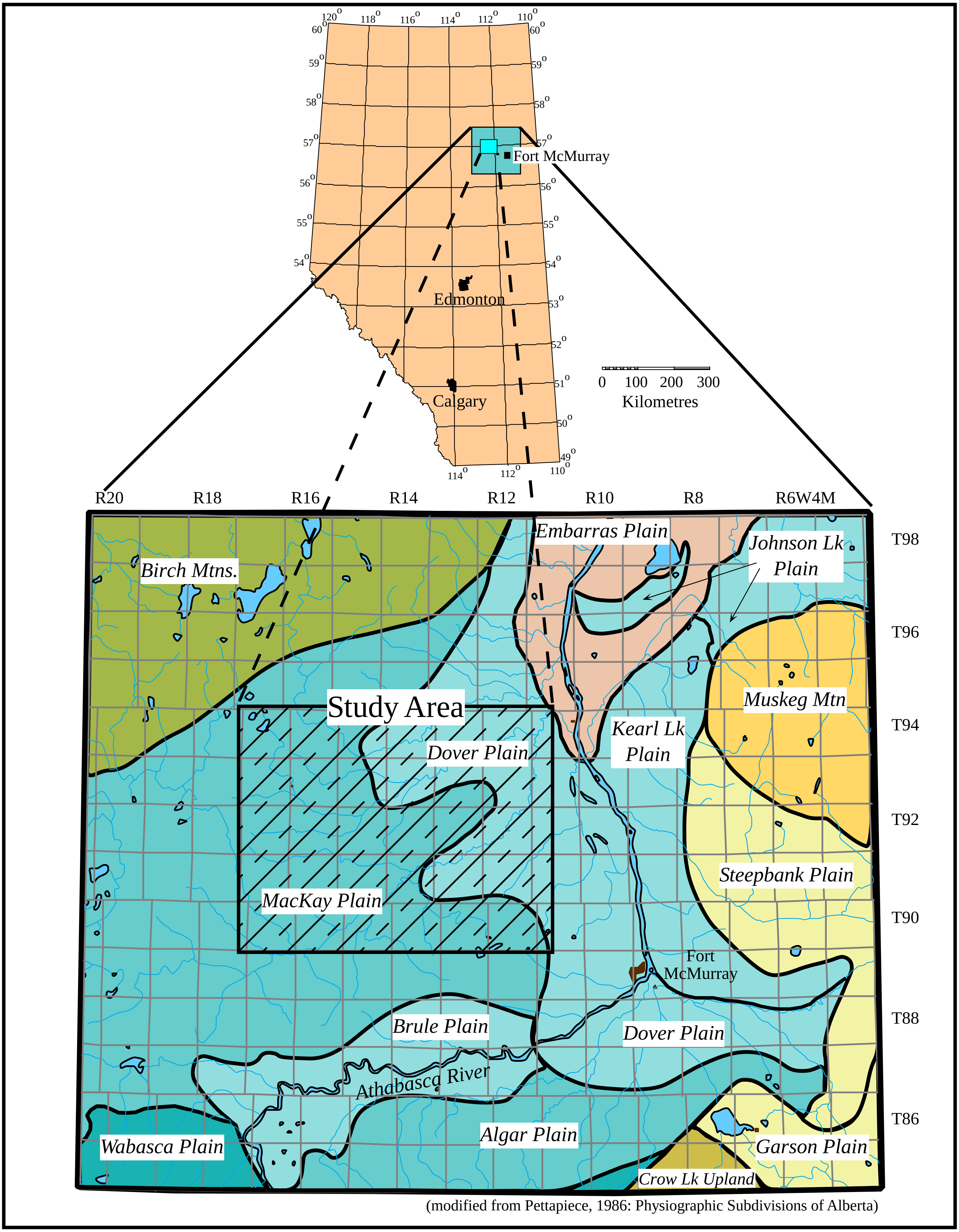

Figure 2. Physiographic setting of the study area.

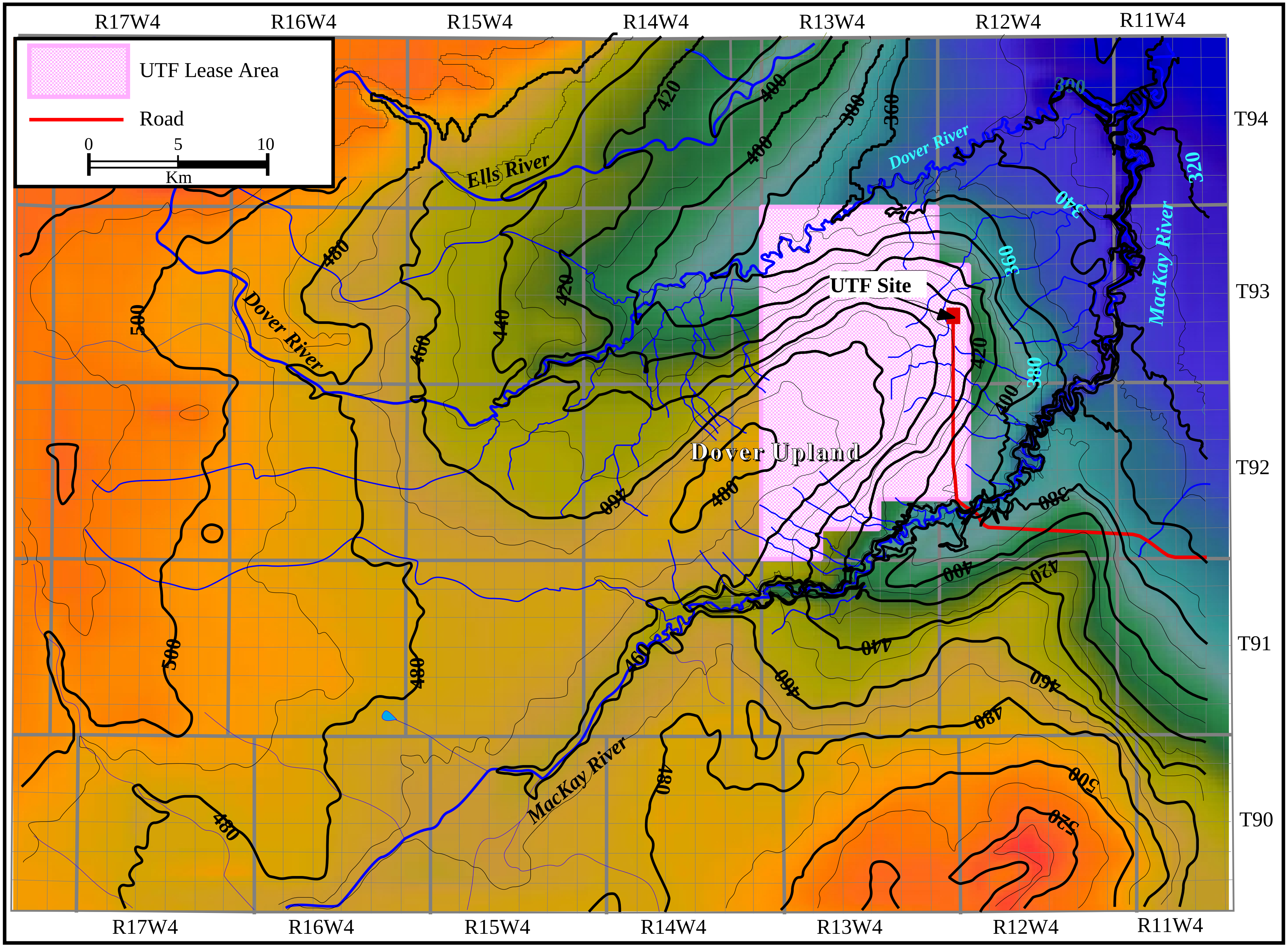

Figure 3. Site geography and surface topography (metres above sea level).

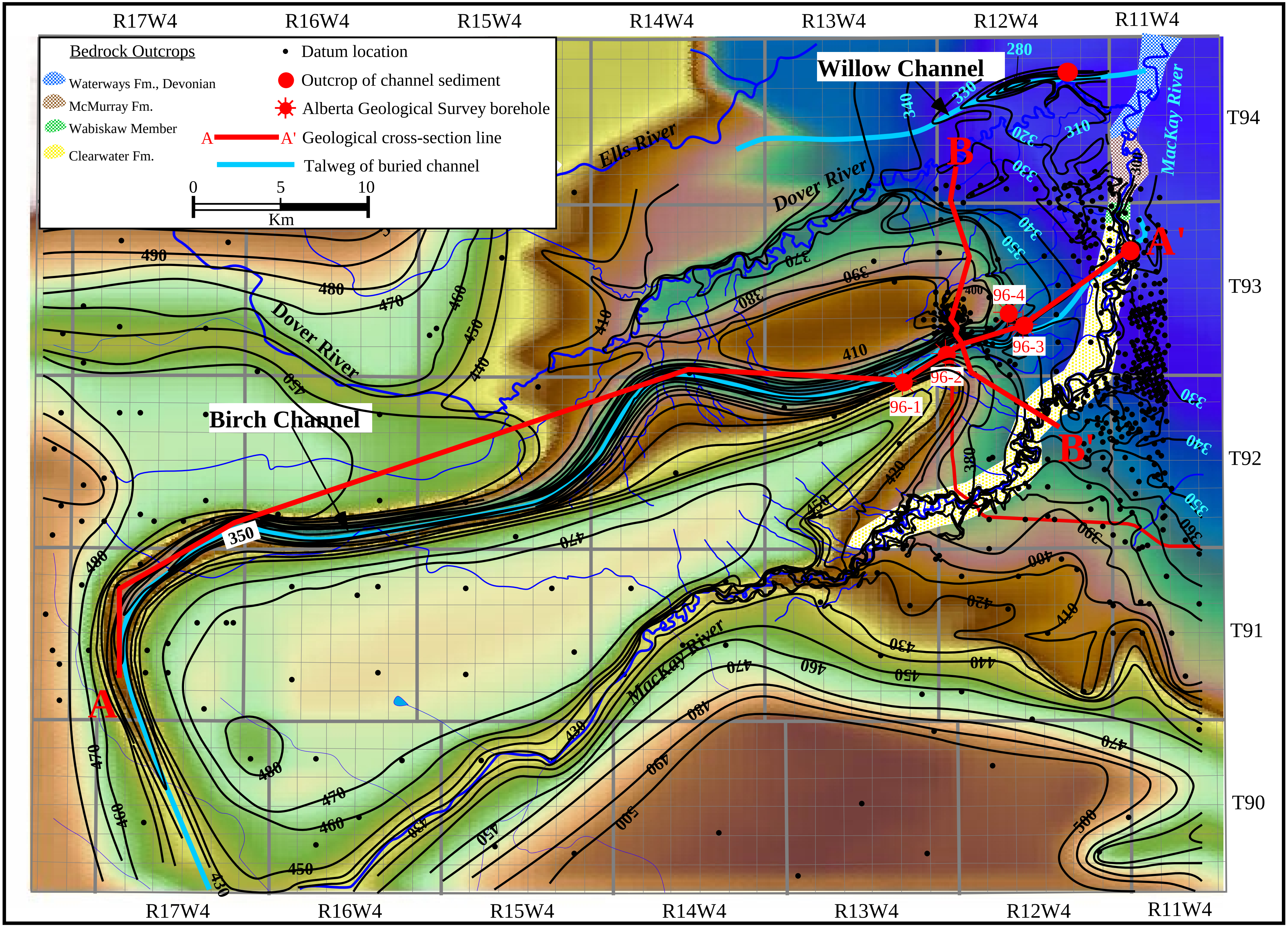

Figure 4. Bedrock topography and talwegs of buried channels.

For example, in places west of the UTF site the channel is no more than 1.25 km wide and has eroded as much as 100 m into the bedrock surface (Figure 4).

Figure 5 depicts an approximate profile of the bedrock surface along the channel. The apparent rise in the floor of the channel at section 29, Tp 91, Rg 17 and at borehole UTF96-3 results from the cross-section being constructed on boreholes that are not located above the channel talweg. One interesting aspect of the channel profile is that the gradient is estimated to be extremely low along the western segment. For example, the elevation of the channel floor in section 1 of Tp 92, Rg 7 is essentially the same as that in section 2, Tp 93, Rg 14 (347 masl and 348 masl respectively), a change of about 1 m over a distance of more than 40 km. The gradient increases more significantly to about 2 m per km along the segment of the channel from the UTF site east to the MacKay River.

A geological cross section constructed across the Birch Channel in the Dover Upland shows an asymmetric channel profile, with the north flank apparent ly steeper than the south (Figure 6). This asymmetry may, however, reflect a paucity of data which does not permit accurate mapping along the southern flank.

The second-most prominent bedrock feature in the study area is the Willow Channel, which lies directly north of, and parallel to the Dover River in Tp 94, Rg 12 (Figure 3). The channel is mapped primarily from oil exploration logs, with the exception of one outcrop which exposes the channel in section 26, Tp 94, Rg 12. The total length of the Willow Channel is currently estimated to be about 20 km, although data are sparse along the western end. The eastern end of the channel is believed to be truncated by the MacKay River in the northwest corner of Tp 94, Rg 11, but this has not been documented in outcrop. Similarly to the Birch Channel, the Willow Channel is also interpreted to have a relatively straight and narrow form, with an average width estimated to be 1 km or less. Maximum depth of erosion is about 40 to 50 m, though the average depth is estimated to be 30 m. The channel gradient is calculated to be about 2 m per km; however, this is based on sparse data.

Thick infill of stratified fluvial sediment, together with a drape of non-stratified glacial sediment, has effectively masked any surface expression of either of the bedrock channels.

4.1 Origin of Channels

The presence of granitic rock fragments, transported southeastward from the PreCambrian Shield, in fluvial sediments on the floors of both bedrock channels is evidence of a glaciofluvial origin and Quaternary age. It is believed that both channels were formed by glacial meltwater in contact with glacial ice, either in a supraglacial or subglacial position. Assuming a supraglacial erosional model, meltwater flowing on the ice surface would have cut through the ice, sequentially eroding the bedrock high in the western part of the study area, and later the bedrock surface in the lowlands to the east. In a subglacial erosional model, meltwater, which was subject to a great hydraulic force beneath the ice, rapidly incised a channel into the bedrock, irrespective of the underlying bedrock topography. In this model, meltwater could have flowed ‘up-hill’, that is, westward onto the bedrock upland, in response to increasing hydrostatic pressure beneath a

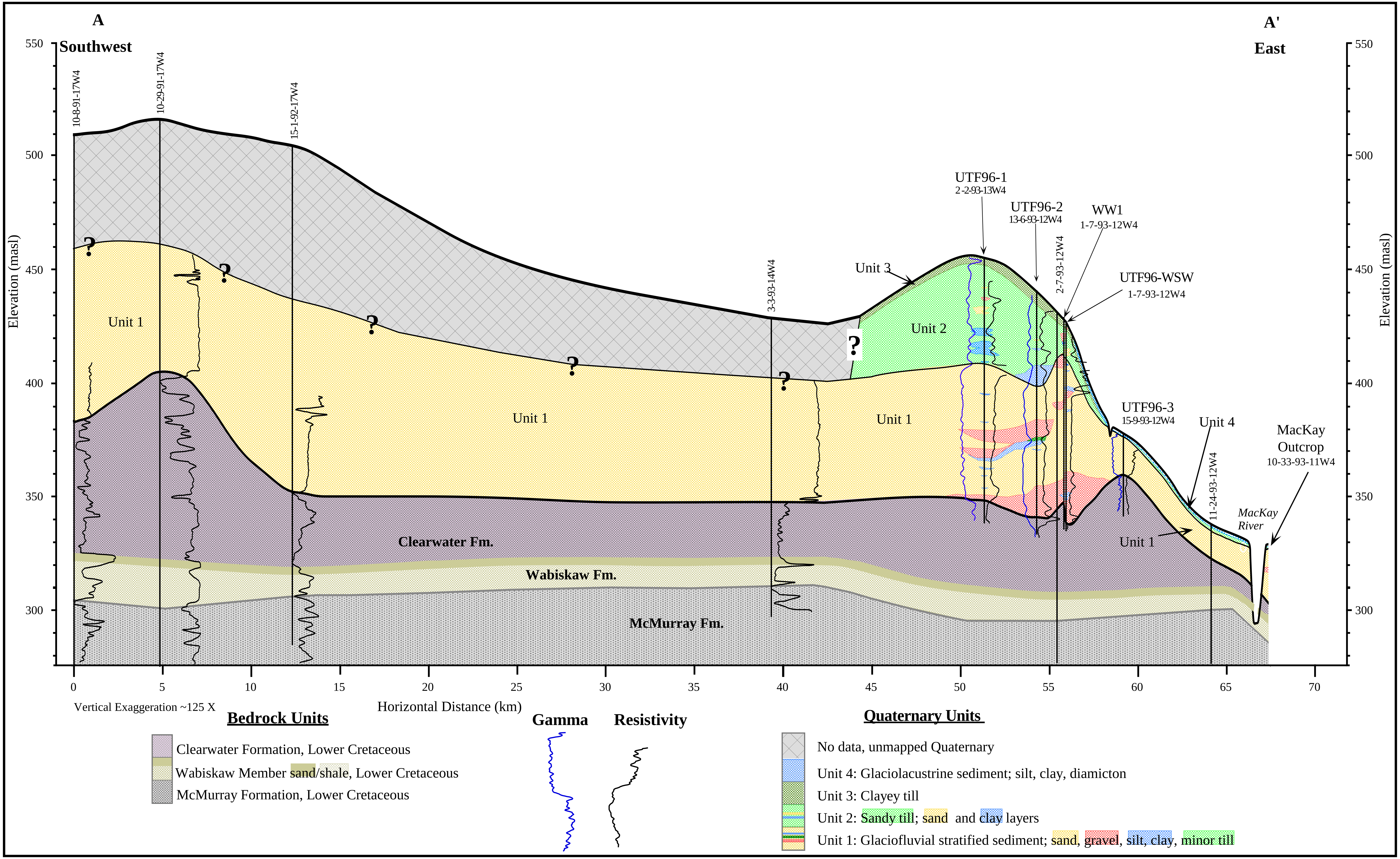

Figure 5. Geological cross-section A-A' along the Birch Channel.

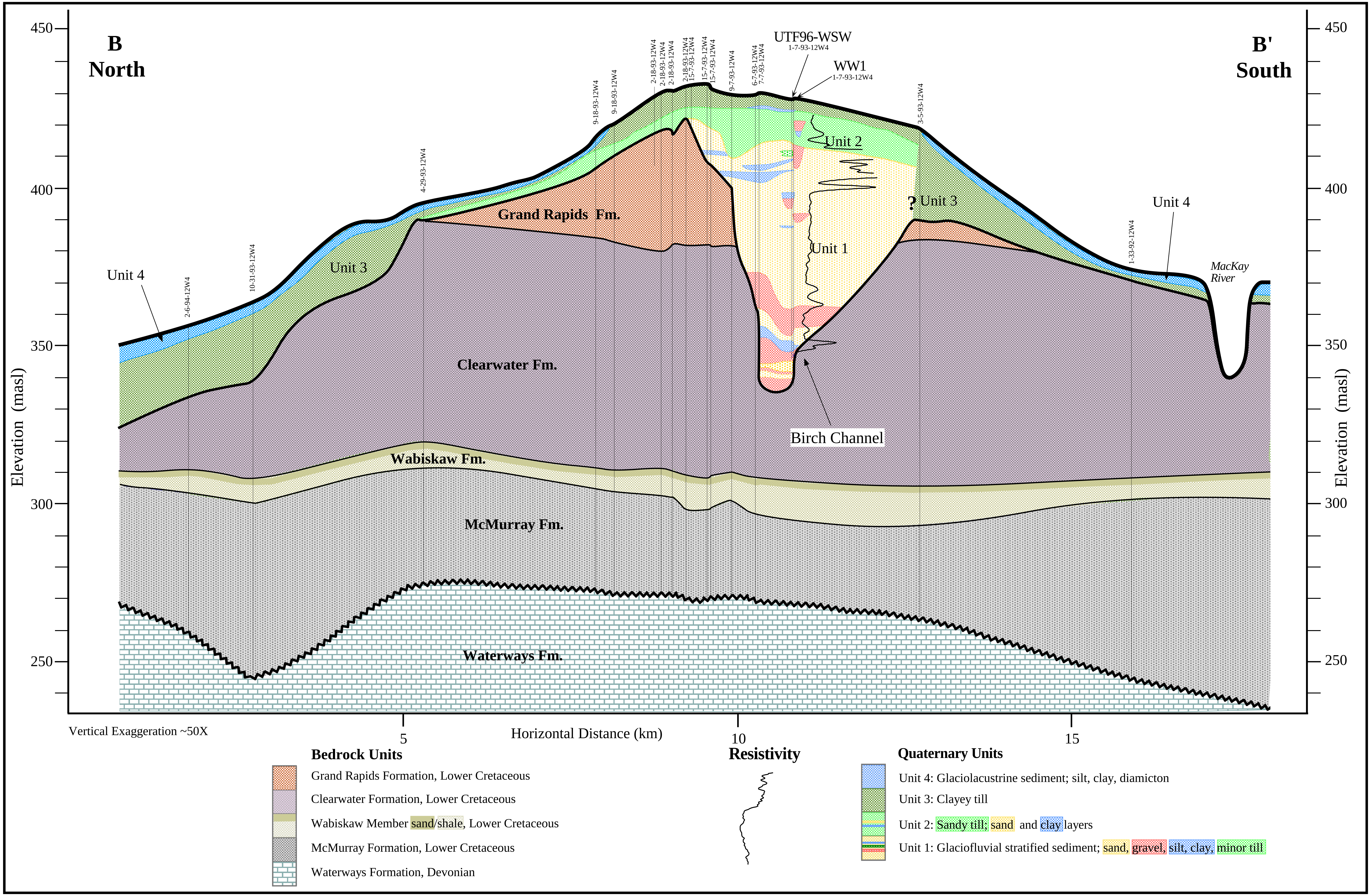

Figure 6. Geological cross-section B-B' across the Birch Channel.

westward advancing glacier as it advanced over the bedrock scarp on the east flank of the Dover Upland (Gilbert, 1990). The relatively straight form and very shallow gradients in both channels, particularly the Birch Channel, suggest that erosion was extremely rapid as a result of a catastrophic release of the subglacial meltwater. A high-energy flow regime is also inferred by the presence of a boulder bed nested in the middle of the fluvial sequences in both the MacKay River outcrop of the Birch Channel and the Dover River outcrop of the Willow Channel (Figures A2-1 and A2-2).

5. Drift Thickness

Figure 7 shows an estimate of the total thickness of Quaternary sediments above the bedrock surface. Excluding the thick drift in the bedrock channels, drift thickness ranges from less than 5 m in the lowlands along the MacKay and Dover rivers, to more than 40 m on the UTF bedrock upland. The thick accumulation of drift above the bedrock upland has enhanced the elevation and expression of the present-day surface of the Dover Upland.

The thickest areas of drift are found above the talwegs of the bedrock channels. More than 150 m of stratified and non-stratified glacial drift are mapped within in the Birch Channel southwest of the UTF site in Tps 91-92, Rg 17 (Figure 7).

6. Quaternary Stratigraphy

Four stratigraphic units have been defined for the Quaternary succession in the study area:
- Unit 1: Stratified glaciofluvial channel sediment; sand, gravel, silt and clay,
- Unit 2: Sandy till, with inclusions of stratified sediment,
- Unit 3: Clayey till and,
- Unit 4: Glaciolacustrine sediment; pebbly silt and clay, beds of water-laid diamicton.

These units have been identified primarily from borehole information, supplemented with observations from outcrops along the MacKay and Dover rivers. The units are described in ascending order.

6.1 Unit 1: Glaciofluvial stratified sediment

6.1.1 Description

Unit 1, the lowermost unit in the stratigraphic sequence, is mapped from petrophysical logs, rotary borehole samples, and outcrops. In the eastern segment of the Birch Channel where there is good lithological information, Unit 1 is described as gravelly sand and gravel, fining upward to fine and medium sand (Figures 5 and 6). Silty and clayey beds occur randomly within the entire sequence. Unoxidized colours range from olive grey (5Y4/2 Munsell) for the sand to very dark grey (5Y 3/1 Munsell) for the clay beds. Outcrops of the unit along the MacKay and Dover rivers show great vertical and lateral variation in sediment size, ranging from fine, rhythmically bedded silt and silty clay, to beds of gravel and boulders more than 30 cm in diameter (Figures A2-1 and A2-2, Appendix 2).

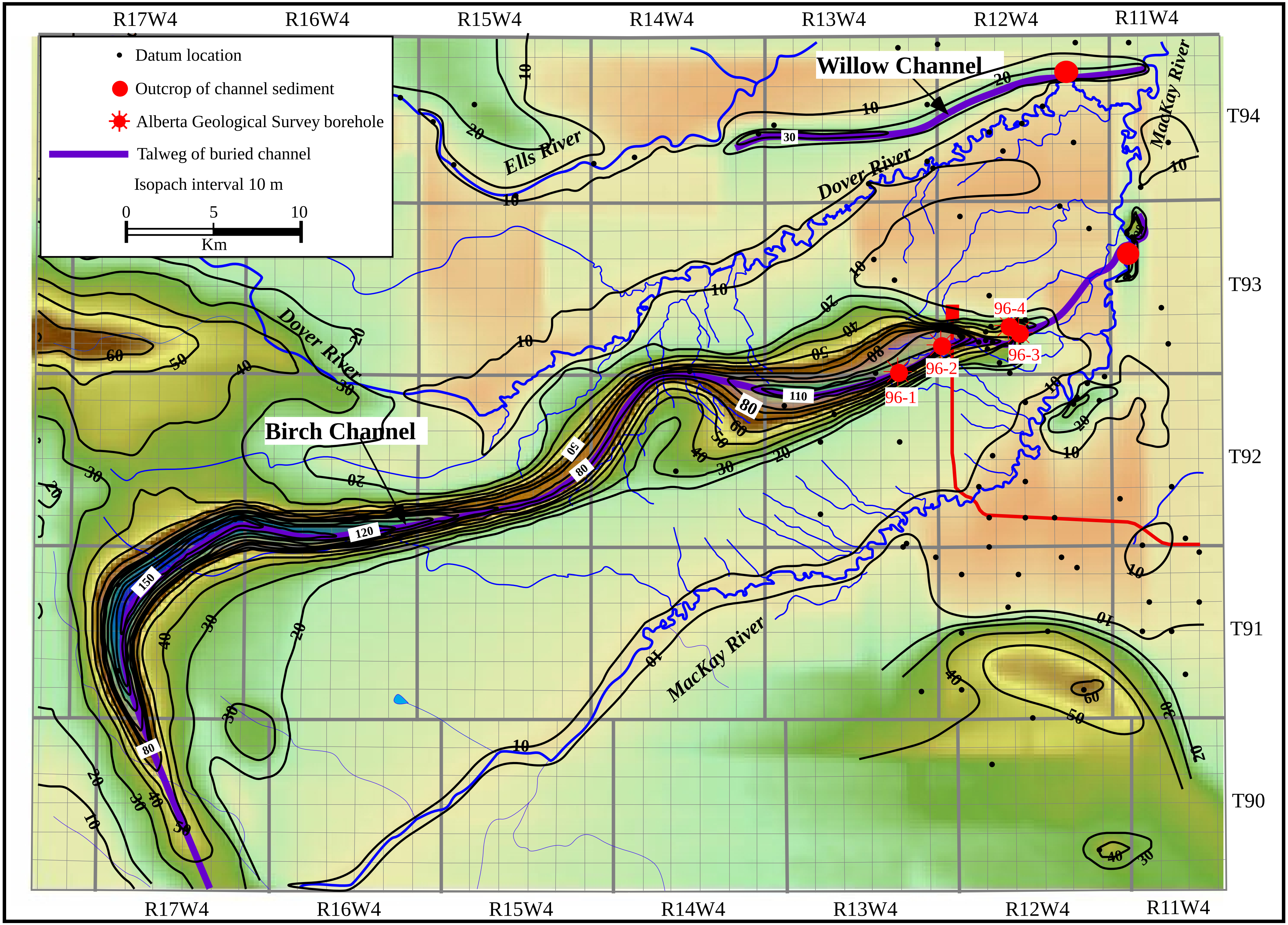

Figure 7. Thickness of Quaternary drift above bedrock.

It is note-worthy, and perhaps coincidental, that a thick (2 m) bed of very coarse gravel and boulders within Unit 1 occupies roughly the same stratigraphic position in both the Dover and MacKay outcrops (Figures A2-1, A2-2, Appendix 2). Sedimentary structures, such as cross-bedded sand, and planar bedded silt and clay, were observed at both outcrops, but were not measured to determine flow direction.

The great variation in particle size observed in the sedimentary succession in the outcrops, from boulders to rhythmically bedded silt and clay, was not recognized in the rotary borehole cuttings. Rotary drill cuttings were predominantly medium grained sand, gravelly sand, fine gravel, and minor silty clay beds (Figures A2-3, A2-4, A2-9, Appendix 2). Although multiple lithological subunits of Unit 1 can be differentiated within the boreholes and correlated with units in nearby boreholes, they are not interpreted to be continuous within the channel.

In the western segment of the Birch Channel, Unit 1 is mapped solely from oil-exploration petrophysical logs, mainly resistivity logs. In this area casing depths extend well into the Quaternary succession and into the top of Unit 1 (Figure 5). Consequently, little can be said regarding the lithological composition and variations in sediment in the western segment of the channel.

6.1.2 Distribution and thickness
Unit 1 is confined to, and rests on the floors of, the Birch and Willow bedrock channels. Although data are sparse, Unit 1 sediments are not believed to extend any significant distance beyond the flanks of either of these channels. The thickest deposits of Unit 1 (80 m) are mapped in the segment of the Birch Channel that lies south and west of the UTF site (Figure 8). A profile along the eastern segment of the Birch Channel reveals that the elevation of the top of Unit 1, and its thickness, both decrease in value eastward from the Dover Upland (Figure 5). Just as the present-day surface elevation decreases abruptly by about 50 m directly east of the UTF site, the top of Unit 1 shows a corresponding 40 m decrease in elevation, essentially mirroring the profile of the surface. The net result is that Unit 1 thins to less than 30 m in the lowland east of the Dover Upland.

6.1.3 Origin
An abundance of granitic rock types from the Canadian Shield indicates a Laurentide glacial meltwater source of the sediment. Of special note is the relative abundance of rounded to subrounded black chert clasts found in the gravel fraction in boreholes UTF96-1 and UTF96-2, compared to amounts found in glaciofluvial deposits mapped elsewhere in central Alberta (Tables 1 and 2, Appendix 1). This rock type is one of several that are typical of preglacial fluvial deposits with source from the Cordilleran Mountains to the west. However, a local source cannot be discounted as thin beds (<2 cm) of black chert pebbles have been recognized within the Pelican Formation in outcrops along the Ells River, north and west of the study area.

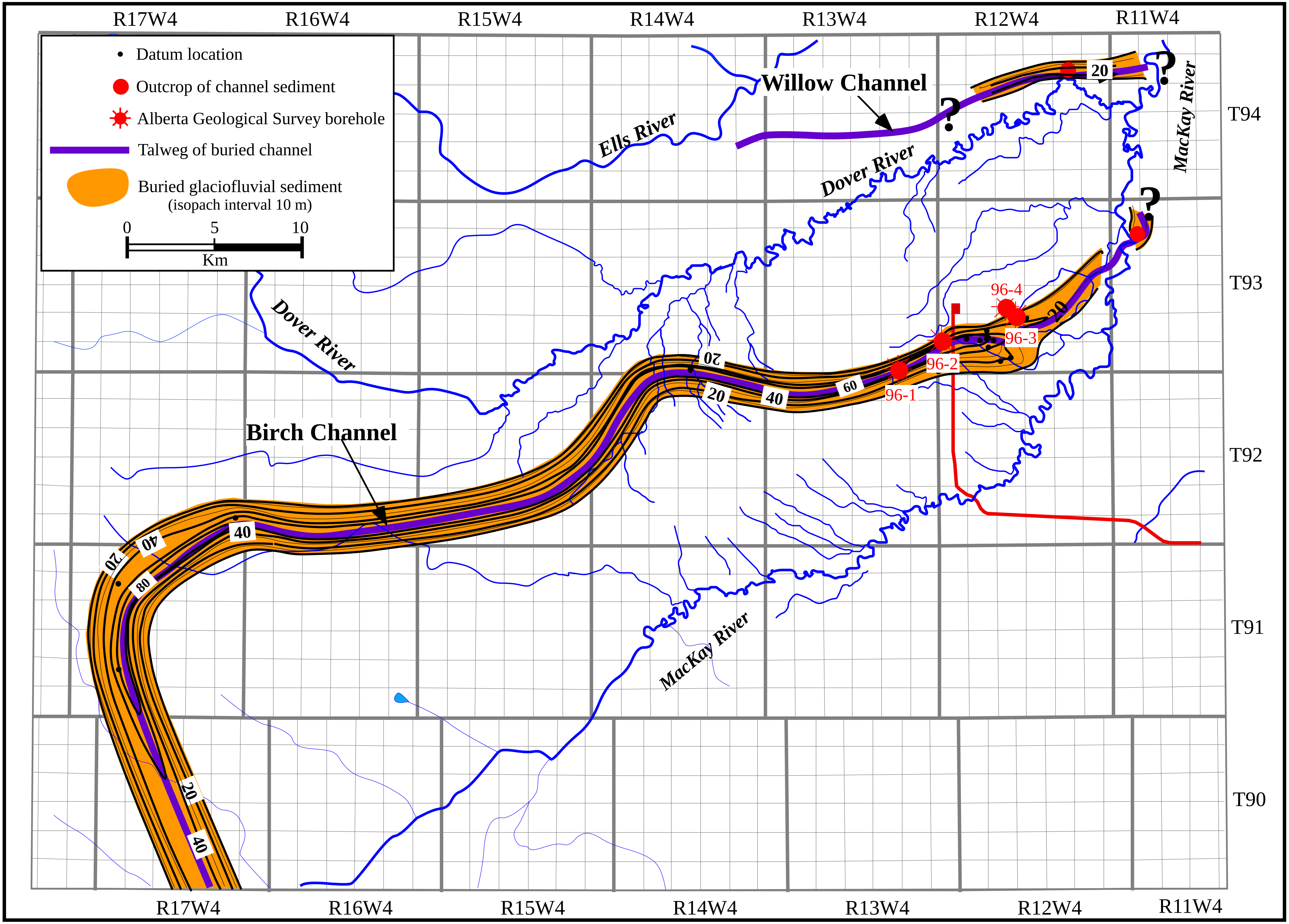

Figure 8. Thickness of glaciofluvial sediment in buried channels.

It seems likely that sedimentation within both the Birch and Willow channels occurred episodically, with rapid, high-energy flow events, which deposited gravel and boulders, followed by calm periods during which rhythmically bedded silt and clay were deposited. Such a rapidly fluctuating energy regime is interpreted to be characteristic of an ice-contact or proglacial depositional environment. Proximity to glacial ice is also indicated by a bed of till deposited at a depth of 64 m within the stratified sequence in borehole UTF96-2 (Figure A2-4, Appendix 2).

The asymmetric surface profile and non-uniform thickness of Unit 1 within the Birch Channel is difficult to explain. The coincidental profiles of the top of Unit 1 and the present land surface suggests that both were modified by the same process, in this case erosion of the area east of the UTF site. The nature of such a large-scale erosional event can only be speculated. A recently proposed theory (Rains et al, 1993, Shaw et al,1996) is that a catastrophic release of subglacial meltwater, or Livingston mega-flood event, from a source north of Alberta eroded much of the Alberta landscape in a north-south swath along the east-central part of the province. The western margin of this mega-flood is believed to lie along the eastern flank of the Dover Upland (Shaw, pers. comm.). Conceivably, much of Unit 1 sediments and surrounding bedrock surface could have been eroded by this catastrophic flood event, resulting in an eroded, asymmetrical profile. A subsequent glacial advance would be required to deposit the thin drape of glacial sediments found above Unit 1 in the lowlands east of the Dover Upland.

6.2 Unit 2: Sandy Till

6.2.1 Description

Unit 2 consists of a sandy clay loam till characterized in the field by an abundance of silt and sand in the matrix. Inclusions or beds of sand, silt, and clay are common, particularly near the base of the unit near the contact with Unit 1. These are included as part of Unit 1. The inclusions range in thickness from about 0.3 m to as much as 2.5 m, particularly clay beds in borehole UTF96-1 (Figure A2-3, Appendix 2). It is uncertain if these inclusions or beds are syngenetic, that is, deposited at the same time as the diamicton (till), or if they represent glacially eroded beds of pre-existing sediment that have been incorporated into the till. The relative abundance of these inclusions affects the grain size of the till, such that the texture ranges with depth from a sand till to a sandy clay loam till to a clay till. If a syngenetic depositional model is valid, the occurrence of stratified beds at the base of Unit 2 suggests a gradational contact with the underlying stratified sediments of Unit 1. As a result of these inclusions, Unit 2 till can be divided into an upper homogeneous diamicton section, about 10-15 m thick, and a lower interbedded diamicton and sand, or clay section, about 10-20 m thick.

The unoxidized colour of Unit 2 till is very dark grey (5Y 2.5/1 Munsell). Pebble amounts are estimated to be about 2-3%, but the amount of very coarse sand and granules is less than 1%. Rotary drill cuttings show the till to be brittle and hard, with low plasticity. Average grain size distribution of the till matrix is 42% sand, 38% silt, and 20% clay in borehole UTF96-1, and about 35% sand, 38% silt, and 27% clay in borehole UTF96-2 (Figures A2-3 and A2-4, Appendix 2, and Table A3-1, Appendix 3). The till has a very low matrix carbonate content, showing very low to no visible reaction to 10% HCL acid in the field. Matrix carbonate analyses using the Chittick apparatus indicate a mean value of about 3% (Figures A2-3 and A2-4). Geochemical properties of the silt-clay fraction are depicted in Figures A2-10 and A2-11, Appendix 2.

Geochemistry results show that, for certain elements, concentrations increase with depth. In borehole UTF96-1, for example, antimony, cerium, hafnium, molybdenum, zirconium and zinc show increased values with depth in the upper, thick, homogeneous till section of the unit (Figures A2-10 and A2-11, Appendix 2). In borehole UTF96-2 concentrations of gold, cobalt, copper, rubidium, manganese, molybdenum, nickel, lead, vanadium and zinc, all increase in value in the basal part of Unit 2 till (Figures A2-12 and A2-13, Appendix 2). This increase is associated with an enrichment of clay, either in the till matrix or as discrete beds within the till.

6.2.2 Distribution and thickness

Unit 2 till is currently mapped only above stratified sediments of Unit 1 in the Birch Channel. At its maximum the unit is about 45 m thick, and is believed to thin to less than 1 or 2 m near the base of the Dover Upland, east of the UTF site. Information regarding the properties of the entire till sequence east of the upland are lacking, and the differentiation between Unit 2 and Unit 3 tills is not possible. It is not known at this time if the till sequence in the Dover and MacKay outcrops is represented by Unit 2 till, or the stratigraphically higher till of Unit 3.

6.3 Unit 3: Clayey Till

6.3.1 Description

Unit 3 consists of a clay loam to heavy clay loam till characterized by a relative abundance of clay in the matrix. Clasts or inclusions of pinkish-grey clayey material were noted in drill cuttings from borehole UTF 96-1. The unit forms the surface geologic unit in the Dover Upland and is therefore exposed and oxidized. It has a dark grey brown oxidized colour (2.5Y 4/2 Munsell) and a very dark grey to black unoxidized colour (5Y 2.5/1 Munsell). It is uncertain if Unit 3 extends into the lowlands east of the UTF site, but, if so, it is recognized at both the Dover and MacKay outcrops as having a iron-stained, prismatic structure. Gamma-ray log signatures of this unit show a relatively higher API reading compared to the underlying till of Unit 2 (Figures A2-3, A2-4, Appendix 2). The matrix grain-size distribution indicates mean values of about 30% sand, 45% silt, and 25% clay in borehole UTF96-1, and 35% sand, 33% silt, and 33% clay in borehole UTF96-2 (Figures A2-3 and A2-4). Similar to till of Unit 2, Unit 3 till has very little to no reaction to 10% HCL acid, indicating a very low matrix carbonate content. The matrix carbonate values average about 2-3% in UTF96-1 and about 5% in UTF96-2 (Figures A2-3 and A2-4). From one borehole to another there is a difference between the matrix carbonate in tills of Unit 2 and Unit 3, but that difference is not consistent. For example, in borehole UTF96-1 the carbonate value of Unit 3 till is slightly less than that of Unit 2 till, whereas in borehole UTF96-1 the opposite is true. Geochemical properties of the silt-clay fraction are depicted in Figures A2-12 and A2-13, Appendix 2.

Bayrock (1971, map unit 4) describes the topography of the surface till in the upland as undulating to hummocky.

6.3.2 Distribution and thickness

There is sufficient uncertainty at this time to permit the differentiation of Unit 3 till from Unit 2 till beyond the margins of the Birch Channel. As discussed in the previous section, Unit 3 clayey till may be a textural facies of a single glacial till, in which case its distribution and extent may be restricted to the Dover Upland setting. Boreholes drilled in the lowland between the Dover Upland and the MacKay River (Figures A2-5 and A2-6, Appendix 2) did not encounter any sediment that could be attributed to either Unit 2 or Unit 3 till. Instead, a pinkish-grey diamicton was identified at the surface, which is interpreted to be water-laid glacial lacustrine sediment of Unit 4. The inclusions of pinkish grey clayey material in the till at UTF96-1 suggest that the clayey till of Unit 3 may be a lateral extension of this surface clayey diamicton found in the lowlands to the east. This issue clearly requires more work.

From a limited amount of borehole information, Unit 3 clay till is generally about 3 to 4 m thick. It appears to form a drape or veneer on the Dover Uplands.

6.3.3 Origin

It is uncertain if the tills of Units 2 and 3 represent distinctly different aged deposits of separate glacial events, or textural facies of a till deposited during a single glacial event. The sandy texture of Unit 2 till may be a local phenomenon related to the incorporation of underlying sandy sediment. Two local sources of sediment may account for sand enrichment in the matrix of the till: eroded sandstone of the Grand Rapids Formation which directly underlies the till adjacent to the Birch Channel, or glaciofluvial sand of Unit 1 which directly underlies the till above the Birch Channel. There are insufficient geochemical data for Unit 3 till to permit any meaningful attempt at differentiating till units based solely on geochemistry. A more comprehensive sampling, and petrological and mineralogical examination are required before this issue can be resolved.

6.4 Unit 4: Glaciolacustrine Sediment

6.4.1 Description

The uppermost and youngest geological unit in the Quaternary stratigraphic sequence in the study area is the glaciolacustrine sediment of Unit 4. Bayrock (1971, map unit 11) describes this material as consisting of pebbly silt and clay with beds of water-laid diamicton (till-like layers). The diamicton layers are generally clayey, with few granules or pebbles in the matrix. The unit has a very characteristic weathered colour which in outcrop appears to be pinkish grey, but which actually is brown to dark brown (10YR 4/3 Munsell colour). In part, this apparent pinkish-grey color differentiates Unit 4 sediment from the dark grey brown colour of the underlying till.

The material encountered in boreholes UTF 96-3 and 96-4 was described as silty clay with a few pebbles and varied amounts of diamicton (till) beds or layers. The matrix carbonate content averages about 6%, with a greater abundance of dolomite, as indicated by the lower calcite to dolomite ratios (Table A3-1, Appendix 3). The unit has a gradational contact with the underlying till and, in some places along the Dover River, as much as 1.5 m of brown coloured diamicton (till), with inclusions of pink coloured diamicton, overlies about 1.5 m of bedded-to-layered diamicton with inclusions or lenses of grey brown till. It is difficult to establish the contact between Unit 3 till and Unit 4 lacustrine sediment based on drill cuttings alone.

6.4.2 Distribution and thickness

The western edge of Unit 4 lies along the upper eastern flank of the Dover Upland and is defined approximately by the 420 m contour line on the 1:50, 000 scale topographic map of the area. Unit 4 is generally between 1.5 and 3 m thick along the MacKay and Dover rivers, and as thick as 6 to 7 m in the lowland west of the MacKay river. As discussed previously, Unit 4 has a gradational contact with till, but the underlying till was absent and in the two boreholes drilled in the lowland Unit 4 lacustrine sediment lies directly on Unit 1 sand or claystone bedrock (Figures A2-5 and A2-6).

6.4.3 Origin

Unit 4 sediment is interpreted to have been deposited in a proglacial environment in which supraglacial muds episodically flowed off the glacier surface into a glacial lake, and ice-rafted diamicton settled out from melting bergs calving along the ice front (Bayrock 1971). It is conceivable that the lake also developed subglacially, that is, beneath the receding ice front and that glacial debris rained out from the melting ice above. Bayrock's (1971) map and accompanying description of the region indicate that the lacustrine sediment becomes more heterogeneous and massive looking, and contains more diamicton layers distant from the MacKay River and west toward the Birch Mountains. One can postulate that the position of the ice-front during the time of deposition was along the Birch Mountains, with debris flowing east toward the MacKay River.

7. Summary

The late Quaternary history of the Athabasca oil sands area of northeastern Alberta has been marked by periodic and catastrophic releases of glacial meltwater which have incised deep and narrow channels into the underlying bedrock surface. The buried Birch and Willow channels are just two examples of other bedrock channel systems in the region, such as the Kearl, Clarke, and Gregoire channels (Andriashek, 2000) which are also interpreted to have been created in the same manner.

The study of the Birch and Willow bedrock channels, and the glaciofluvial sediments contained within, highlights the important potential of buried Quaternary aquifer systems to provide high quality and high yields of water for bitumen recovery in northeastern Alberta. The extraordinarily thick deposits of coarse glaciofluvial sediment contained within these channels make them highly desirable targets for groundwater to supply local, small scale SAGD steam operations. To illustrate, the thick glaciofluvial deposits contained within the Birch Channel have already proven capable of providing sufficient quantities of high quality water for two nearby SAGD recovery operations (UTF and PetroCanada).

Given the relatively narrow width of these channels, combined with a thick infill of stratified and nonstratified glacial sediment which has masked any surface expression, mapping additional channels in the region may prove difficult. However, as more detailed oil sands investigations are undertaken in the region, it is anticipated that additional drilling and high resolution seismic surveys will identify new channels systems, and permit more accurate mapping and definition of known channels such as the Birch and Willow.

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Appendix 1. Alberta Geological Survey Borehole Lithologs

Table A1-1. Borehole UTF96-1 Litholog Table A1-1. Borehole UTF96-1 Litholog

Project: UTF AQUIFER **Data No.**UTF96-1 **Logged by:** L. Andriashek **Date:** January 27 1996 **Drill Co.:** Elk Point **Driller:** Gregg Sander **Drill Type:** Failing 1500 **Bit Diameter:** 4 3/4" Insert **Surface Elev.** 455.49 m surveyed **Location:** SW of L.S.D.2, Sec. 2, Tp. 93, R.13, W4M **UTM Zone** 12, **Easting** 440719.48, **Northing** 6321348.1 **Comments on Location:** Flat; 10-15' Black Spruce; North side of cutline, about 20m NW of LD10 corehole				**Remarks** -minus 35C at noon -rocks at 15' -boulder at 36' -sand at 44.5' -boulder at 62' - spinnning on -boulder (Athabasca Sst.); drilled 1' through bldr. -165-170 sand -4:20 - Tripping out to seal hole and check bit; 5:15 start drilling -220-230' stony, pebbly; 250-260' -drill chatter -269' large stone, drill change at 275' (boulders from 275-277')
Indicate if feet or metres: feet			**Time: Start** 1:00 P.M. to 7:00 P.M.; 9:15 A.M. to 12:00	
Unit Depth		**Described Interval**	**Material Lithology**	**Comments:** Texture, Color, CaCO3, %Pebbles & Granules, Clast Lithology, Moisture, Angularity
From	**To**			
0	44	0 - 5	Till	sandy-clay till (clay loam); mottled, oxidized & unoxidized; peat fragments
		5 - 10	Till	clay loam till, sandy, gritty; abundant pink blebs in matrix; 10YR 4/3
		10 - 15	Till	totally unoxidized at 13' ; very sandy till, clayey-sand; brittle cuttings; hard; no HCL reaction; pebbles 2-3%; inclusions of unoxidized silty-clay (lacustrine?); clay does not react to 10%HCL
		15 - 20	Till	as above; good cuttings; hard. brittle, clayey-silty sand texture; very gritty; no HCL react., unoxid. 5Y 2.5/1, v.dk.grey, no clay inclusions
		20 - 25	Till	as above; clayey-sand texture (sandy-clay loam); some claystone/siltstone fragments; 5Y2.5/1; no HCL reaction
		25 - 30	Till	a few clay lenses (driller's comments); sandy-clay loam (v. sandy, hard, brittle cuttings); 2-3% pebbles
		30 - 35	Till	as above, not too many granules(1%) but numerous pebbles in pan; no HCL reaction
		35 - 40	Till	boulder at 36'; sandy-clay loam (v. sandy till) with lenses of silt and sand (seen in cuttings), lenses are lighter grey color; v. weak HCL react., numerous pebbles in pan (more than above)
		40 - 45	Till	0-44' till, as above
44	46		Sand	44-45' sand; medium to coarse; some pebbles, numerous rounded shale pebbles (black) in sand; glacial origin
		45 - 50	Till	out of sand at 46'; sandy-clay till, more clay than at 35-45' but still abundant sand in matrix; numerous pebbles but v. few granules or coarse sand in matrix; some shale clasts; v.dk.grey
		50 - 55	Till	a few stones & rocks at this interval; clayey sand till; cuttings are moderately hard to brittle (non-plastic); little change
57	76	55 - 60	Sand&Till	55' to 56'- 1' of pebbles, stones; clayey sand till from 56' - 59', as above; 59'-60' fine to medium glacial sand;
		60 - 65	Sand&Till	out of sand at 61'; driller says pebbles at 61'; 61-62' boulder; driller says layers of sand; cuttings show clayey-silty sand which

				crumble in hand; till-like but could be v. poorly sorted fluvial sediment; some cuttings are hard, crumbly clayey-silt (shale-like); sand component is very fine
		65 - 70	Till	clayey-silty sand; less clay and more silt in matrix; rusty brown blebs/clasts in matrix; cuttings are smaller, moderately good; some very faint oxidized streaks in cuttings; v.weak to no HCL react.;fewgranules, 2-3% Pebbles; driller says sandy with depth
		70 - 75	Sand?	Driller says v. sandy; pan sample is mostly fine glacial sand with some clayey cuttings (likely till); numerous stones 2-3cm size (Quarttzite-Athabasca Sst.)
		75 - 80	Clayey sand & Grvly Sand	layers or beds of clayey si-sand (soft cuttings) interbedded with coarse sand to fine gravel (rice size); clayey sand cuttings resemble sandy till but are too soft and are better sorted; some large siltstone clasts 2-3cm; rusty iron cemented sand clasts noted in pan sample throughout last 20' - assumed to be from above, but driller thinks may be in place at this depth
76	105	80 - 85	Till	very silty-sandy till; some rusty cuttings have rootlets in them, therefore from top of hole; till cuttings in pan mod. good quality; till is soft to moderatley hard; v.dk.grey
		85 - 90	Till	crumbly, si-sand texture, brittle; driller says thin sand layers from 80-90', and "good" till at 91'; sample of fine sand from 80-90'
		90 - 95	Till	clayey-silty sand; numerous pebbles in pan could be from above; no HCL react
		95 - 100	Till-clayey	clay loam; more clay in matrix; <1% granules; no HCL react.; plastic, stiffer
105	115	100 - 105	Till&Clay	clay at 105'; waxy, moderately stiff; lacustrine/fluvial?; no visible laminae or sedimentary structure; 5Y2.5/1 v.dk.grey
		105 - 110	Clay	same as above; plastic; good cuttings - 3 cm in size
		110 - 115	Clay	v. thin silt partings in clay
115	160	115 - 120	Till	clayey-silty sand; abundant sand in matrix; till same as at 90-95'
		120 - 125	Clay	thin silt partings, cuttings 2-3 cm size, some till and clay cuttings
		125 - 130	Clay	more thin silt partings than above, cutting size 1-2 cm
		130 - 135	Till	clayey-sand; a lot of sand in matrix
		135 - 140	Till&Clay	equal amounts of clayey-sand till and clay
		140 - 145	Till	clayey-silty sand; same as 130-135'
		145 - 150	Till	clayey-silty sand; same as above
		150 - 155	Till&Clay	clayey sand, lots of sand in matrix numerous clay cuttings
160	274	155 - 160	Till	clayey sand; same as above; some cuttings are a dense silty sand; fewer clay cuttings, some with silt partings, clay clasts in till
		160 - 165	Si-Sand & Clay	pan sample mostly silty sand; some cuttings are clayey silt (layers or lenses?); no sample collected; poor
		165 - 170	Sand	medium; glacial; 5Y 4/2 olive grey; about 90% quartz; moderately well rounded; some feldspar
		170 - 180	Sand	Sampling at 10' intervals; Driller says same material as at 170-180; fine to medium; mostly quartz
		180 - 190	Sand	1' thick clay layer at 184'; fine to medium; as above; grey; sample 180-185' interval
		190 - 200	Sand	1' thick silty clay layer at 197'; sample 185-200'; some coarse (1mm) mafic clasts; mostly quartz
		200 - 210	Sand	same fine to medium; some coarse sand, granules (<<1%); angular black grains (Shield origin?)
		210 - 220	Sand	as above; a few thin (2-3mm) clay? shale? cuttings in pan; fewer black clasts; mostly quartz., some granites
		220 - 230	Sand, coarse	Driller says pebbles; gravelly in this interval; also tank is silting up in 210-220' interval; coarse and to fine gravel at 220-230'; pebbly coarse sand; glacial; black chert granules; some shale pebbles, (angular)
		230 - 240	Sand	medium to coarse; a few pebbles; some angular brittle clay cuttings (fluvial?)

		240 - 250	Gravelly Sand	pebbly coarse sand to fine gravel; some cuttings of clay (clay layers probably); black cherts
		250 - 260	Pebbly Sand	same; pebbly coarse sand; numerous black chert; abundant feldspars; glacial sand
		260 - 270	Sand	medium to coarse, some pebbles; large stone at 269"
		270 - 275	Sand	coarse sand; gravel bed or layer at 274'
274	277	275 - 280	Gravel	pan sample mostly gravel 1-2 cm; some clay clasts in sample, angular, shale-like in appearance; driller says 274-277' gravel;
277	279		Clay	277-279 hard clay;
279	290		Gravelly sand	279-280 gravelly
		280 - 290	Pebbly sand	driller says gravelly sand from 280-290', more uniform, finer sand at 290-300'; pan sample is mainly medium sand; grey; numerous small cuttings of hard clay
290	353	290 - 300	Sand	same as above; medium sand with thin, small cuttings of hard clay (gives sand a pepery appearance)
		300 - 310	Sand	as above; medium; some pebbles
		310 - 320	Sand & Clay	driller says sand and silt lenses from 313-320'; drill chatter; pan sample mostly sand with hard, angular silty clay cuttings, very dark grey; medium sand with angular pebbles
		320 - 330	Sand & Clay	as above; sand with beds of silty clay; med. to coarse sand with some pebbles (2%)
		330 - 340	Sand & Clay	as above; driller thought it was gravelly because drill was chattering, but chatter probably due to drill stopping on clayey layers.
		340 - 350	Sand	coarse pebbly sand
353	387	350 - 355	Clay & Gravel	large cuttings of angular, blocky clay; large pebbles (glacial), broken by drill bit; some chert granules; gravel 1-5 cm
		355 - 360	Clay & Gravel	pan sample contains both gravel and clay (claystone?); drill break at 355', possibly bedrock
		360 - 370	SaSt & Claystone	very fine sandstone to siltstone, 5Y 3.5/1, very dark grey; cuttings of v.dk.grey claystone; blocky
		370 - 380	Claystone	very dark grey claystone with lighter grey inclusions or partings
387	388	380 - 388	Claystone	380-387 claystone, v. dk. grey; crumbly; 387-388 hard sandstone; cemented, very weak HCL reaction
				T.D. 388' according to driller T.D. on BPB geophysical logs is 390' Ran FE Resistivity, Natural Gamma, Density, Caliper, Sonic logs (3 hours) Bedrock at 353' on Gamma Log

Table A1-2. Borehole UTF96-2 Litholog

Project: UTF AQUIFER **Data No.** UTF96-2 **Logged by:** L. Andriashek **Date:** Feb. 3 1996 **Drill Co.:** Elk Point **Driller:** Gerry Topilka **Drill Type:** Failing 1500 **Bit Diameter:** 5 5/8" Insert **Surface Elev.** 440.24 m surveyed **Location:** NW of L.S.D.13, Sec. 6, Tp. 93, R.12, W4M **UTM Zone** 12, **Easting** 443194.64, **Northing** 6322824.65 **Comments on Location:** PA16 Oil Sand Corehole location; wooded, level				**Remarks** • tricone to set casing • driller says unoxidized @ 10-13' stone/boulder at 55', 58'; lost bit; trip out to change • 1:00 P.M. start to drill again @ 60' • 1:15 P.M. stopped for lunch • 130-133' sand & cl-silt • 135-138' sand • 308' rotating on boulder • 312' trip out - stop for day (6 P.M.) Start at 8:00 A.M. Feb4
Indicate if feet or metres: feet				**Time: Start** 10:30 A.M.
Unit Depth		**Described Interval**	**Material Lithology**	**Comments:** (Texture, Color, CaCO3, %Pebbles & Granules, Clast Lithology, Moisture, Angularity**)**
From	**To**			
0	86?	0 - 5	Till	boulder at 1'; 2.5Y4/2, dk. grey brown; clay loam (silty clay till); iron stain nodules; some cuttings are very clayey (clay till)
		5 - 10	Till	becoming mottled, rusty brown and v. dk. grey brown, 5Y3/2; driller says oxid. to 10', unoxidized layer, oxid. and unoxid. by 15'; silty-clay till, much more clay and less sand than at UTF96-1
		10 - 15	Till	unoxidized between 10-15'; 5Y2.5/1, v. dk. grey to black; pebbles 2-3%, granules 2-3%; coarse sand in pan at 5-10' (not much); stiff; firm; no reaction to HCL
		15 - 20	Till	as above; abundant pebbles, granules; clay loam (sandy-clay till), more sand in matrix than above; a few coal clasts; no reaction to 10% HCL; v. dk. grey to black, 5Y2.5/1
		20 - 25	Till	switched to 5 5/8" insert bit - good cuttings; clay loam (sandy silty-clay); stiff; abundant local bedrock clasts; no HCL reaction
		25 - 30	Till	as above; some clayey silty sand cuttings, less firm than till, may be dirty lenses in till
		30 - 35	Till	poorer cuttings, some clayey-sand cuttings, may be lenses or layers in till; abundant pebbles in pan
		35 - 40	Till	larger cuttings; varied texture from silty-clay to sandy-clay; v. slightly lighter grey 5Y3/1, v. dk. grey; v. weak HCL reaction
		40 - 45	Till	sandy silty-clay till, abundant pebbles and granules, stiff, good cuttings
		45 - 50	Till	as above; texture varied from stiff clay till to silty sandy-clay till
		50 - 55	Till	varied texture; dense stiff clay till and sandy-clay till; boulder at 55'; v. weak to no HCL reaction
		55 - 60	Till	grinding on boulder at 58'; sandy till (sandy-clay loam), abundant pebbles
		60 - 65	Till	dense, stiff heavy clay till; shiny when cut; some sandy-clay till cuttings

		65 - 70	Till	as above; stiff; dense clay till with some sandy-clay to clayey-sand till cuttings; no HCL reaction
		70 - 75	Till	as above, little change
		75 - 80	Till	dense, stiff heavy clay till, abundant siltstone/claystone (?) streaks in matrix; large cuttings
		80 - 85	Till & Clay	cuttings of laminated clay and silty-clay, and till (v. clayey till); no HCL reaction in clay sample; looks like lacustrine clay, not shale inclusions
86?	100?	85 - 90	Till(sandy)	very sandy till cuttings mixed with some clay; driller says different till; silty-sand till; some bedrock clasts, some clayey-silt cuttings (lacustrine?)
		90 - 95	Till	same silty-sand till; iron stained blebs and some greenish white salt? accumulations
		95 - 100	Till	silty-sand till; very soft, easy to crush in fingers; v. few granules or coarse sand
100?	140	100 - 105	Clay	silty-clay, v. dark grey, 5Y 3/1; lacustrine, soft
		105 - 110	Silty Clay	as above; lacustrine, some clayey-silt cuttings
		110 - 115	Silty-clay & Silt	mostly silty-clay with silt layers or laminations; lacustrine
		115 - 120	Silty-clay & Silt	as above
		120 - 125	Silty-clay & Silt	mostly silty-clay with clayey-silt
		125 - 130	Silty-clay & Silt	as above
		130 - 135	Silty Clay	130-133’ sand, medium; abundant coal flecks, 3-4 mm in pan 133-135’ silty-clay and clayey-silt, mostly silty-clay in pan
		135 - 140	Sand silty-clay	135-138’ medium glacial sand; sampled 138-140’ silty clay; no cuttings in pan
140	180	140 - 150	Sand	medium; glacial; no pebbles, some coarse sand fragments; unoxidized grey, appears well sorted in pan
		150 - 160	Sand	medium; some 2 mm coal clasts in sample
		160 - 170	Sand	medium to coarse; coal clasts
		170 - 180	Sand	pebbly, medium to coarse; coal clasts
		180 - 190	Sand	pebbly, medium; not as coarse as above 10’; <<1% pebbles (granites)
190	210	190 - 200	Fine Gravel	v. coarse sand to fine gravel (3-5 mm); some angular silty clay cuttings in pan sample at 200’ (thin beds in coarse sand); note - these are sandy-clayey silt till lenses
		200 - 210	Fine Gravel	v. coarse sand to fine gravel; some hard angular till cuttings and sandy-silt cuttings & laminated silt and clay at 208-210’ depth; abundant subrounded black chert
210	215	210 - 215	Till	sandy-clay loam; gritty, dense, stiff, v. dk. grey
215	220	215 - 220	Silt & Clay	laminated, v. dk. grey and med. grey (silt component); could be varved; v. finely bedded (1 mm)
220	222	220 - 225	Silt	220-222’ dense, hard silty to v. fine sand; angular cuttings; has till appearance
222	250		Sand	222-225’ medium, no pebbles or coarse fraction
		225 - 230	Sand	medium, as above; no coarse fraction

		230 - 240	Sand	dense, clayey-sandy silt lens or layer at 230'; most of interval is medium sand, coal flecks, peppery
250	290	240 - 250	Sand	grades from medium to coarse with depth; drills hard - dense packed sand; glacial; 2 samples collected -
				medium sand near top and pebbly coarse sand at 250' (black cherts)
		250 - 260	Sand	medium to coarse, fewer coarse fragments than above; "gritty" says driller
		260 - 270	Sand	medium; some very thin clasts of silty clay in pan sample (thin beds?); no pebbles in sample
		270 - 280	Sand	coarse sand; abundant black clasts (chert?); no pebbles in sample
		280 - 290	Sand	pebbly medium sand and coarse sand beds, stratified; bulk sample of both types; abundant chert
290	312	290 - 300	Sand	interbedded medium and coarse sand to fine gravel (2-4 mm); bulk sample of both
		300 - 308	Sand & Gravel	likely interbedded medium sand and medium gravel (5-8 mm); stopped on boulder at 308' - rotating; abundant chert; glacial
		308 - 312	Gravel	308-312' gravel and stones; rotating on large stones for 10 minutes; limestone chips in sample; fine gravel sample
312	313	312 - 320	Gravel	312-313' gravel
313	320		Sand	313-320' medium sand; few pebbles
320	326	320 - 326	Sand	320-326' as above; driller says sand and gravel to 326'
326	327		Siltstone	326-327' change to light grey sandy-silt material; poor cuttings (tricone bit); driller says it drills like till; no sample
327	328	327-328	Sandstone	cemented fine sandstone; some chips are calcareous; some siliceous; boulder?, stone?; sample taken 5Y 2.5/2 black
328	338	328-338	Siltstone&Sandstone	driller says interbedded fine sandstone and siltstone; no sample taken; siltstone is light grey
338	340	338 - 340	Claystone	poor sample; mostly indurated sandstone chips in pan; driller says shale at this interval
340	345	340 - 345	Siltstone and Claystone	5Y 4/1 dk. grey siltstone and 5Y 2.5/1 black claystone; smooth drilling; stopped at 347' for water; same clayey siltstone and claystone, soft
345	361	345 - 360	Claystone	silty claystone; some thin (2-3 cm), hard siltstone/sandstone layers (layer at 359-360'); stopped drilling; very poor cuttings in last 20'; some soft siltstone cuttings in pan
				T.D. 361' - 110m - BPB on site at 12:15 P.M. - run Natural Gamma, FE Resistivity, Sonic (to 50m), Porosity (Neutron) BPB off site at 2:30 P.M. Bedrock at 326'

Table A1-3. Borehole UTF96-3 Litholog

Project: UTF AQUIFER **Data No.** UTF96-3 **Logged by:** L. Andriashek **Date:** Feb. 5, 1996

Drill Co.: Elk Point **Driller:** Gerry Topilka **Drill Type:** Failing 1500 **Bit Diameter:** 4 7/8" Insert

Surface Elev. 377.99 m surveyed

Location: NE of L.S.D.15, Sec. 9, Tp. 93, R.12, W4M

UTM Zone 12, **Easting** 447625.31, **Northing** 6324469.99

Comments on Location: wooded, level, 250 m southeast of stream/beaver pond

Remarks
- on site 8:15 A.M.
- unoxidized @ about 15'

Indicate if feet or metres: feet **Time: Start** 8:15 A.M.

Unit Depth From	To	Described Interval	Material Lithology	**Comments:** (Texture, Color, CaCO3, %Pebbles & Granules, Clast Lithology, Moisture, Angularity)
0	6.5	0 - 5	Lacustrotill	oxidized; pinkish brown lacustrine-till; silty-clay with granules, pebbles 10YR 4/3 dk. brown
6.5	62	5 - 10	Sand	fine to medium, silty sand, oxidized; numerous black clasts; 2.5Y 5/2 grey brown; some si-clay
		10 - 15	Sand	medium; some silty-clay cuttings in pan; 2.5Y 4/2 dk. grey brown; less silt
		15 - 20	Sand	medium; 5Y 4/2 olive grey; clean, well sorted; no pebbles or large fragments
		20 - 30	Sand	medium, as above; well sorted, clean; unoxidized
		30 - 40	Sand	as above, no change
		40 - 50	Sand	medium, well sorted; numerous black clasts (flecks)
		50 - 60	Sand	coarse sand; some granules, numerous black (coal?) flecks; 60-62' fine gravel?
62		60 - 80	Si-Clay to Cl-Silt	driller says change at 62' into silty-clay material; drawing down on Kelly; poor cuttings mixed with very coarse sand in the 60-75' interval; some cuttings are silt, others are silty-clay; good sample from about 75-80' - clayey-silt and silty-clay, shiny, plastic; streaky v. dk. grey to black and lighter grey (still dk. grey); cuttings show layering; 5Y 3/1 v. dk. grey; no reaction to HCL; interpreted as bedrock
		80 - 85	Claystone	waxy, shiny cuttings with blebs of v. dk. brown material (carbonaceous?); some siltstone cuttings
		85 - 90	Claystone	some v. thin cemented siltstone beds; some soft silty laminations
		90 - 95	Claystone	as above; mostly silty claystone
		95 - 100	Claystone	as above
		100 - 105	Claystone & Siltstone	mostly v. dk grey claystone with lighter grey siltstone beds
		105 - 110	Claystone & Siltstone	as above

		110 - 115	Claystone	minor siltstone beds
		115 - 120	Claystone & Siltstone	as above; some v. fine sandstone cuttings (greenish grey appearance - still dk. grey color) 116’, 118’ hard ledges
				T.D. 121’ 36.9m Stopped at 10:00 A.M. Run Natural Gamma, FE Resistivity, Neutron Density, Caliper logs
				Bedrock at 62’

Table A1-4. Borehole UTF96-4 Litholog

Project: UTF AQUIFER **Data No.** UTF96-4 **Logged by:** L. Andriashek **Date:** Feb. 6 1996 **Drill Co.:** Elk Point **Driller:** Gerry Topilka **Drill Type:** Failing 1500 **Bit Diameter:** 4 7/8" Insert **Surface Elev.** 381.64 m surveyed **Location:** WC of L.S.D.6, Sec. 16, Tp. 93, R.12, W4M **UTM Zone** 12, **Easting** 446951.35 **Northing** 6324898.3 **Comments on Location:** Wooded; Cutline; on slight knoll, drops to SE; about 450 m NW of beaver pond				**Remarks** - unoxidized at 15' - bedrock at 20-25'
Indicate if feet or metres: feet				**Time: Start** 2:45 P.M. **Finish** 3:10 P.M.
Unit Depth		**Described Interval**	**Material Lithology**	**Comments:** (Texture, Color, CaCO3, %Pebbles & Granules, Clast Lithology, Moisture, Angularity**)**
From	**To**			
0	20	0 - 5	Lacustrotill	10YR 4/3 brown to dark brown (pinkish brown), si-clay; lacustrine sediment with some clasts; lacustrine diamicton
		5 - 10	Lacustrotill	as above; large cuttings; v. clayey (silty-clay) with some sand clasts
		10 - 15	Lacustrotill	as above; unoxidized at 15'; possibly grading into till; silty-clay; v.dk grey at 15'
		15 - 20	Lacustrotill	v. dk. grey lacustrine/till; clay texture; v. few clasts in matrix
20	>80	20 - 25	Siltstone to Fine Sandstone	fine sandstone to siltstone and claystone; cuttings of both in pan
		25 - 30	Fine Sandstone	with claystone beds?; 5Y 3/1 - 3/2, v. dk. grey to olive grey; v. fine texture
		30 - 35	Claystone, Siltstone, Sandstone	interbedded
		35 - 40	Claystone, Siltstone, Sandstone	sandstone is very fine; mostly silty claystone in pan
		40 - 45	Claystone, Siltstone, Sandstone	
		45 - 50	Claystone,Si ltstone,	some cemented, indurated brown siltstone nodules/lenses (concretions?)

			Sandstone	
		50 - 55	Claystone, Siltstone, Sandstone	mostly claystone with v. fine sandstone and siltstone
		55 - 60	Claystone, Siltstone, Sandstone	mostly claystone with v. fine sandstone and siltstone
		60 - 65	Claystone, Siltstone, Sandstone	
		65 - 70	Claystone, Siltstone, Sandstone	some indurated, cemented siltstone lenses
		70 - 75	Claystone, Siltstone, Sandstone	mostly v. dk. grey to black claystone with fine soft sandstone
		75 - 80	Claystone, Siltstone, Sandstone	interbedded sequence from 20’ to 80’ T.D. 80’ Buried channel not encountered. No petrophysical logs; Bedrock at 20’

Appendix 2. Lithologs, Geophysical logs, Mineralogy and Geochemistry of Quaternary Sediments

NE LSD 10 Section 30 Tp 93 Rg 11W4M
Long. 111.758056 Lat. 57.0986111
Elevation 330 masl (estimated)

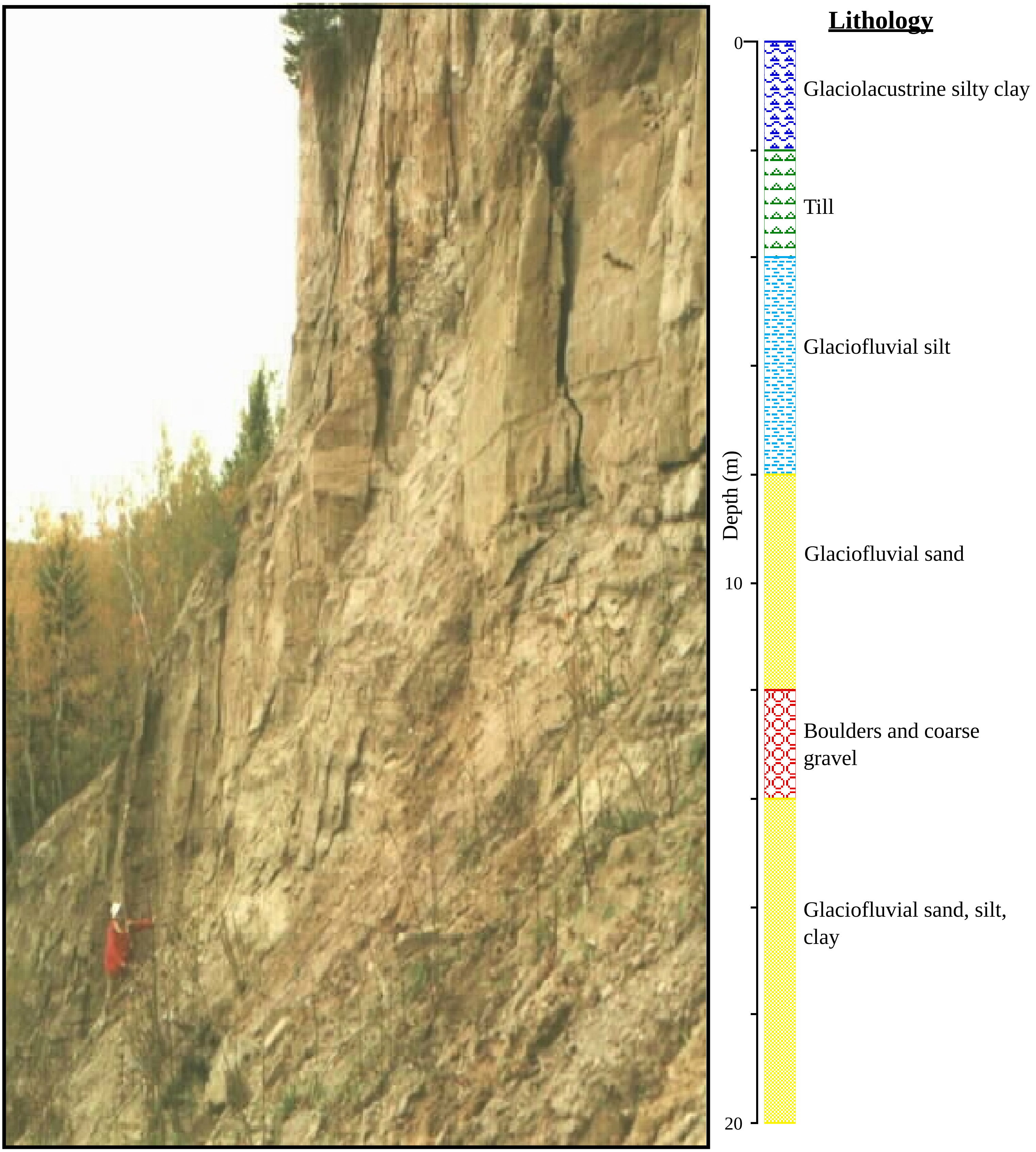

Figure A2-1. Litholog of Birch Channel outcrop, Mackay River.

Figure A2-2. Boulder bed within glaciofluvial sequence, Birch Channel outcrop, Mackay River.

LSD 6, Section 26 Tp 94 Rg 12W4M
Long. 111.821111 Lat. 57.1808333
Elevation 310 masl (estimated)

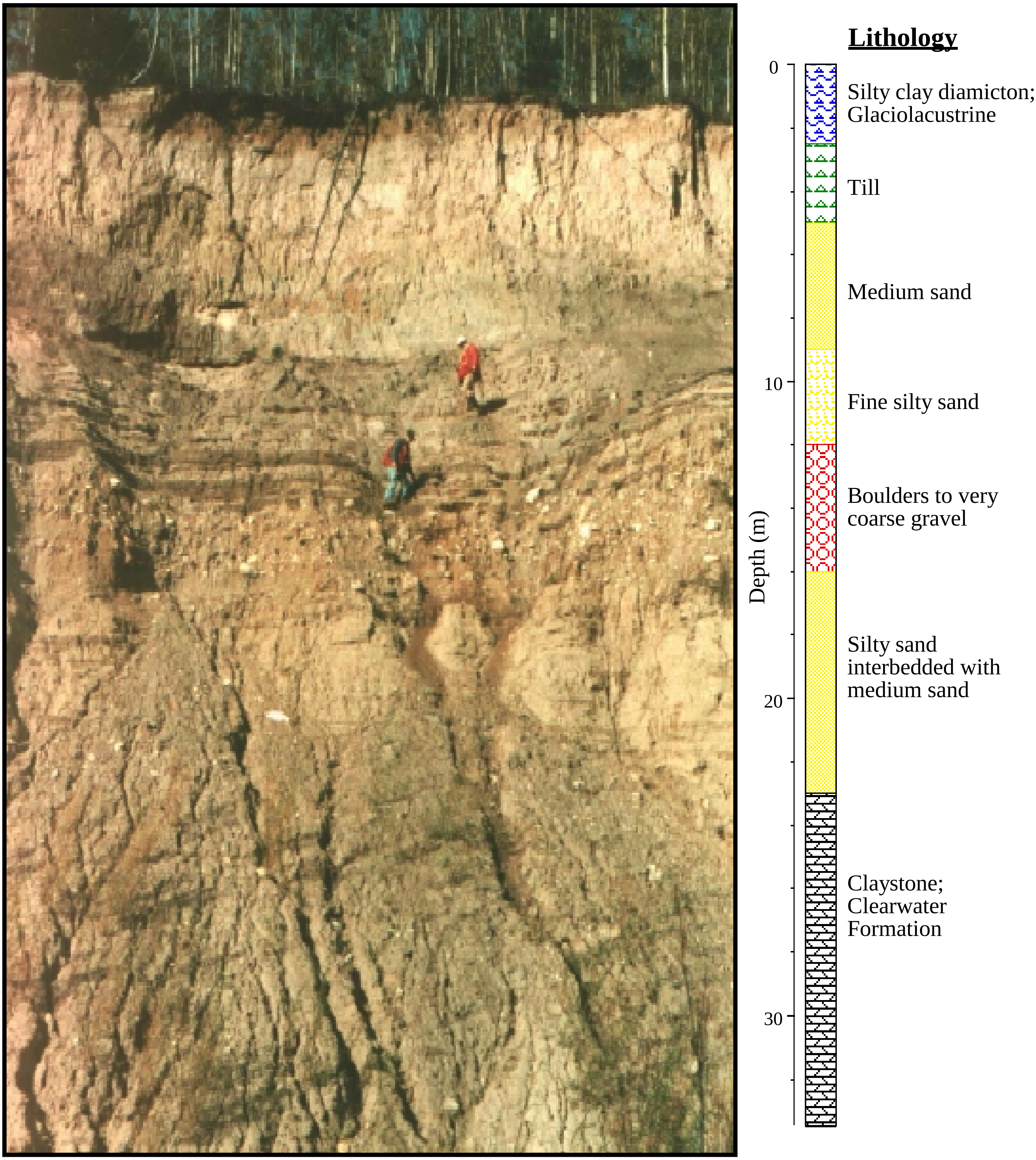

Figure A2-3. Litholog of Willow Channel outcrop, Dover River.

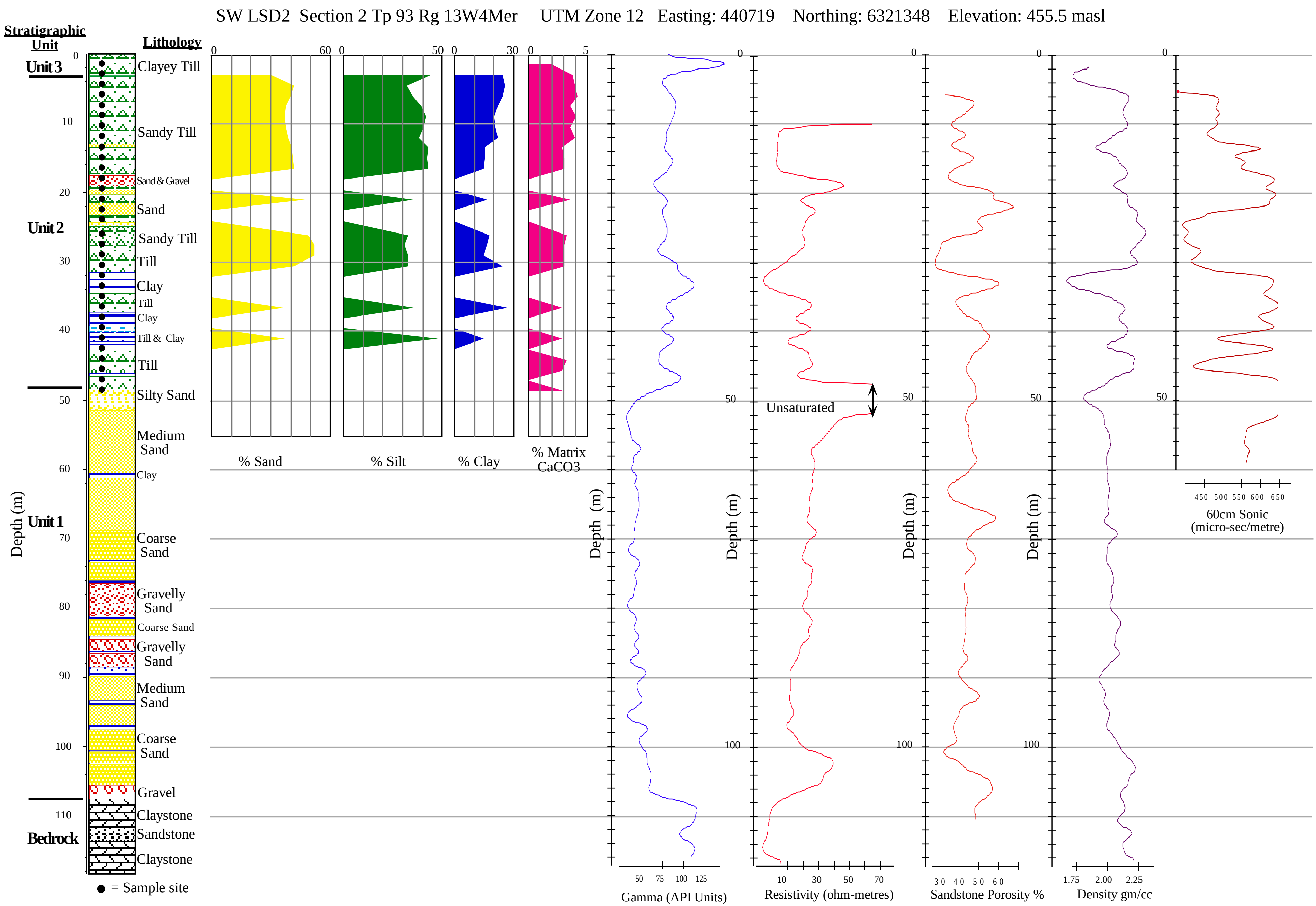

Figure A2-4. Lithological, mineralogical, and downhole geophysical properties of Quaternary sediments in borehole UTF 96-1 .

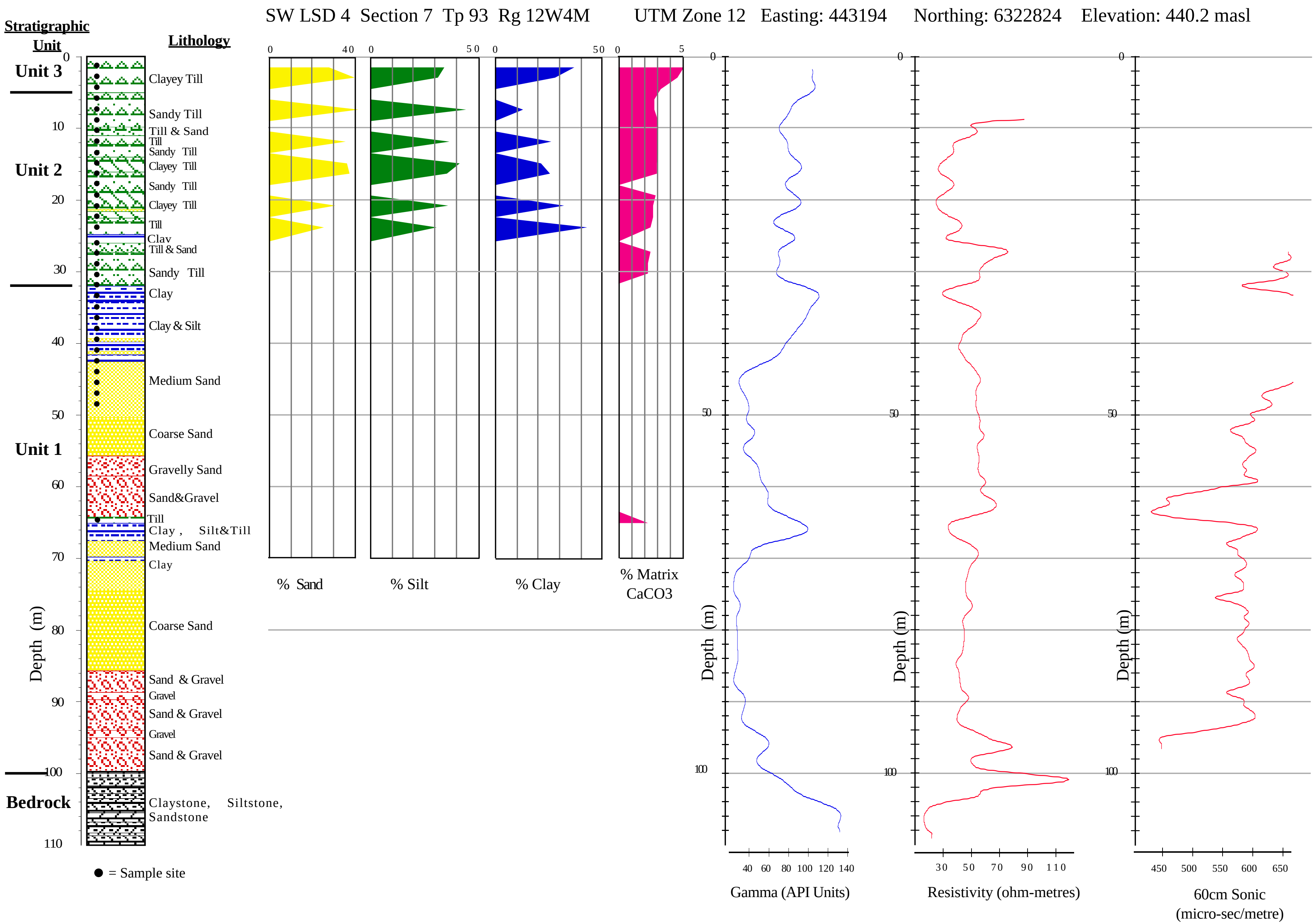

Figure A2-5. Lithological, mineralogical, and downhole geophysical properties of Quaternary sediments in borehole UTF96-2.

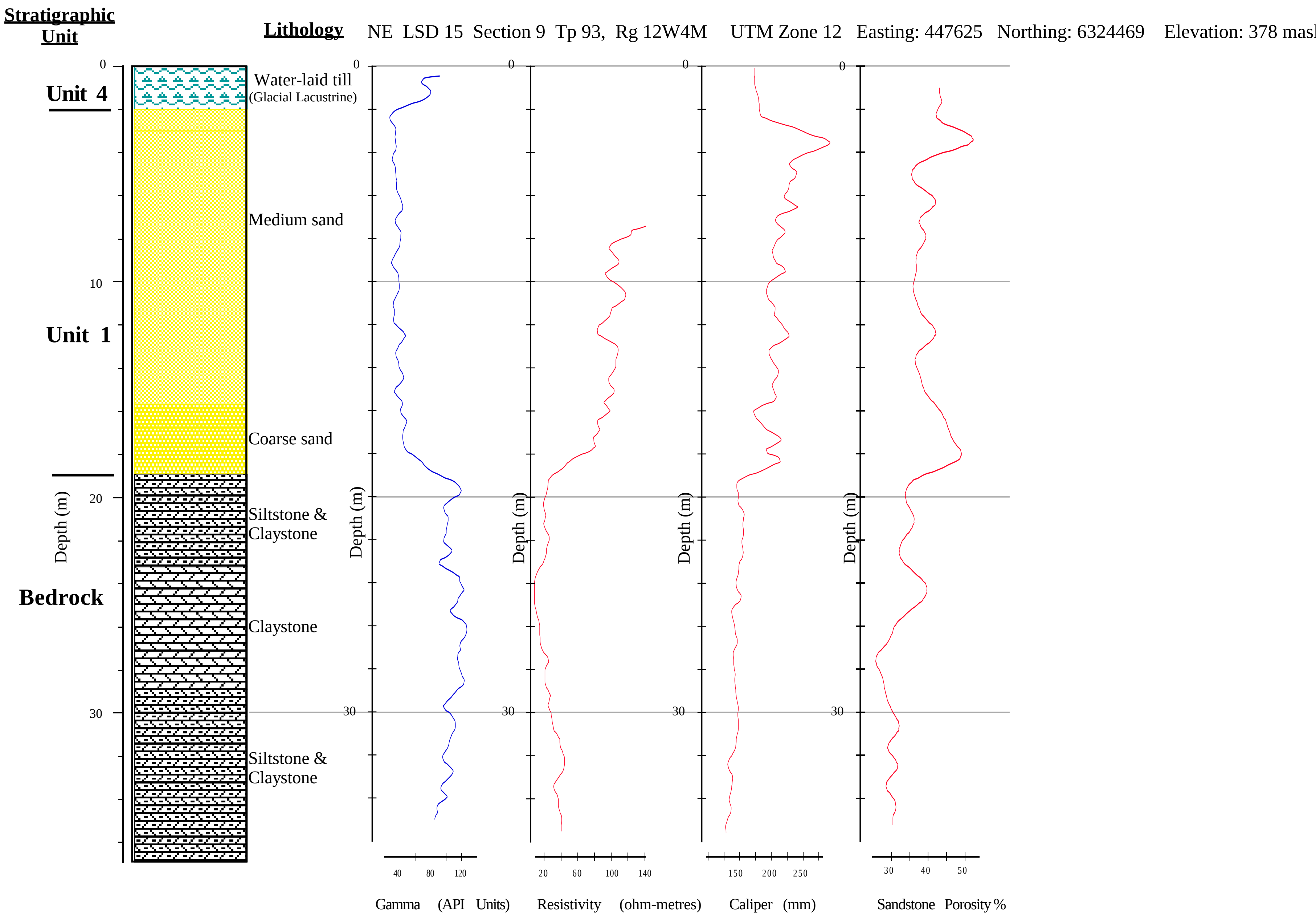

Figure A2-6. Lithological and downhole geophysical properties of Quaternary sediments in borehole UTF96-3.

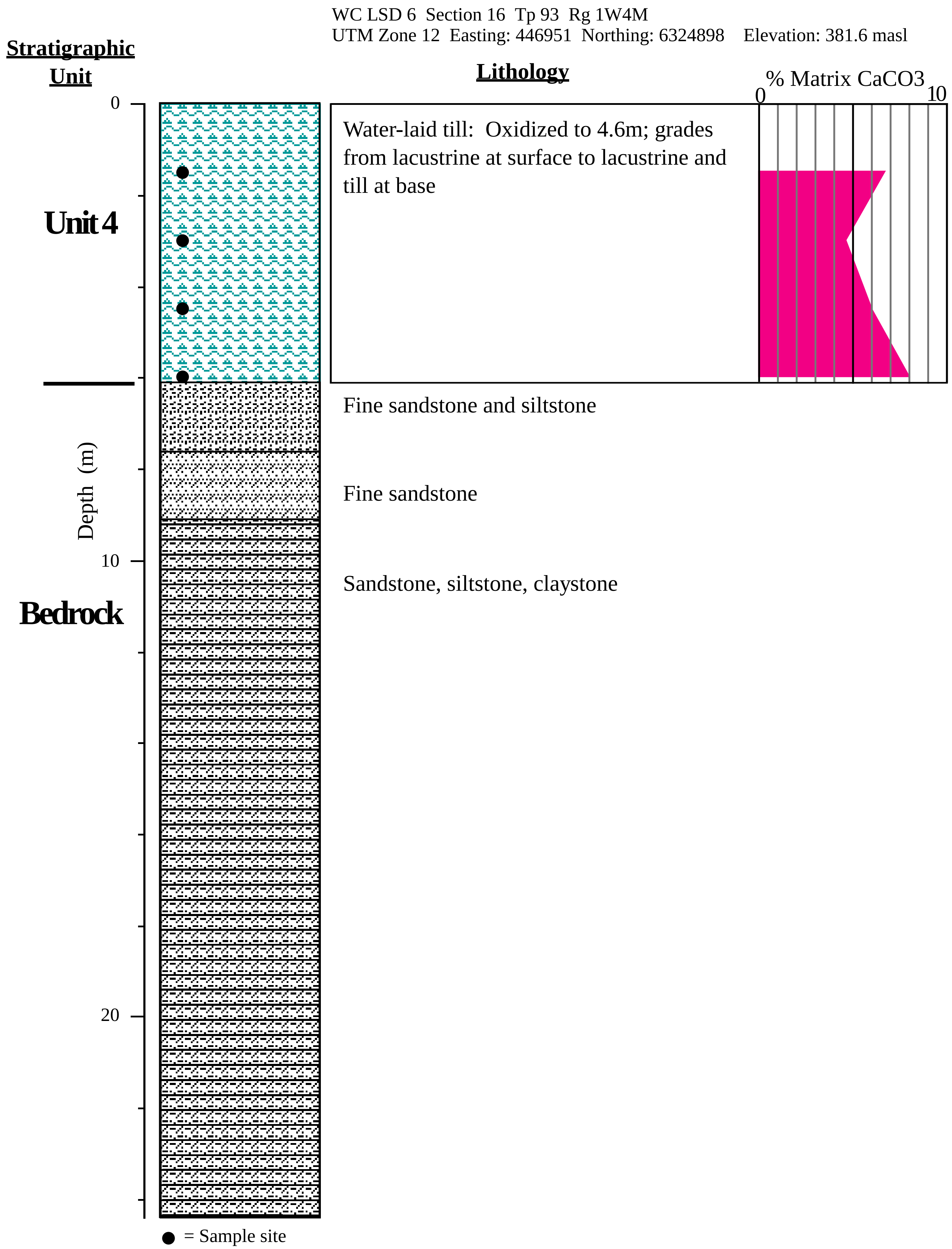

Figure A2-7. Lithological and mineralogical properties of Quaternary sediments in borehole UTF96-4.

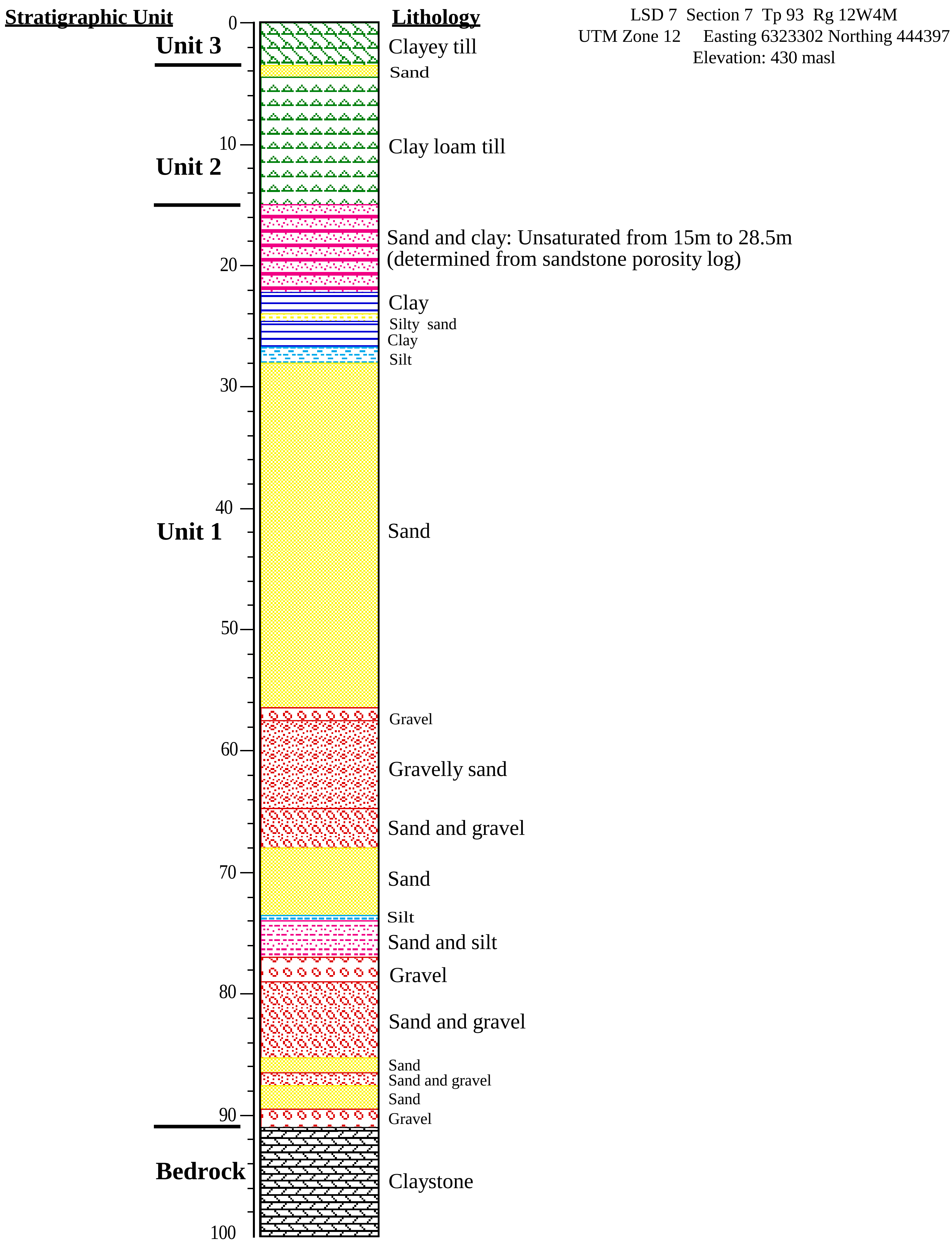

Figure A2-8. Litholog of borehole WDW3 Dover.

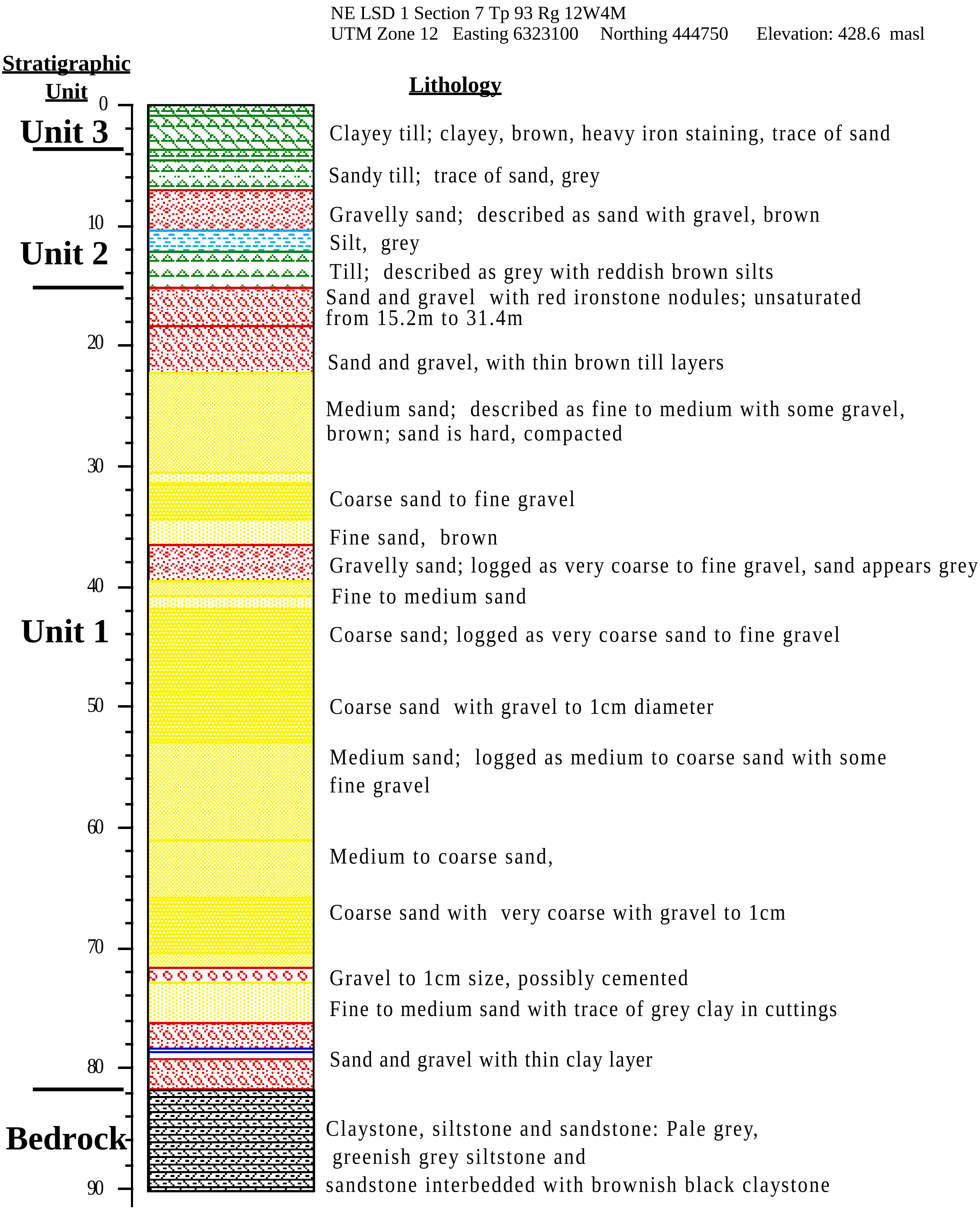

Figure A2-9. Litholog of borehole WW1.

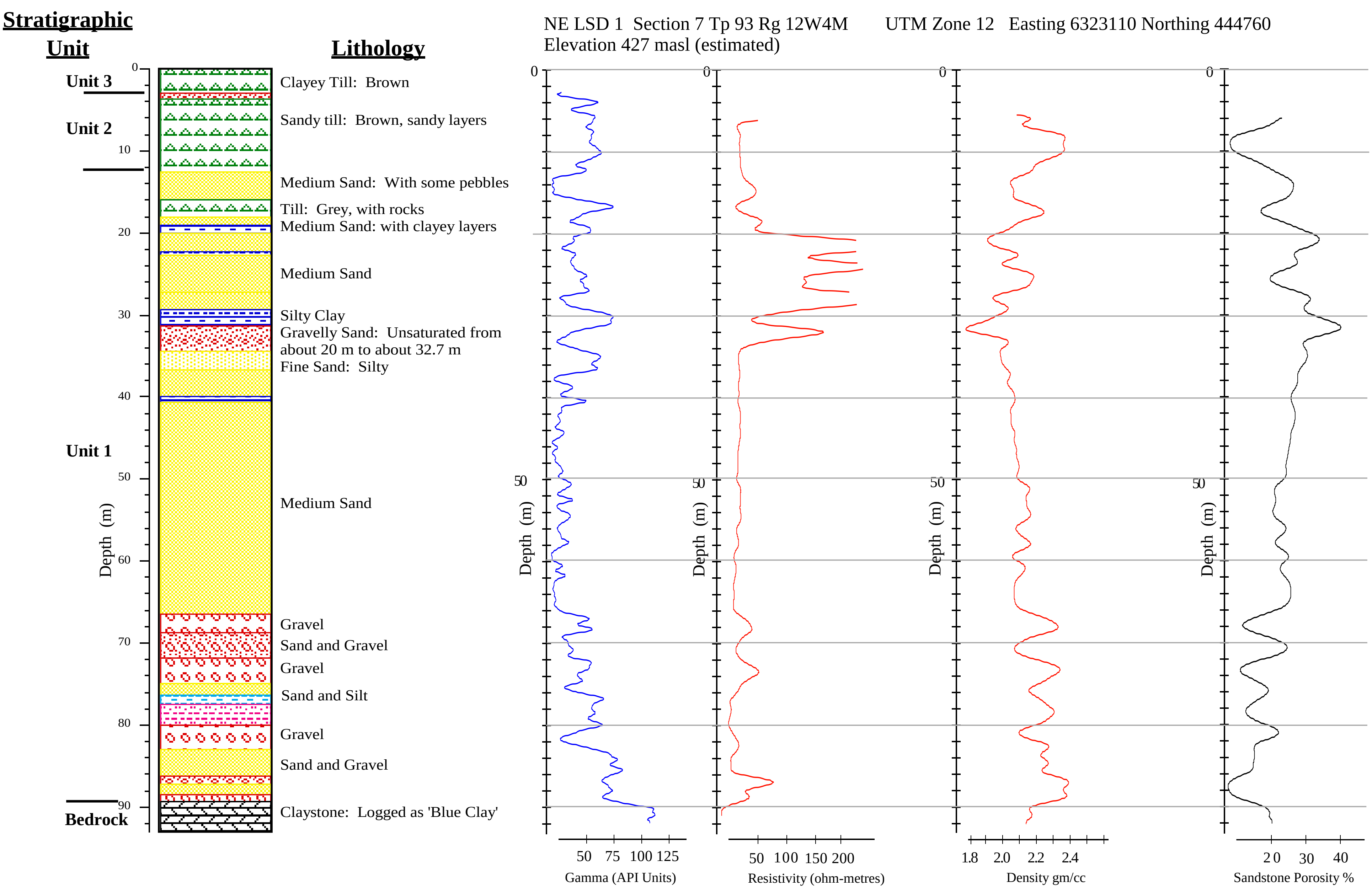

Figure A2-10. Lithological and downhole geophysical properties of Quaternary sediments in borehole UTF96 water supply well (UTF96-WSW).

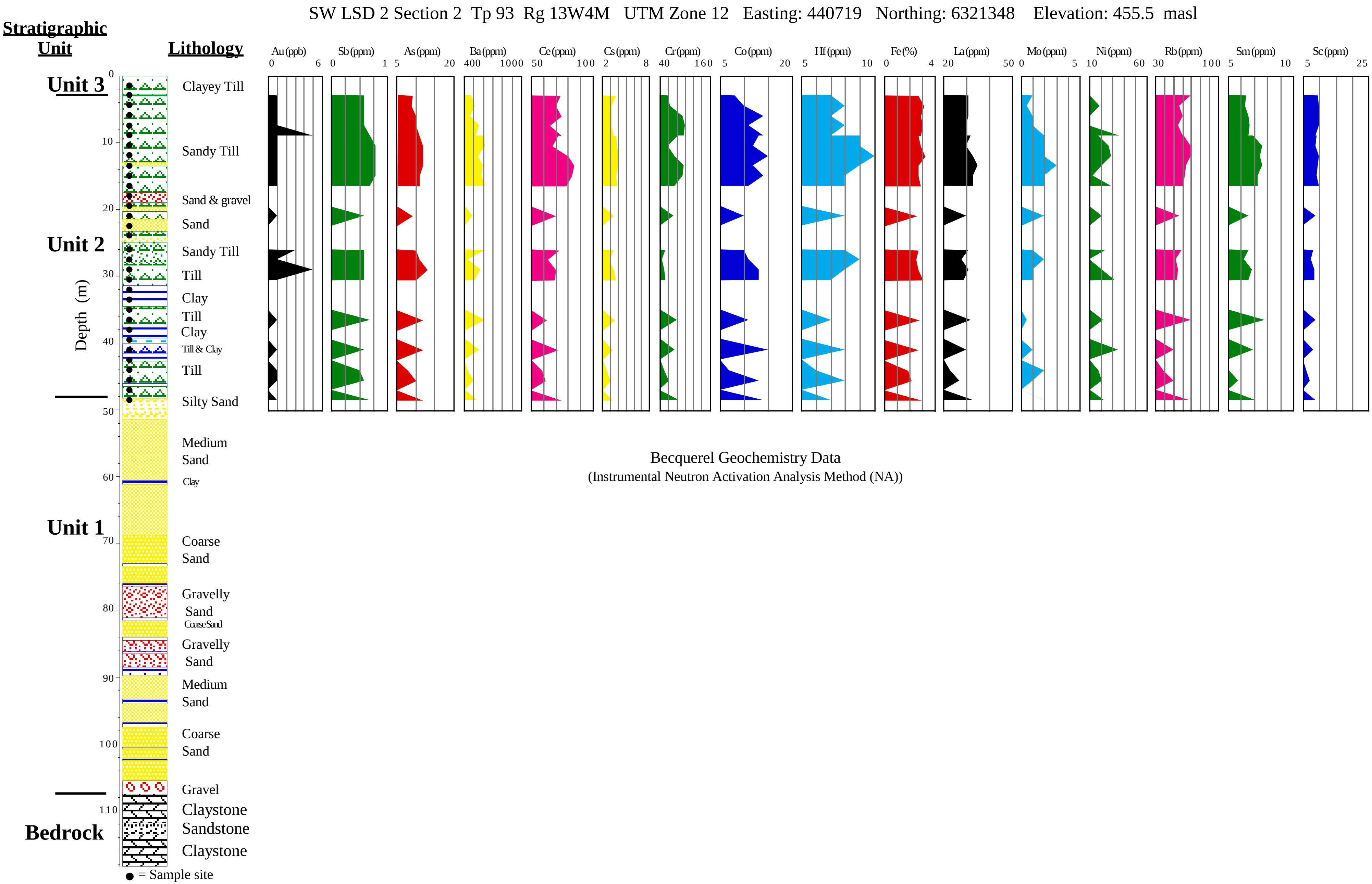

Figure A2-11. Geochemical analysis of the silt-clay fraction of tills, borehole UTF96-1.

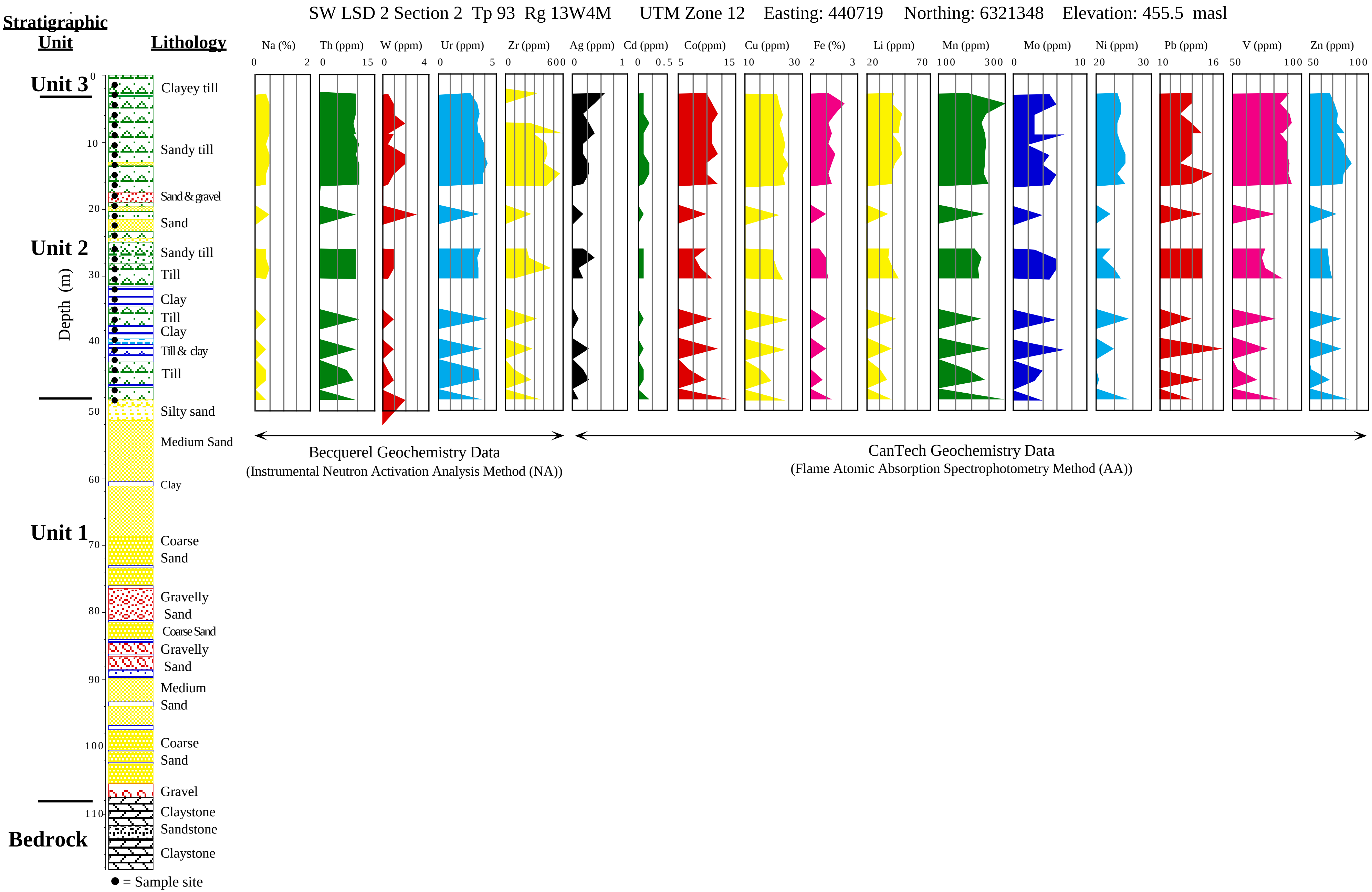

Figure A2-12. Geochemical analysis of the silt-clay fraction of tills, borehole UTF96-1.

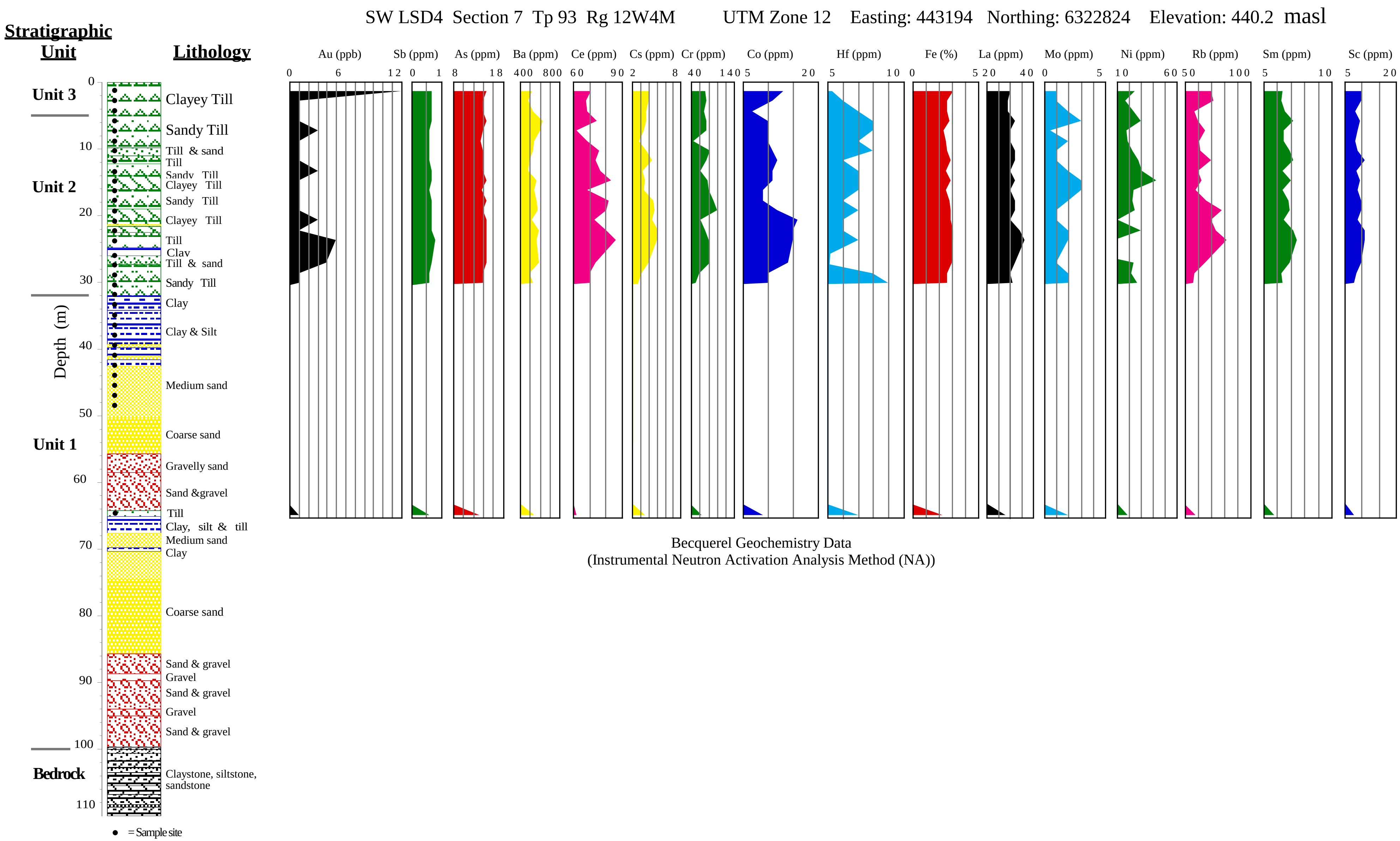

Figure A2-13. Geochemical analysis of the silt-clay fraction of tills, borehole UTF96-2.

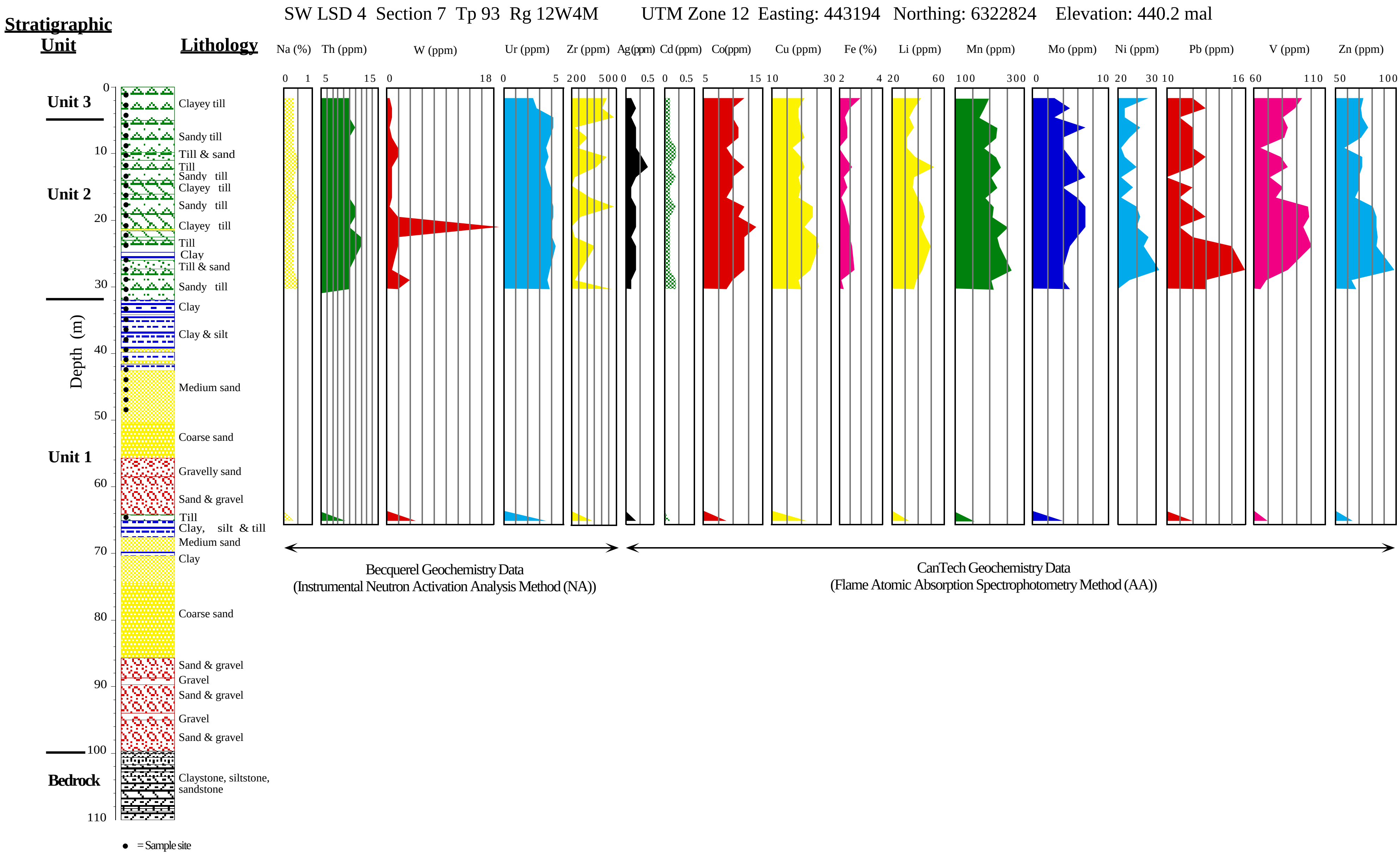

Figure A2-14. Geochemical analysis of the silt-clay fraction of tills, borehole UTF96-2.

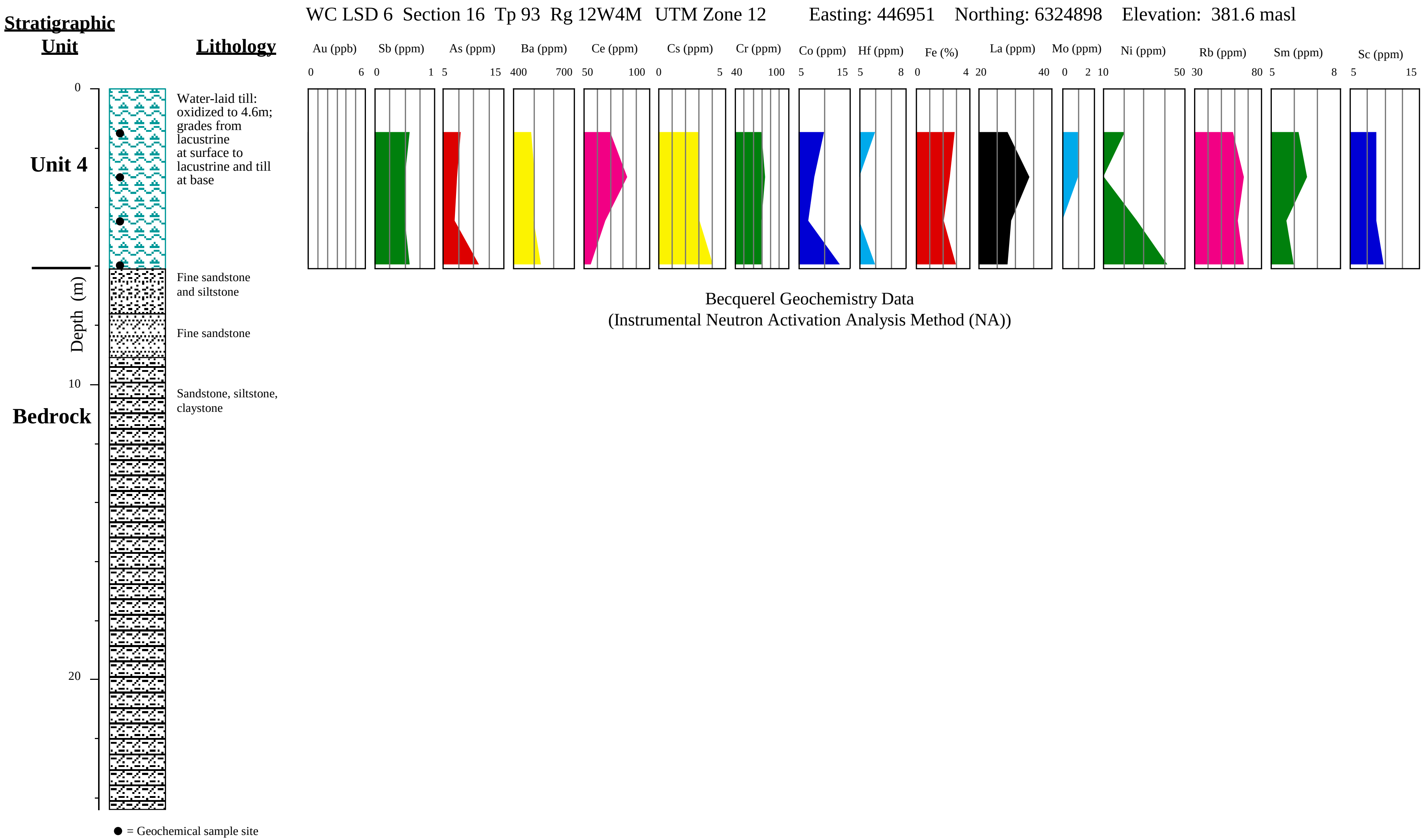

Figure A2-15. Geochemical analysis of the silt-clay fraction of tills, borehole UTF96-4.

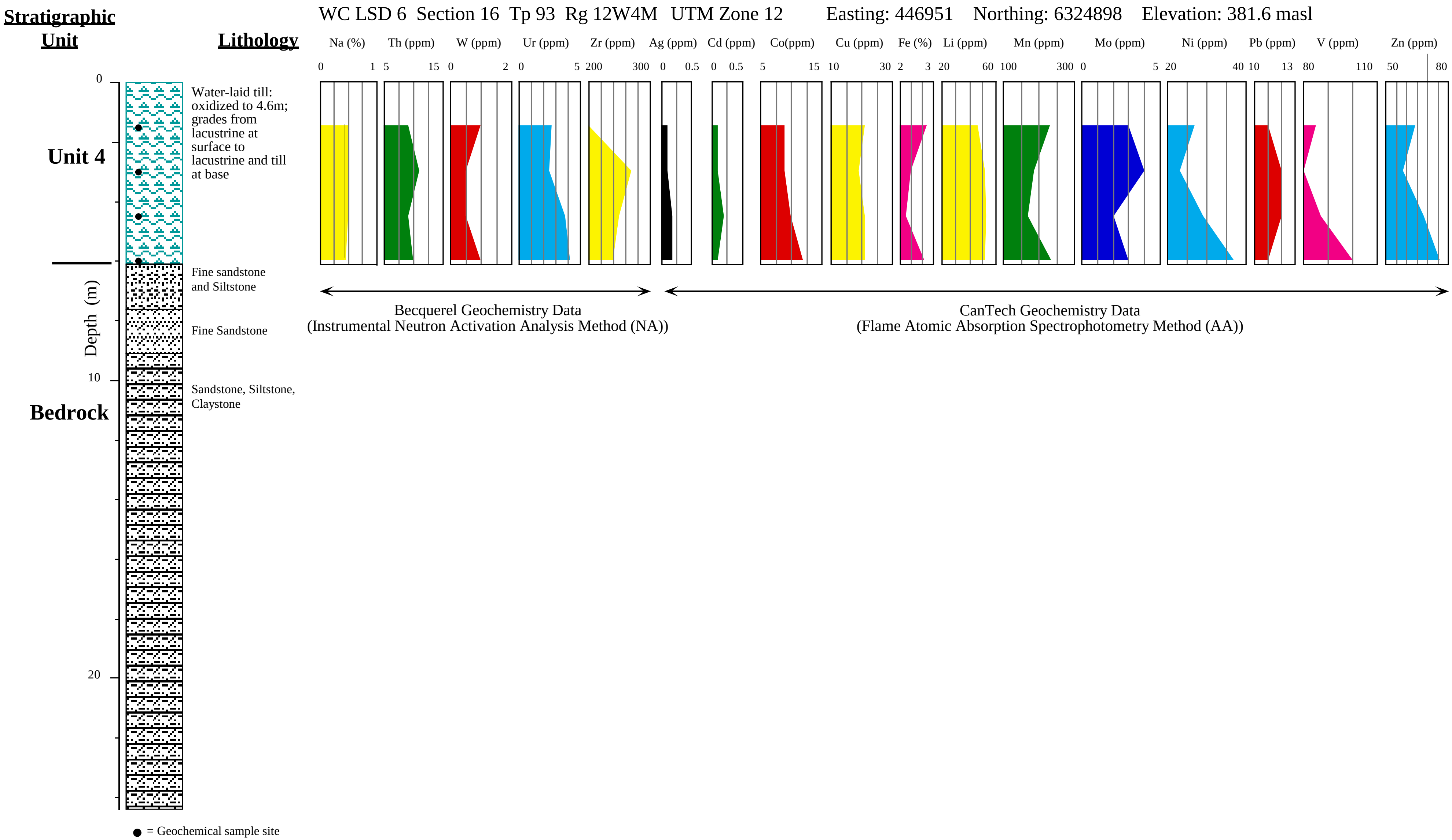

Figure A2-16. Geochemical analysis of the silt-clay fraction of tills, borehole UTF96-4.

Appendix 3. Till lithology, mineralogy and geochemistry data

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

Borehole Sample Depth	Lithology	AGS Lab#	Depth Interval (m)	%Sand (>63)	%Silt (<63)	%Clay (<4)	%Sand (>50)	%Silt (<50)	%Clay (<2)	%1-2mm Sand	Wgt. % Total CaCO3	Volume CO2	Ca/Do Ratio
UTF96-1 0-5'	Till		0-1.5								2.0	4.8	0.62
UTF96-1 5-10'	Till	97G 017	1.5-3	30.9	44.6	24.5	33.4	48.8	17.8	0.94	3.8	9.1	0.41
UTF96-1 10-15'	Till	97G 018	3-4.5	42.0	32.3	25.7	44.4	37.1	18.5	3.10	4.0	9.5	0.21
UTF96-1 15-20'	Till	97G 019	4.5-6	40.3	35.3	24.4	42.8	39.9	17.3	1.50	4.2	9.9	0.27
UTF96-1 20-25'	Till	97G 020	6-7.5	38.0	39.7	22.3	40.8	44.5	14.7	1.40	3.6	8.6	0.27
UTF96-1 25-30'	Till	97G 021	7.5-9	37.3	42.1	20.6	40.0	47.1	12.9	1.10	4.1	9.9	0.23
UTF96-1 25-30'	Till	97G 029	7.5-9										
UTF96-1 30-35'	Till	97G 022	9-10.5	38.0	41.1	20.9	40.9	45.5	13.6	1.00	3.6	8.6	0.22
UTF96-1 35-40'	Till	97G 023	10.5-12	39.2	38.4	22.4	41.8	43.4	14.8	1.50	4.0	9.5	0.32
UTF96-1 40-45'	Till	97G 024	12-13.5	40.7	43.5	15.8	43.3	45.7	11.0	3.60	2.9	6.9	0.31
UTF96-1 45-50'	Till	97G 025	13.5-15	41.6	42.5	15.9	44.4	44.2	11.4	1.70	3.1	7.3	0.36
UTF96-1 50-55'	Till	97G 026	15-16.5	42.1	43.1	14.8	44.9	44.8	10.3	1.40	3.1	7.4	0.27
UTF96-1 65-70'	Till	97G 027	19.5-21	47.7	35.4	16.9	50.3	37.3	12.4	2.20	3.6	8.6	0.29
UTF96-1 80-85'	Till	97G 028	24-26	49.0	33.1	17.9	51.1	37.5	11.4	2.10	3.3	7.8	0.29
UTF96-1 85-90'	Till	97G 030	26-27.5	52.2	31.2	16.6	54.3	34.9	10.8	2.40	3.1	7.4	0.31
UTF96-1 90-95'	Till	97G 031	27.5-29	52.1	33.1	14.8	54.3	35.8	9.9	2.40	3.1	7.4	0.36
UTF96-1 95-100'	Till	97G 032	29-30.5	42.1	33.1	24.8	43.8	38.8	17.4	2.20	3.1	7.4	0.36
UTF96-1 115-120'	Till	97G 033	35-36.5	36.7	36.2	27.1	38.5	44.9	16.6	2.20	2.9	7.0	0.39
UTF96-1 130-135'	Till	97G 034	39.5-41	37.1	48.0	14.9	38.9	53.5	7.6	2.40	2.9	7.0	0.34
UTF96-1 140-145'	Till	97G 035	42.5-44								3.3	7.9	0.29
UTF96-1 145-150'	Till	97G 037	44-45.5								2.9	7.0	0.36
UTF96-1 155-160'	Till	97G 038	47-48.5								3.0	7.0	0.46
UTF96-2 0-5'	Till	97G 039	0-1.5	28.2	34.6	37.2	31.5	38.2	30.3	0.60	5.1	12.2	0.24
UTF96-2 5-10'	Till	97G 040	1.5-3	39.9	31.7	28.4	42.4	34.1	23.5	0.90	4.6	10.9	0.34
UTF96-2 10-15'	Till	97G 042	3-4.5								3.3	7.9	0.42
UTF96-2 15-20'	Till	97G 044	4.5-6								2.8	6.6	0.64
UTF96-2 20-25'	Till	97G 041	6-7.5	41.8	45.1	13.1	44.6	48.5	6.9	1.10	2.8	6.6	0.54
UTF96-2 20-25'	Till	97G 049	6-7.5										
UTF96-2 25-30'	Till	97G 045	7.5-9								3.1	7.4	0.45
UTF96-2 30-35'	Till	97G 046	9-10.5								3.1	7.4	0.50
UTF96-2 35-40'	Till	97G 047	10.5-12	36.2	37.2	26.6	38.7	41.6	19.7	0.70	3.1	7.4	0.56
UTF96-2 40-45'	Till	97G 048	12-13.5								3.1	7.4	0.56
UTF96-2 45-50'	Till	97G 050	13.5-15	36.5	41.8	21.7	39.0	45.5	15.5	1.20	3.0	7.0	0.58
UTF96-2 50-55'	Till	97G 051	15-16.5	38.1	36.1	25.8	40.0	42.7	17.3	1.30	3.0	7.0	0.62
UTF96-2 60-65'	Till	97G 052	18-19.5								2.9	6.9	0.62

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

		Becquerel Geochemistry Data																					
Borehole Sample Depth	Lithology	Weight gms	Au ppb	Sb ppm	As ppm	Ba ppm	Br ppm	Cd ppm	Ce ppm	Cs ppm	Cr ppm	Co ppm	Eu ppm	Hf ppm	Ir ppb	Fe %	La ppm	Lu ppm	Mo ppm	Ni ppm	Rb ppm	Sm ppm	Sc ppm
UTF96-1 0-5'	Till																						
UTF96-1 5-10'	Till	29.90	-2	0.6	9.2	470	0.7	-5	74	3.7	60	8	1	7	-50	2.7	31	0.4	1	-10	69	6.4	9.5
UTF96-1 10-15'	Till	26.48	-2	0.6	9.0	510	1.1	-5	70	3.1	65	10	1	8	-50	3.2	31	0.2	-1	19	57	6.3	10.0
UTF96-1 15-20'	Till	26.49	-2	0.6	10.0	460	0.9	-5	75	3.1	95	14	1	7	-50	2.9	31	-0.2	1	-10	61	6.6	10.0
UTF96-1 20-25'	Till	23.85	-2	0.6	10.0	560	1.3	-5	66	3.1	100	11	1	8	-50	3.1	30	-0.2	1	-10	56	6.7	10.0
UTF96-1 25-30'	Till	22.13	5	0.7	11.0	520	1.3	-5	75	3.4	97	14	1	7	-50	2.9	30	-0.2	2	36	60	6.6	8.8
UTF96-1 25-30'	Till	30.43	-2	0.7	11.0	590	1.2	-5	72	3.7	85	13	-1	9	-50	2.7	32	0.3	2	18	62	6.9	9.1
UTF96-1 30-35'	Till	22.35	-2	0.8	12.0	610	1.7	-5	68	3.9	60	12	1	9	-50	2.9	30	-0.2	2	27	70	7.6	8.7
UTF96-1 35-40'	Till	25.54	-2	0.8	12.0	540	1.7	-5	81	4.1	77	15	1	10	-50	3.3	33	-0.2	2	29	70	7.5	10.0
UTF96-1 40-45'	Till	24.88	-2	0.8	12.0	590	1.9	-5	85	4.1	99	12	-1	9	-50	2.7	35	0.2	3	21	64	7.6	9.4
UTF96-1 45-50'	Till	26.56	-2	0.8	11.0	580	1.9	-5	83	3.7	95	14	1	8	-50	2.7	33	0.3	2	13	63	7.3	9.3
UTF96-1 50-55'	Till	27.61	-2	0.7	11.0	620	1.7	-5	79	3.9	76	11	1	8	-50	2.9	33	0.2	2	29	61	7.3	10.0
UTF96-1 65-70'	Till	26.76	-2	0.6	9.2	480	1.1	-5	70	3.5	73	10	1	8	-50	2.6	30	-0.2	2	21	57	6.6	8.9
UTF96-1 80-85'	Till	26.42	3	0.6	10.0	610	1.4	-5	73	3.4	55	10	1	8	-50	2.7	31	0.3	1	24	59	6.6	8.2
UTF96-1 85-90'	Till	28.71	-2	0.6	11.0	440	1.3	-5	64	2.9	46	11	-1	9	-50	2.5	28	0.3	2	-10	53	6.2	7.4
UTF96-1 90-95'	Till	28.45	5	0.6	13.0	570	1.4	-5	70	3.4	51	13	-1	8	-50	2.7	31	-0.2	1	21	55	6.8	8.5
UTF96-1 95-100'	Till	20.44	-2	0.6	10.0	510	1.3	-5	69	3.7	54	13	1	7	-50	3.1	29	-0.2	1	32	54	6.6	8.6
UTF96-1 115-120'	Till	23.14	-2	0.7	12.0	620	1.3	-5	63	3.6	80	11	1	7	-50	2.8	32	-0.2	-1	22	70	7.8	8.8
UTF96-1 130-135'	Till	23.19	-2	0.6	12.0	560	1.4	-5	72	3.3	77	15	-1	8	-50	2.7	30	-0.2	1	35	51	6.9	8.3
UTF96-1 140-145'	Till	25.30	-2	0.5	7.9	440	1.0	-5	59	2.6	50	7	1	6	-50	1.9	23	-0.2	2	18	39	5.1	5.9
UTF96-1 145-150'	Till	25.49	-2	0.6	10.0	490	1.0	-5	62	3.0	63	13	-1	8	-50	2.2	27	-0.2	1	21	51	5.8	7.1
UTF96-1 155-160'	Till	18.68	-2	0.7	12.0	530	1.6	-5	75	3.3	87	14	1	7	-50	3.0	33	-0.2	2	23	68	7.1	8.7
UTF96-2 0-5'	Till	24.46	12	0.7	11.0	520	1.0	-5	71	4.2	72	13	1	5	-50	3.1	30	-0.2	1	25	70	6.4	10.0
UTF96-2 5-10'	Till	19.64	-2	0.7	10.0	480	1.3	-5	68	4.1	76	11	-1	6	-50	2.6	29	-0.2	1	17	72	6.3	10.0
UTF96-2 10-15'	Till	21.80	-2	0.7	10.0	530	2.0	-5	69	3.7	69	7	1	7	-50	2.6	29	-0.2	2	24	57	6.6	8.3
UTF96-2 15-20'	Till	29.60	-2	0.7	11.0	630	2.2	-5	75	3.8	77	10	1	8	-50	2.8	32	-0.2	3	30	60	7.2	9.4
UTF96-2 20-25'	Till	28.08	3	0.6	10.0	600	1.7	-5	62	3.5	76	10	1	8	-50	2.4	30	-0.2	-1	18	65	6.5	9.0
UTF96-2 20-25'	Till	30.35	-2	0.7	11.0	570	1.8	-5	84	3.6	78	11	-1	7	-50	2.9	32	0.2	3	43	63	7.0	9.4
UTF96-2 25-30'	Till	29.16	-2	0.6	9.1	540	1.7	-5	69	2.9	45	10	-1	7	-50	2.5	30	-0.2	2	19	61	6.5	8.3
UTF96-2 30-35'	Till	29.73	-2	0.6	10.0	530	1.5	-5	76	3.7	84	11	1	8	-50	2.6	32	0.3	1	23	62	6.9	8.8
UTF96-2 35-40'	Till	21.68	-2	0.6	10.0	500	0.9	-5	74	4.4	76	12	2	6	-50	2.9	32	0.3	1	28	70	7.2	11.0
UTF96-2 40-45'	Till	29.34	3	0.7	10.0	480	1.6	-5	77	3.3	62	11	-1	7	-50	2.5	30	-0.2	2	31	60	6.4	8.4
UTF96-2 45-50'	Till	23.14	-2	0.6	9.5	540	1.7	-5	69	3.5	81	9	1	7	-50	2.5	30	0.2	3	24	58	6.4	8.8
UTF96-2 50-55'	Till	19.07	-2	0.7	11.0	570	1.6	-5	82	4.6	92	9	1	6	-50	2.8	32	-0.2	2	23	66	6.8	10.0
UTF96-2 60-65'	Till	28.71	-2	0.7	10.0	580	1.4	-5	81	4.8	100	12	-1	7	-50	2.9	32	-0.2	1	25	78	6.9	10.0

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

Borehole Sample Depth	Lithology	Se ppm	Ag ppm	Na %	Ta ppm	Te ppm	Tb ppm	Th ppm	Sn ppm	W ppm	U ppm	Yb ppm	Zn ppm	Zr ppm
UTF96-1 0-5'	Till													
UTF96-1 5-10'	Till	-5	-2	0.44	0.6	-10	0.8	10.0	-100	-1	2.8	1	-100	350
UTF96-1 10-15'	Till	-5	-2	0.49	0.6	-10	0.7	10.0	-100	1	3.4	1	-100	-200
UTF96-1 15-20'	Till	-5	-2	0.46	0.9	-10	0.6	10.0	-100	1	3.6	2	-100	-200
UTF96-1 20-25'	Till	-5	-2	0.46	0.9	-10	0.8	9.5	-100	2	3.4	2	-100	260
UTF96-1 25-30'	Till	-5	2	0.45	1.0	-10	0.9	10.0	-100	-1	3.5	1	-100	600
UTF96-1 25-30'	Till	-5	-2	0.47	0.8	-10	1.0	9.5	-100	1	3.6	2	-100	300
UTF96-1 30-35'	Till	-5	-2	0.44	0.9	-10	0.8	11.0	-100	-1	4.0	2	-100	430
UTF96-1 35-40'	Till	-5	-2	0.48	0.9	-10	0.9	10.0	-100	2	4.0	1	-100	440
UTF96-1 40-45'	Till	-5	-2	0.48	1.1	-10	0.8	11.0	-100	2	4.3	2	-100	410
UTF96-1 45-50'	Till	-5	-2	0.44	0.9	-10	0.9	11.0	-100	1	3.9	2	-100	580
UTF96-1 50-55'	Till	-5	-2	0.44	1.1	-10	1.0	11.0	-100	-1	3.9	2	-100	430
UTF96-1 65-70'	Till	-5	-2	0.46	1.0	-10	0.8	10.0	-100	3	3.6	2	-100	280
UTF96-1 80-85'	Till	-5	-2	0.44	0.9	-10	0.8	10.0	-100	1	3.7	1	-100	230
UTF96-1 85-90'	Till	-5	-2	0.42	0.7	-10	0.7	10.0	-100	1	3.4	1	-100	250
UTF96-1 90-95'	Till	-5	-2	0.46	1.0	-10	0.8	10.0	-100	1	3.5	1	-100	480
UTF96-1 95-100'	Till	-5	-2	0.36	0.9	-10	0.9	10.0	-100	-1	3.5	1	-100	-200
UTF96-1 115-120'	Till	-5	2	0.42	1.0	-10	1.0	11.0	-100	1	4.3	1	-100	340
UTF96-1 130-135'	Till	-5	-2	0.43	1.1	-10	0.8	10.0	-100	1	3.8	2	-100	290
UTF96-1 140-145'	Till	-5	-2	0.38	0.8	-10	0.6	7.6	-100	-1	3.5	1	-100	-200
UTF96-1 145-150'	Till	-5	-2	0.42	0.9	-10	0.7	9.3	-100	1	3.6	1	-100	270
UTF96-1 155-160'	Till	-5	-2	0.43	0.9	-10	1.0	10.0	-100	2	3.8	1	-100	370
UTF96-2 0-5'	Till	-5	-2	0.41	0.7	-10	0.9	10.0	-100	-1	2.5	1	-100	440
UTF96-2 5-10'	Till	-5	2	0.43	0.5	-10	0.6	10.0	-100	1	2.8	1	-100	410
UTF96-2 10-15'	Till	-5	-2	0.40	0.9	-10	0.9	10.0	-100	1	4.2	1	-100	490
UTF96-2 15-20'	Till	-5	-2	0.43	0.8	-10	0.9	11.0	-100	-1	4.2	2	-100	220
UTF96-2 20-25'	Till	-5	-2	0.39	0.9	-10	0.8	10.0	-100	1	3.9	2	-100	310
UTF96-2 20-25'	Till	-5	2	0.42	0.7	-10	0.9	10.0	-100	1	4.0	2	-100	-200
UTF96-2 25-30'	Till	-5	-2	0.41	0.7	-10	0.8	10.0	-100	2	3.6	1	-100	240
UTF96-2 30-35'	Till	-5	2	0.45	1.2	-10	0.9	10.0	-100	2	3.8	2	-100	440
UTF96-2 35-40'	Till	-5	-2	0.45	0.9	-10	1.0	10.0	-100	1	3.5	1	-100	370
UTF96-2 40-45'	Till	-5	-2	0.43	1.0	-10	0.7	10.0	-100	1	3.7	1	-100	220
UTF96-2 45-50'	Till	-5	-2	0.45	0.7	-10	0.8	10.0	-100	1	4.0	1	-100	330
UTF96-2 50-55'	Till	-5	-2	0.42	0.8	-10	0.8	11.0	-100	-1	4.2	1	-100	490
UTF96-2 60-65'	Till	-5	-2	0.43	0.7	-10	1.0	11.0	-100	2	4.2	1	-100	260

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

		CanTech Geochemistry Data											
Borehole Sample Depth	**Lithology**	**Ag** ppm	**Cd** ppm	**Co** ppm	**Cu** ppm	**Fe** %	**Li** ppm	**Mn** ppm	**Mo** ppm	**Ni** ppm	**Pb** ppm	**V** ppm	**Zn** ppm
UTF96-1 0-5'	Till												
UTF96-1 5-10'	Till	0.6	<0.2	10	21	2.60	42	190	5	26	13	92	68
UTF96-1 10-15'	Till	0.4	<0.2	11	22	3.10	40	303	6	27	13	85	72
UTF96-1 15-20'	Till	0.2	<0.2	12	23	2.80	48	245	3	27	12	92	75
UTF96-1 20-25'	Till	0.3	0.2	11	22	2.60	46	231	3	26	13	93	74
UTF96-1 25-30'	Till	0.4	<0.2	11	23	2.70	45	240	3	26	14	87	80
UTF96-1 25-30'	Till	0.4	<0.2	11	23	2.70	40	243	7	26	13	85	74
UTF96-1 30-35'	Till	0.2	<0.2	11	24	2.60	46	246	2	27	13	91	79
UTF96-1 35-40'	Till	0.2	<0.2	12	23	2.80	48	243	5	28	13	90	81
UTF96-1 40-45'	Till	0.3	0.2	10	25	2.70	43	240	4	28	12	92	86
UTF96-1 45-50'	Till	0.3	0.2	10	23	2.60	40	239	6	26	15	91	79
UTF96-1 50-55'	Till	0.2	<0.2	12	24	2.70	40	252	5	28	13	93	78
UTF96-1 65-70'	Till	0.2	<0.2	10	22	2.50	37	240	4	24	14	82	74
UTF96-1 80-85'	Till	0.2	<0.2	10	20	2.30	38	210	3	24	14	74	66
UTF96-1 85-90'	Till	0.4	<0.2	8	20	2.50	37	230	6	22	14	72	67
UTF96-1 90-95'	Till	<0.2	<0.2	9	21	2.50	41	221	6	25	14	74	68
UTF96-1 95-100'	Till	0.2	<0.2	11	23	2.60	45	225	5	27	14	87	70
UTF96-1 115-120'	Till	<0.2	<0.2	11	25	2.50	44	230	6	29	13	82	77
UTF96-1 130-135'	Till	0.3	<0.2	12	24	2.50	40	254	7	25	16	76	77
UTF96-1 140-145'	Till	0.2	<0.2	7	16	1.90	31	190	4	19	10	54	52
UTF96-1 145-150'	Till	0.3	<0.2	10	19	2.40	36	243	3	21	14	68	68
UTF96-1 155-160'	Till	<0.2	0.2	14	24	2.70	40	300	4	29	13	85	84
UTF96-2 0-5'	Till	<0.2	<0.2	12	21	3.00	43	201	3	28	12	94	74
UTF96-2 5-10'	Till	0.2	<0.2	10	19	2.50	37	185	5	22	13	89	72
UTF96-2 10-15'	Till	<0.2	<0.2	10	19	2.30	34	174	3	22	11	81	73
UTF96-2 15-20'	Till	0.2	<0.2	11	20	2.40	37	223	7	26	12	84	77
UTF96-2 20-25'	Till	0.2	<0.2	11	21	2.40	32	220	4	23	12	82	72
UTF96-2 20-25'	Till	<0.2	<0.2	10	20	2.40	36	224	4	24	12	81	71
UTF96-2 25-30'	Till	0.2	0.2	9	17	2.00	32	185	4	21	12	65	58
UTF96-2 30-35'	Till	0.3	0.2	10	20	2.30	38	220	5	22	13	79	73
UTF96-2 35-40'	Till	0.4	<0.2	12	21	2.60	53	234	6	25	12	84	73
UTF96-2 40-45'	Till	0.2	0.2	10	19	2.20	37	207	7	21	10	72	70
UTF96-2 45-50'	Till	<0.2	<0.2	9	19	2.10	40	190	6	21	11	76	67
UTF96-2 50-55'	Till	0.2	0.2	12	24	2.30	44	213	7	25	12	98	81
UTF96-2 60-65'	Till	0.2	<0.2	11	24	2.40	45	210	7	26	13	99	84

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

Borehole Sample Depth	Lithology	AGS Lab#	Depth Interval (m)	%Sand (>63)	%Silt (<63)	%Clay (<4)	%Sand (>50)	%Silt (<50)	%Clay (<2)	%1-2mm Sand	Wgt. % Total CaCO3	Volume CO2	Ca/Do Ratio
UTF96-2 65-70'	Till	97G 053	19.5-21	31.3	36.5	32.2	33.5	43.8	22.7	0.50	2.7	6.4	0.54
UTF96-2 70-75'	Till	97G 054	21-22.5								2.7	6.4	0.54
UTF96-2 75-80'	Till	97G 055	22.5-24	25.7	31.1	43.2	27.0	41.1	31.9	0.80	2.5	5.9	0.60
UTF96-2 85-90'	Till	97G 056	26-27.5								2.5	5.9	0.60
UTF96-2 90-95'	Till	97G 057	27.5-29								2.3	5.5	0.48
UTF96-2 95-100'	Till	97G 058	29-30.5								2.3	5.5	0.63
UTF96-2 210-215'	Till	97G 059	64-65.5								2.3	5.5	0.48
UTF96-4 0-5'	Lacustrine Diamicton	97G 060	0-1.5								6.8	16.3	0.23
UTF96-4 5-10'	Lacustrine Diamicton	97G 061	1.5-3								4.7	11.1	0.25
UTF96-4 10-15'	Lacustrine Diamicton	97G 062	3-4.5								6.1	14.6	0.16
UTF96-4 15-20'	Lacustrine Diamicton	97G 063	4.5-6								8.1	19.6	0.10

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

		Becquerel Geochemistry Data																				
Borehole Sample Depth	Lithology	Weight gms	Au ppb	Sb ppm	As ppm	Ba ppm	Br ppm	Cd ppm	Ce ppm	Cs ppm	Cr ppm	Co ppm	Eu ppm	Hf ppm	Ir ppb	Fe %	La ppm	Lu ppm	Mo ppm	Ni ppm	Rb ppm	Sm ppm	Sc ppm
UTF96-2 65-70'	Till	27.14	3	0.7	11.0	520	1.2	-5	73	4.5	62	16	-1	6	-50	2.9	30	-0.2	1	-10	70	6.5	8.8
UTF96-2 70-75'	Till	29.46	-2	0.7	11.0	590	1.7	-5	81	5.2	73	15	1	6	-50	3.1	34	-0.2	2	30	74	7.2	11.0
UTF96-2 75-80'	Till	19.86	5	0.8	11.0	570	1.5	-5	87	5.1	82	15	1	7	-50	3.1	36	-0.2	2	-10	82	7.5	11.0
UTF96-2 85-90'	Till	27.17	4	0.7	11.0	590	1.5	-5	74	4.0	85	14	1	5	-50	3.0	32	-0.2	1	24	65	6.9	10.0
UTF96-2 90-95'	Till	27.65	-2	0.6	10.0	490	1.3	-5	70	3.2	58	10	-1	8	-50	2.6	30	0.3	2	22	57	6.3	8.4
UTF96-2 95-100'	Till	28.73	-2	0.6	10.0	530	1.4	-5	70	2.5	51	10	-1	9	-50	2.6	31	-0.2	2	27	56	6.4	7.7
UTF96-2 210-215'	Till	27.34	-2	0.6	8.7	540	1.9	-5	62	3.6	66	9	1	7	-50	2.3	28	0.2	2	19	58	5.8	7.8
UTF96-4 0-5'	Lacustrine Diamicton	30.00	-2	0.6	7.9	490	1.9	-5	70	3.4	70	10	-1	6	-50	2.9	28	0.3	1	21	59	6.2	8.8
UTF96-4 5-10'	Lacustrine Diamicton	19.96	-2	0.5	7.3	510	1.1	-5	83	3.4	74	8	1	5	-50	2.5	34	-0.2	1	-10	67	6.6	8.8
UTF96-4 10-15'	Lacustrine Diamicton	28.44	-2	0.5	6.9	500	0.8	-5	67	3.5	71	7	1	5	-50	2.1	29	-0.2	-1	27	63	5.7	8.8
UTF96-4 15-20'	Lacustrine Diamicton	23.85	-2	0.6	11.0	540	0.8	-5	56	4.3	71	13	-1	6	-50	3.0	28	-0.2	-1	42	67	6.0	10.0

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

Borehole Sample Depth	Lithology	Se ppm	Ag ppm	Na %	Ta ppm	Te ppm	Tb ppm	Th ppm	Sn ppm	W ppm	U ppm	Yb ppm	Zn ppm	Zr ppm
UTF96-2 65-70'	Till	-5	-2	0.37	1.0	-10	0.8	10.0	-100	19	4.0	1	-100	-200
UTF96-2 70-75'	Till	-5	-2	0.43	0.8	-10	0.8	12.0	-100	2	4.1	1	-100	220
UTF96-2 75-80'	Till	-5	-2	0.42	0.9	-10	1.0	12.0	-100	2	4.4	2	-100	360
UTF96-2 85-90'	Till	-5	-2	0.40	1.1	-10	1.0	10.0	-100	1	3.9	2	-100	260
UTF96-2 90-95'	Till	-5	-2	0.45	0.7	-10	0.7	10.0	-100	4	3.7	1	-100	220
UTF96-2 95-100'	Till	-5	-2	0.50	0.9	-10	0.7	10.0	-100	2	3.9	1	-100	470
UTF96-2 210-215'	Till	-5	2	0.41	-0.5	-10	0.6	9.4	-100	5	3.6	2	-100	330
UTF96-4 0-5'	Lacustrine Diamicton	-5	-2	0.48	0.5	-10	0.8	9.2	-100	1	2.7	1	-100	-200
UTF96-4 5-10'	Lacustrine Diamicton	-5	-2	0.48	0.8	-10	0.7	11.0	-100	-1	2.5	1	-100	270
UTF96-4 10-15'	Lacustrine Diamicton	-5	-2	0.48	0.5	-10	0.7	9.1	-100	-1	3.8	1	-100	250
UTF96-4 15-20'	Lacustrine Diamicton	-5	-2	0.44	0.8	-10	0.7	10.0	-100	1	4.2	1	-100	240

Table A3-1:Laboratory analyses of Quaternary sedimentary units, Birch Channel study area.

		CanTech Geochemistry Data											
Borehole Sample Depth	**Lithology**	**Ag** ppm	**Cd** ppm	**Co** ppm	**Cu** ppm	**Fe** %	**Li** ppm	**Mn** ppm	**Mo** ppm	**Ni** ppm	**Pb** ppm	**V** ppm	**Zn** ppm
UTF96-2 65-70'	Till	0.2	<0.2	14	21	2.50	43	256	7	25	11	95	84
UTF96-2 70-75'	Till	<0.2	<0.2	12	25	2.50	46	224	6	28	12	98	85
UTF96-2 75-80'	Till	0.2	<0.2	12	26	2.60	50	230	5	27	15	101	84
UTF96-2 85-90'	Till	0.2	<0.2	12	23	2.70	44	264	4	31	16	84	99
UTF96-2 90-95'	Till	<0.2	0.2	10	19	2.10	39	208	4	23	13	69	64
UTF96-2 95-100'	Till	<0.2	0.2	9	20	2.20	37	215	5	20	13	65	68
UTF96-2 210-215'	Till	0.2	<0.2	9	22	1.90	34	160	4	20	12	70	65
UTF96-4 0-5'	Lacustrine Diamicton	<0.2	<0.2	9	21	3.20	46	231	3	27	11	85	64
UTF96-4 5-10'	Lacustrine Diamicton	<0.2	<0.2	9	19	2.50	52	185	4	23	12	80	58
UTF96-4 10-15'	Lacustrine Diamicton	0.2	0.2	10	21	2.30	53	170	2	29	12	87	68
UTF96-4 15-20'	Lacustrine Diamicton	0.2	<0.2	12	21	3.10	52	234	3	37	11	100	76

A3-2. Till matrix geochemistry, analytical methods and detection limits.

Element	Method	Detection Limit
Ag - Silver	AA/Total digestion	0.2 ppm Ag
Cd - Cadmium	AA/Total digestion	0.2 ppm Cd
Co - Cobalt	AA/Total digestion	2 ppm Co
Cu - Copper	AA/Total digestion	2 ppm Cu
Fe - Iron	AA/Total digestion	0.02% Fe
Li - Lithium	AA/Total digestion	1.0 ppm Li
Mn - Manganese	AA/Total digestion	5 ppm Mn
Mo - Molybdenum	AA/Total digestion	2 ppm Mo
Ni - Nickel	AA/Total digestion	2 ppm Ni
Pb - Lead	AA/Total digestion	2 ppm Pb
V - Vanadium	AA/Total digestion	5 ppm V
Zn - Zinc	AA/Total digestion	2 ppm Zn
Ag - Silver	NA	2 ppm Ag
As - Arsenic	NA	0.5 ppm As
Au - Gold	NA	2 ppb Au
Ba - Barium	NA	50 ppm Ba
Br - Bromine	NA	0.5 ppm Br
Cd -Cadmium	NA	5 ppm Cd
Ce - Cerium	NA	5 ppm Ce
Co - Cesium	NA	5 ppm Co
Cr - Chromium	NA	20 ppm Cr
Cs - Cobalt	NA	0.5 ppm Cs
Eu - Europium	NA	1 ppm Eu
Fe - Iron	NA	0.2% Fe
Hf - Hafnium	NA	1 ppm Hf
Ir - Iridium	NA	50 ppm Ir
La - Lanthanum	NA	2 ppm La
Lu - Lutetium	NA	0.2 ppm Lu
Mo - Molybdenum	NA	1 ppm Mo
Na - Sodium	NA	0.02% Na
Ni - Nickel	NA	10 ppm Ni
Rb - Rubidium	NA	5 ppm Rb
Sb - Antimony	NA	0.1 ppm Sb
Sc - Scandium	NA	0.2 ppm Sc
Se - Selenium	NA	5 ppm Se
Sm - Samarium	NA	0.1 ppm Sm
Sn - Tin	NA	100 ppm Sn
Ta - Tantalum	NA	0.5 ppm Ta
Tb - Terbium	NA	0.5 ppm Tb
Te - Tellurium	NA	10 ppm Te
Th - Thorium	NA	0.2 ppm Th
U - Uranium	NA	0.2 ppm U
W - Tungsten	NA	1 ppm W
Yb - Ytterbium	NA	1 ppm Yb
Zn - Zinc	NA	100 ppm Zn
Zr - Zirconium	NA	200 ppm Zr