Chapter 26 – Quaternary Geology of the Western Plains

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Introduction

This chapter focuses primarily on the Quaternary-age sediment in the area bounded by the Canadian Shield in the northeast, the disturbed belt in the west, the 49th parallel in the south, and the 60th parallel in the north (Fig. 26.1). However, because the regional isopach map encompasses all the unconsolidated sediment above the bedrock, including stratified sediment between the lowermost till and the bedrock, some older sediment of Late Tertiary age is also incorporated. This is particularly true in the deeper portions of preglacial valleys. This preglacial sediment is discussed in the section illustrating the subregional relations.

Previous Work

Investigation of the Quaternary sediments of Western Canada began with the early expeditions to the region during the 1800s. Early publications include Dawson (1875, 1885, 1898), Dawson and McConnell (1895), McConnell (1885), and Tyrrell (1887). Recent papers include those by Klassen (1989), Fenton (1984), Fulton et al. (1984), and Fullerton and Colton (1986, this paper focuses on Montana). Works by Klassen (1989), Dyke and Prest (1987) and Prest (1984) provide additional information on the Late Wisconsinan and Holocene history of the area.

Geological Framework

The Quaternary sediments of the Interior Plains were deposited on nearly flat-lying sedimentary rocks consisting largely of a narrow belt of Paleozoic carbonates subcropping along the edge of the Shield, poorly consolidated sandstones of Late Cretaceous and Early Tertiary age subcropping along its western margin, and Cretaceous shales in the central area (Green, 1972; Whitaker and Pearson, 1972; Manitoba Mineral Resources Division, 1979).

The Quaternary sediment covering the Interior Platform is of glacial, fluvial, lacustrine, aeolian and organic origin. The majority of the sediment is till (glacial diamicton), with lacustrine sediment the next most abundant. The sediment deposited directly by the glaciers consists primarily of till. One of the most noticeable properties of this sediment is the presence of clasts of Precambrian and Paleozoic bedrock that have been glacially transported from the east and north. The till can be subdivided into a number of units or facies (see for example Proudfoot, 1985, and Mougeot, 1991). The sediment deposited beyond the glaciers and during the nonglacial intervals is predominantly stratified material of lacustrine and fluvial origin, ranging from gravel to clay (Teller and Clayton, 1983).

The tills are generally massive and therefore form aquitards. The stratified units form aquifers where coarse grained and aquitards where fine grained. Overall, the Quaternary stratigraphy consists of a series of till aquitards confining aquifers composed of comparatively coarse-grained stratified sediment. In areas of thick sediment, these aquifers are a major source of groundwater. The Quaternary sediments also provide a major portion of the aggregate and fill used in the plains.

The Interior Plains comprise a variety of terrain types of which about 70 percent are of glacial origin and 20 percent lacustrine origin. The glacial terrain can again be divided into a number of terrain types, all of which can be recognized on airphotos. Each type is characterized by certain sediments (Prest, 1970; Clayton et al., 1980; Mougeot, 1991).

Stratigraphy

Stratigraphic Nomenclature

Quaternary stratigraphy and nomenclature has been described in the review and synthesis paper by Klassen (1989). Other relevant papers include those by Fenton (1984) and Fulton et al. (1984). A review and synthesis by Fullerton and Colton (1986) focusing on the Quaternary stratigraphy of the adjacent Montana Plain includes discussion of the correlations with Quaternary units in adjacent areas of Alberta and Saskatchewan. The paper by Clayton and Moran (1982) focuses on the North Dakota, Minnesota, Manitoba, and Saskatchewan regions.

The stratigraphic nomenclature for southern and central Saskatchewan is undergoing significant revision (Christiansen, pers. comm., 1991), with the definition of a number of new units being considered. Therefore the current version of the stratigraphy, reviewed in the above papers, is not repeated here.

The till units can be identified and traced or correlated over extensive areas, both on the surface and in the subsurface, on the basis of texture, mineralogy, geochemistry, petrology, stratigraphic position, and geophysical log signature (Andriashek and Fenton, 1989; Christiansen, 1968 a,b; Klassen, 1979; Shetsen, 1984; and Schreiner, 1990). Problems concerning the regional Quaternary stratigraphy have been discussed by the authors mentioned in the preceeding paragraphs.

Stratigraphic History

Fenton (1984) summarized the basic history of the region. Prior to glaciation the plains consisted of broad, northeast- and southeast-trending valleys separated by low uplands. Stream deposits in the valleys consisted predominantly of quartz sand and gravel dominated by clasts of resistant quartzite, argillite and chert derived from the Cordillera or reworked, by glacial or fluvial processes, from older Tertiary and Cretaceous deposits.

The Laurentide glaciers advanced across the plains at least five times (Klassen, 1989; Fenton, 1984). Investigations indicate the earliest was likely prior to 1.8 Ma, when the glacier advanced at least into southwestern Saskatchewan (Barendregt, 1985; Foster and Stalker, 1976; Klassen 1989; Fenton, 1984). Each advance and subsequent melting resulted in the deposition of glacial and nonglacial units rich in igneous and metamorphic rock fragments derived from the Precambrian Shield, and carbonate fragments excavated from the adjacent belt of Paleozoic bedrock. The glaciers deposited units composed mainly of till, which can be correlated for many kilometres on the basis of composition, stratigraphic position and/or geophysical log characteristics.

During each ice advance the northeast drainage was dammed so that lakes developed in the valleys and depressions, and drainage was diverted to the south (Christiansen, 1979; Clayton and Moran, 1982; Teller and Clayton, 1983; Teller, 1987). During ice retreat, ice marginal lakes developed as melting took place downslope and steep-walled valleys were cut where 1) meltwater flowed from one lake basin to the next, 2) flow was channelled southward along the ice margin, and 3) drainage was re-established in sediment-filled segments of preglacial valleys. During nonglacial times, the drainage commonly followed the preglacial valleys with, in many places, the channels cutting down into the thick sequence of sediment left behind by the retreating ice. Locally, flow was diverted from one valley system to another through trenches cut by meltwater. Stream deposits laid down during nonglacial periods in part consist of sands and gravels containing resistant pebbles similar to those deposited during preglacial times, but also include important and distinctive admixtures of material from the Precambrian Shield and the adjacent fringe of Paleozoic carbonate bedrock that had been transported westward and southward by the ice. Repeated glacial and nonglacial intervals left a complex sequence of glacial, fluvial and lacustrine sediment of different ages.

Holocene rivers cut new valleys in this complex of Quaternary sediments. The most extensive and complete sections of these Quaternary deposits are exposed in the old valley systems occupied by the South Saskatchewan River in southern Alberta and western Saskatchewan, the Qu'Appelle Valley in eastern Saskatchewan and the Assiniboine River in western Manitoba.

Regional Cross Sections and Reference Logs

Most Quaternary stratigraphic units are relatively thin and discontinuous. This attribute complicates the construction of regional cross sections similar to those shown in other chapters. Quaternary lithostratigraphic units composed of till can be correlated, using outcrop and subsurface data, within individual regions on the basis of their composition (texture, petrology, geochemistry, and mineralogy), geophysical log signature and stratigraphic position. Interprovincial correlation is accomplished primarily using data obtained from widely scattered key outcrops, and testholes and waterwells. The chronological data (absolute and relative) for correlations come from a combination of paleontological, paleomagnetic, paleoecological, and tephra studies, together with the stratigraphic position of the units.

Subsurface correlation focuses primarily on the composition (obtained from cuttings, core and auger samples) and geophysical log signature of the till units. Geophysical logs are used extensively in the correlation of Quaternary units. They are used primarily to differentiate till units from stratified units. It is not usually possible to distinguish between individual till units except within specific study areas. Therefore reference logs typical of the Quaternary units for the entire basin are not included. The section dealing with subregional relations provides an example of the use of geophysical logs and lithological properties to aid in identifying different Quaternary formations within an individual study area.

Maps

Topography Map

The surface topography map (Fig. 26.1) was produced at the Saskatchewan Research Council by contouring remotely sensed data spaced at 5 intervals. The land slopes toward the north and east from elevations of 1200 m in the foothills, adjacent to the Rocky Mountains, to 200 m at Lake Winnipeg, Manitoba and Lake Athabasca, Alberta and Saskatchewan.

The map shows the basic physiographic features of the Interior Plains. These features include: 1) the three prairie "steps" – the Manitoba Plain, the Saskatchewan Plain and the Alberta Plain (the latter extending only as far north as approximately the Athabasca River) and the Peace River Lowland; 2) the step margins – the Manitoba Escarpment and the Missouri Coteau; and 3) the major topographic highs – Turtle Mountain, Riding Mountain, Duck Mountain and Porcupine Hills in Manitoba; the Pasquia Hills, Wapawekka Hills, Moose Mountain, Wood Mountain and Cypress Hills in Saskatchewan; and the Swan Hills, Pelican Mountains, Buffalo Head Hills, Clear Hills, Milligan Hills (Pettapiece, 1986), Birch Mountains, Caribou Mountains, and Cameron Hills in Alberta. Additional information on these features can be found in Bostock (1970 a,b) and Klassen (1989, Fig 2.16).

Comparing this map to the bedrock topography map discussed in the next section reveals how strongly the surface topography, particularly the positive features, are influenced by the bedrock topography.

Bedrock Topography

Introduction

Unlike the maps for the other chapters of this Atlas, the plains-wide maps for the Quaternary Chapter, the bedrock topography map (Fig. 26.2) and the isopach of top of bedrock to surface (Fig. 26.3), were not produced by computer contouring of the picks from the Atlas database. Information on the production of these maps can be found in Dyck and Schreiner (*in press*). Briefly, the Alberta portion of these maps was produced by digitizing the data from existing sources, primarily the Alberta Research Council 1:250 000 scale bedrock topography series and the groundwater map series, together with, for the northern portions of Alberta where no maps existed, picks from selected water and petroleum wells. The Saskatchewan and Manitoba portions of the bedrock topography maps were produced by computer contouring of test hole picks and information digitized from the 1:250 000 bedrock maps supplied by the Saskatchewan Research Council and the Manitoba Mines Branch, to form a combined database. The digital information for the Alberta portion of this map was subsequently added to the database to yield the final map. The isopach map of bedrock top to surface was constructed by subtraction of the bedrock topography map from the surface topography map. A check of this method was made by comparing the final map to earlier isopach maps prepared by hand for various portions of the area.

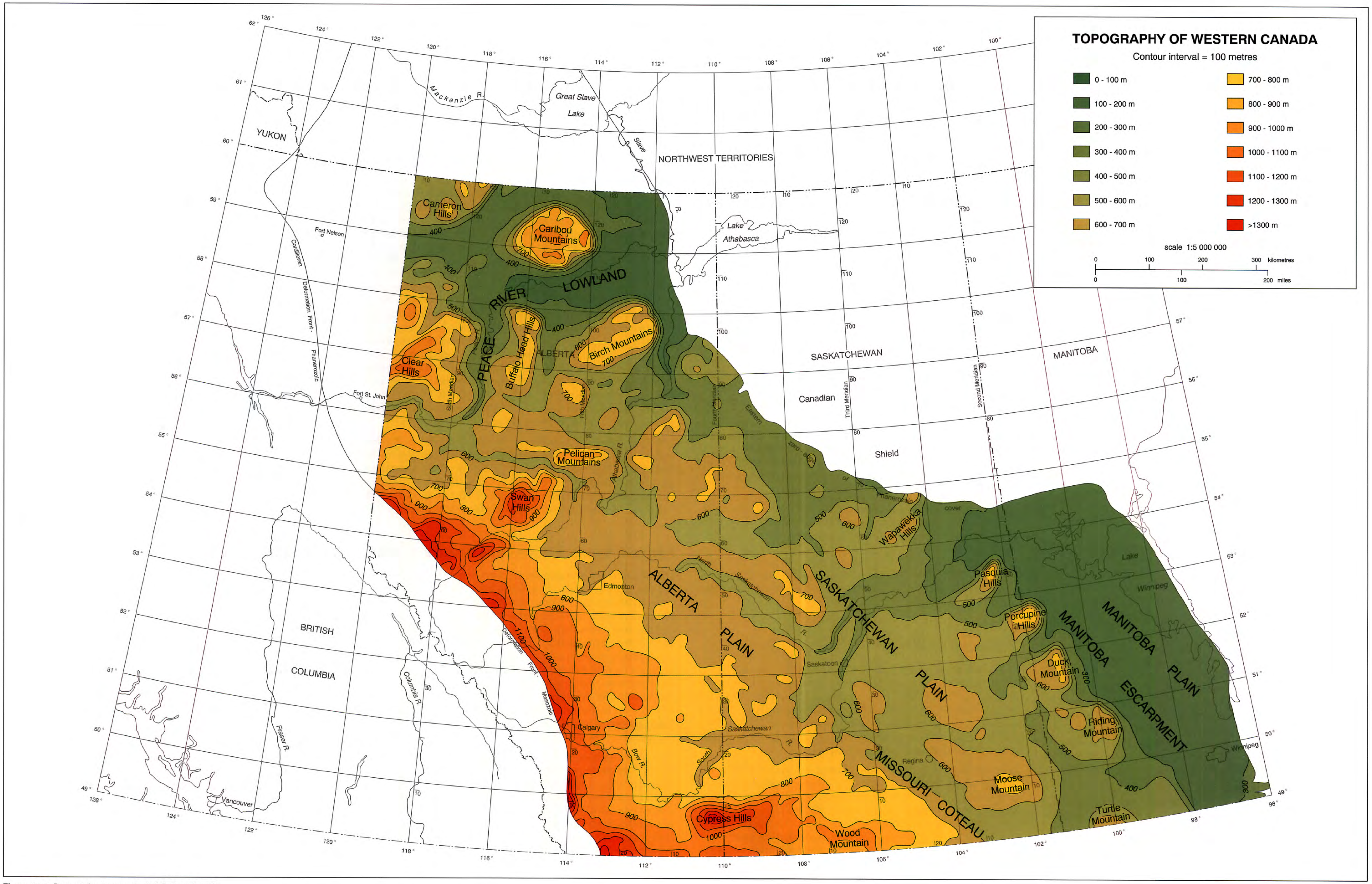

Figure 26.1 Present-day topography in Western Canada.

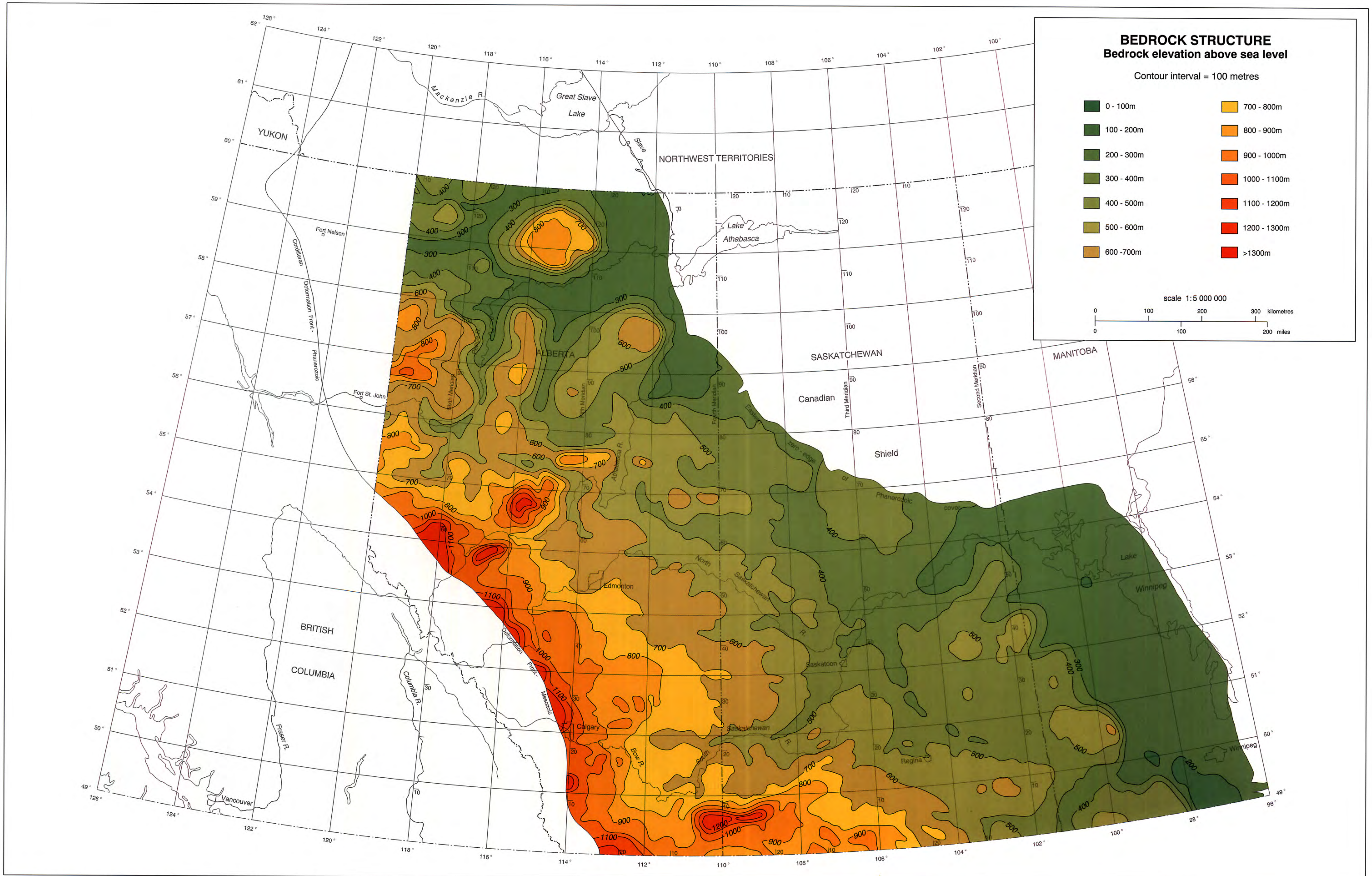

Figure 26.2 Bedrock structure map (bedrock topography map) of Western Canada.

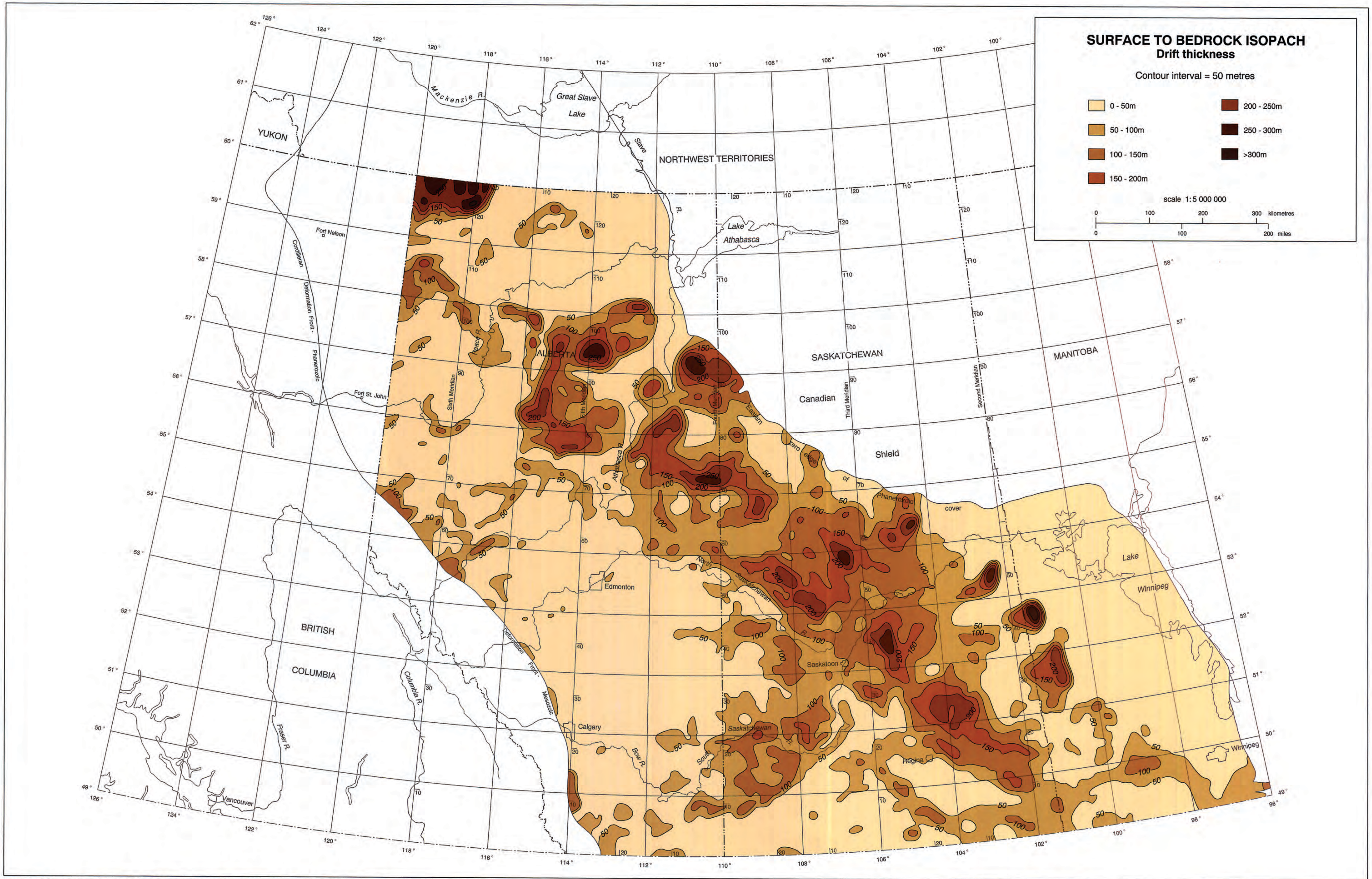

Figure 26.3 Isopach map of the interval from the present-day land surface to the top of bedrock (drift thickness).

Map Features

The bedrock topography (Fig. 26.2) is drawn on the surface of the bedrock underlying the unconsolidated Quaternary-age sediment and, mainly in the deep portions of the preglacial channels, unconsolidated sediment of late Tertiary age.

This map shows three basic topographic elements: the broad generally northeast- and southeast-trending valleys; uplands formed by erosional bedrock remnants; and between these two elements, broad, relatively level interfluve areas.

The bedrock topography map shows that most of the positive landforms shown on the surface topography map (Fig. 26.1) are bedrock controlled. Bedrock highlands contribute significantly to the Manitoba Escarpment, Turtle Mountain, Riding Mountain, Duck Mountain, and Porcupine Hills in Manitoba; the Pasquia Hills, Moose Mountain, Wood Mountain, and Cypress Hills in Saskatchewan; and the Swan Hills, Pelican Mountains, Buffalo Head Hills, Clear Hills, Milligan Hills, Birch Mountains, and Caribou Mountains in Alberta. Note however that in the vicinity of the Cameron Hills (Fig. 26.1, northwest Alberta) the bedrock high is much less extensive than is the surface expression of these hills.

The topographic lows are primarily the major preglacial valleys. The presence of preglacial sediment at the base of the valley-fill sediment indicates that these valleys were eroded during preglacial time. They are most easily recognizable in western Manitoba, south and central Saskatchewan, and northern Alberta, and generally trend northeast or southeast. The most obvious preglacial valley is the Hatfield Valley, which trends southeast across central Saskatchewan. Others include the Tyner Valley, which trends northeast from southeastern Alberta under the present South Saskatchewan River and passes north of Saskatoon, and the northeast-trending valleys in northern Alberta underlying the modern Peace River and Wabasca River.

Land Surface to Bedrock Isopach (Drift Thickness Map)

The isopach map of the interval from the land surface to the top of bedrock (Fig. 26.3) shows the thickness of unconsolidated sediment overlying the bedrock. It includes sediment of both late Tertiary and Quaternary age, although Quaternary sediment forms the major portion of the sequence. The Tertiary sediment is confined largely to the lower parts of the preglacial channels (see Dawson et al., *this volume*, Chapter 24). This grouping of map units was chosen for Atlas mapping purposes because deposition within the valleys was more or less continuous from the close of the Tertiary into the Quaternary. That is, the deposition of nonglacial fluvial sediment continued until the preglacial drainageways were first blocked by the earliest glacial advance. The first stratigraphic marker positively identifying Quaternary sediment, at any particular site, is the stratigraphically lowest appearance of till and/or stratified sediment containing 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.

Figure 26.3 was produced by subtraction of the grid for the surface topography from that for the bedrock topography. This figure, like the other two maps in this chapter, shows only the regional trends. Local areas where the sediment may be comparatively thick or thin are not shown. The preceding section describing the bedrock topography map provides additional information on the preparation of this map.

Sediment thickness varies from 300 m in a few preglacial valleys to zero on some of the interfluves and highlands. In general, a broad northwest-southeast-trending band of thick sediment lies southwest of the Precambrian Shield and a northeast-trending band of thick sediment is present in southwestern Saskatchewan (Fig. 26.3). Bedrock lows, primarily preglacial channels, have been substantially filled, thus subduing the local relief on the present land surface.

Areas of thick sediment include: Duck Mountain and Porcupine Hills in Manitoba; the Pasquia Hills in Saskatchewan; and the Birch Mountains and Cameron Hills in Alberta. Areas where Quaternary sediment is thin or absent include Wood Mountain (Saskatchewan), the Cypress Hills (Saskatchewan and Alberta); and the Swan Hills, Clear Hills, and Milligan Hills (Alberta).

Factors influencing the location of thick accumulations of sediment are: 1) the preglacial valleys, 2) bedrock highlands and remnants, 3) areas of ice marginal stillstands, and 4) bedrock contacts or scarps. An example of thick sediment accumulation in a preglacial channel occurs in the southeast-trending channel shown in southern Saskatchewan east of 106°W (Fig. 26.3). These valleys influenced deposition in a number of ways. They acted as sediment traps, accumulating thick sequences of stratified sediment as the advancing or retreating glaciers dammed the eastward-flowing streams; they influenced glacial dynamics, contributing to the accumulation and preservation of comparatively thick sequences of till within them; during the nonglacial intervals, they formed lows favorable to the deposition of stratified sediment; and, because of their low position in the landscape, they tended to preserve the existing sediment from erosion during subsequent glacial advances.

Examples of the influence of bedrock highlands occur on the tops of features such as Duck Mountain and the Porcupine Hills in Manitoba, the Pasquia Hills in Saskatchewan, and the Birch Mountains in Alberta. Thick accumulations of sediment were deposited on each by the southward- and westward-flowing glaciers.

The effect of deposition at an ice marginal stillstand is shown in the Cameron Hills in northwestern Alberta. The hills are believed to have originated through buildup of a thick succession of Quaternary sediment, rather than through draping over a bedrock upland. Similarly, an arc of comparatively thick sediment trending northwestward from the prominent point on the west shore of the northwest coast of Lake Winnipeg defines a glacial moraine known as the Pas End Moraine (Dyke and Prest, 1986).

Bedrock contacts or scarps are areas where glaciers deformed the bedrock and stacked comparatively thick accumulations of thrusted bedrock and glacial sediment. Southwest of Regina, for example, a northwest-trending series of relatively thick accumulations (Fig. 26.3) represents glacial disturbance of the bedrock along the edge of the Missouri Coteau. Two of the thrust masses form the Dirt and Cactus hills, features which, although they are too small to show on the surface topography map (Fig. 26.1) are shown in Whitaker and Pearson (1972). The Neutral Hills, Misty Hills and Mud Buttes in central-eastern Alberta (Green, 1972), are other examples of glaciotectonism. These three thrust masses were formed at the contact of the Belly River and Bearpaw formations.

Subregional Relations: Sand River Region

On a subregional scale, the Quaternary deposits of the plains can be characterized and mapped in considerable detail, given sufficient subsurface control. The Sand River area (Fig. 26.4), which covers much of the Cold Lake oil sands deposit, provides a representative example. The following information is taken from Andriashek and Fenton (1989).

Bedrock Topography

Bedrock topography in the Sand River region is typical of many areas on the plains: a weathered bedrock surface incised by a number of channels developed either prior to the first glacial advance or during succeeding deglaciations as ice marginal channels (Fig. 26.5). Segments of pre-existing channels were commonly reoccupied during the nonglacial intervals, resulting in the accumulation of thick and complex sequences of glacial and nonglacial deposits (Figs. 26.6, 26.7). Sediment thickness varies from about 20 to 200 m, with the thickest areas along the preglacial channels (Fig. 26.6).

The preglacial channels (Beverly, Helina, and Imperial Mills) tend to be wider, deeper, and traceable for much greater distances than the glacial channels (Moore Lake, Big Meadow, Bronson Lake and Holyoke). They also contain, in their lowest portions, nonglacial sediment lacking the characteristic clasts of crystalline and carbonate bedrock transported into the region by glaciers advancing southwestward and southward from the Precambrian Shield.

Stratigraphy

Deposition during both glacial and nonglacial events produced a complex stratigraphy composed of till (diamicton), and stratified, predominantly lacustrine and fluvial sediment in the Sand River area. Eight glacial and nonglacial formations are recognized (Fig. 26.8) on the basis of geophysical log response, composition, texture and stratigraphic position.

The Empress Formation (first defined in Saskatchewan as the Empress Group by Whitaker and Christiansen, 1972) is the oldest, and is divided into three units on the basis of lithology: Unit 1, preglacial sand and gravel; Unit 2, silt and clay; and Unit 3, glacial sand and gravel. The overlying Bronson Lake Formation consists of clayey till and clay deposited during the first glacial advance. Glaciofluvial sand and gravel of the Muriel Lake Formation were deposited on top, both during the melting of this glacier and the subsequent glacial advance. This second advance deposited till of the Bonnyville Formation, which is characterized by a relative abundance of quartz and a paucity of carbonate in both the silt-clay fraction and very coarse-grained sand fraction.

Overlying this is glaciolacustrine silt and clay of the Ethel Lake Formation, which was laid down in proglacial lakes during the next advance. Till of the Marie Creek Formation was deposited during later stages of that advance and is characterized by a relative abundance of carbonate rocks, mainly dolostone, in the silt-clay and the very coarse-grained sand fractions. Glaciofluvial sand of the Sand River Formation was deposited during the melting back of this glacier and during the subsequent advance of the last glacier. The Grand Centre Formation consists of till and glacially displaced sediment deposited during the last glacial advance into this region, which occurred during Late Wisconsinan time. The till is characterized by an abundance of igneous and metamorphic rock fragments in the very coarse-gained sand fraction. The formation is divided into four members, based mainly on grain size.

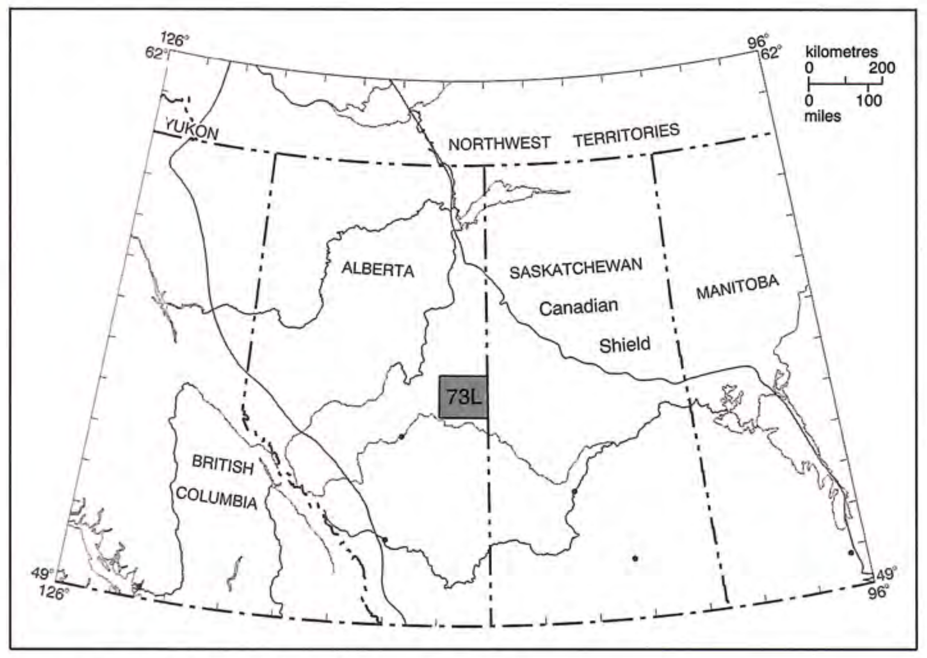

Figure 26.4 Location of Sand River map area 73L.

Quaternary stratigraphic units are normally thinner and more discontinuous than those of other ages (Figs. 26.7). Four generalizations are possible however:

1. Till units are more widespread than the stratified units (mainly lacustrine and fluvial deposits) and are therefore the units with the greatest potential for regional correlation. The cross section (Fig. 26.7; and the unit distribution maps in Andriashek and Fenton, 1989) show that the tills of the Marie Creek, Bonnyville and Grand Centre formations are more extensive than stratified units such as Units 1 and 2 of the Empress Formation, the Muriel Lake Formation and the Ethyl Lake Formation.
2. Older units are generally preserved only in the lower portions of the preglacial and interglacial valley fills – for example, the distribution of Units 1 and 2 of the Empress Formation, and the Bronson Lake Formation (Fig. 26.7).
3. The older the unit the more discontinuous the distribution – the Empress, Bronson Lake and Muriel Lake formations.
4. The till units can be discontinuous; they do not always form a blanket – for example, the distribution of the Bronson Lake and Marie Creek formations (Fig. 26.7).

Economic Geology

Quaternary deposits are considered to have significant economic and environmental importance (Fenton and Andriashek, 1980) because they are sources of quality well water, and construction-fill material and aggregate. The Sand River area provides examples illustrating the availability of groundwater and construction-fill.

The stratified sediments lying between the till units have the greatest potential to function as aquifers. The stratified units, which are composed predominantly of sand and gravel, such as Unit 1 of the Empress Formation and the Muriel Lake Formation, have a higher potential than the Ethyl Lake Formation, which is predominantly silt and clay. The local absence of a till aquiclude can result in the superimposition of aquifers that are generally separate bodies, a condition which can result in movement of water and/or contaminants from one aquifer to another.

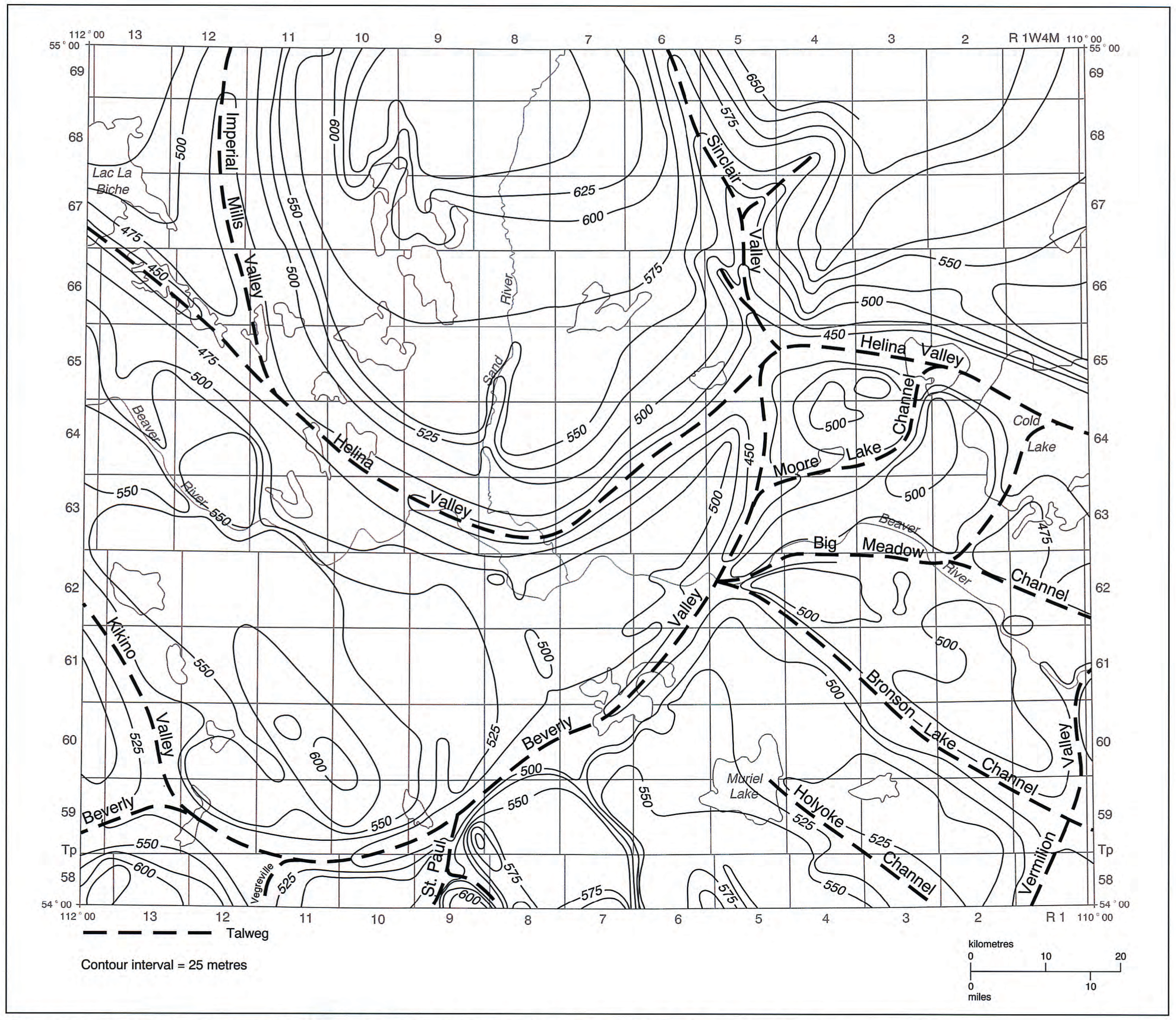

Figure 26.5 Bedrock topography of the Sand River map area (from Andriashek and Fenton, 1983). Contours are in metres above sea level.

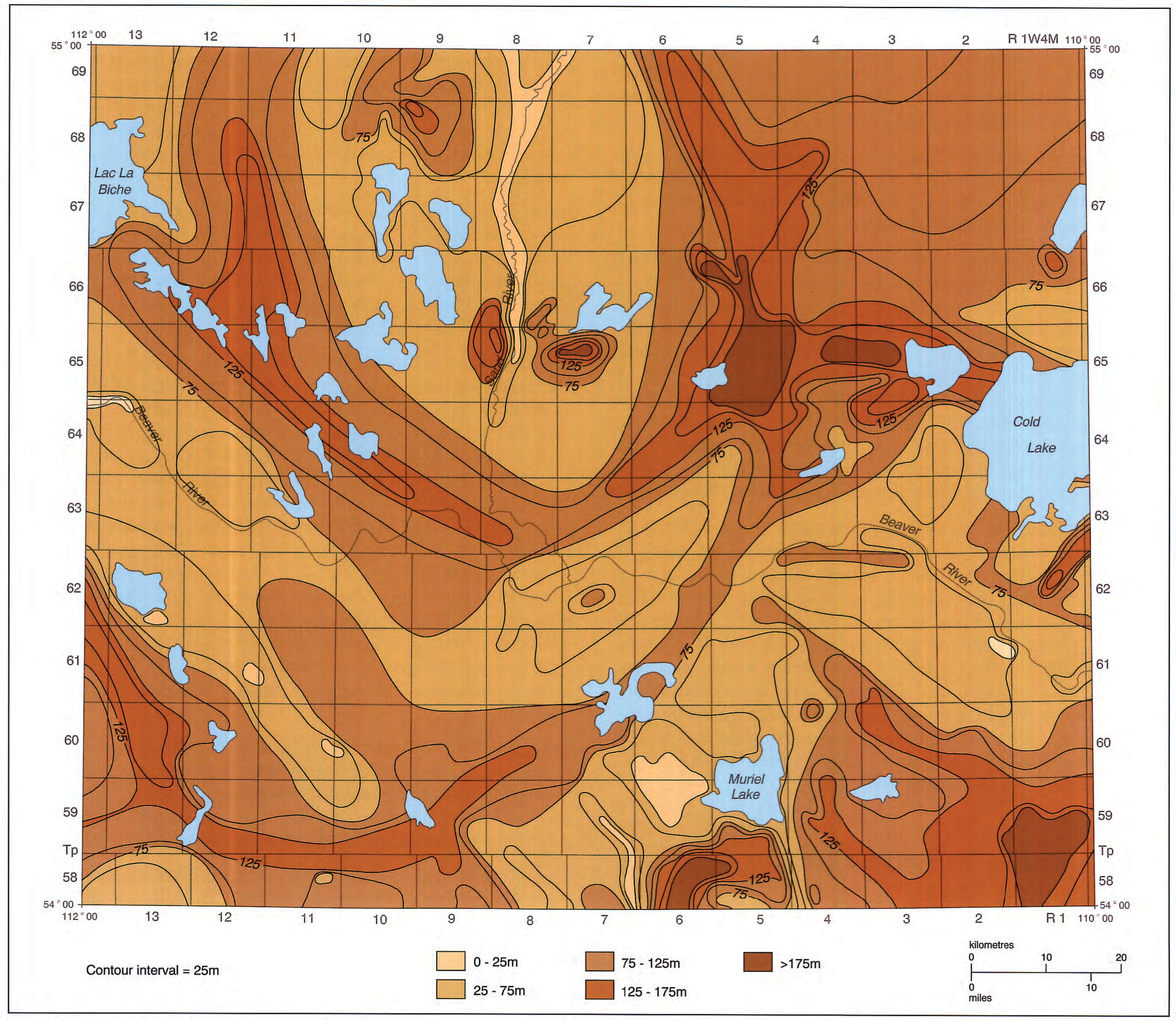

Figure 26.6 Isopach map of the interval from the present-day land surface to the top of bedrock, Sand River area (modified from Gold et al., 1983).

Till is preferable to sand, silt or clay as fill material, mainly because its well-graded grain size makes this sediment more easily excavated, emplaced, compacted, and trafficable under moist to wet conditions. Some tills are more suitable than others as fill because of differences in such properties as grain size, amount of coarse clasts, degree of consolidation, fracture density (affecting ease of excavation) and moisture content. In the eastern part of the map area, the surface till, the Grand Centre Formation, is softer, more clayey, and moister than the underlying sandy, weathered, fractured, and dense Marie Creek till. Where the Marie Creek Formation is near the surface it is the more desirable sediment. Similarly, geotechnical studies in central Saskatchewan (MacDonald and Sauer, 1970) demonstrate that the upper, soft, compressible till of the Battleford Formation (Christiansen 1968a), overlies a more suitable, very dense, hard, but fractured till in the Floral Formation.

Discussion

The bedrock succession of the Western Canadian Sedimentary Basin is capped by an alternating succession of till (diamicton) and stratified sediment deposited during the Quaternary. The stratified sediment is primarily of lacustrine and fluvial origin. This stratigraphic succession records multiple glacial and nonglacial intervals. During each nonglacial interval the ice melted back at least as far as the Precambrian Shield and at times disappeared entirely. The earliest glaciation may have occurred about 2 million years ago.

Although the broad lithostratigraphic framework is known, information at even an intermediate level is lacking in many areas. The types of information needed vary from region to region. In Alberta, for example, there is almost no information on the surficial geology nor the Quaternary stratigraphy for the northern third of the province. Also, a subsurface lithostratigraphic framework is lacking for most of the province. Comparatively comprehensive studies have been completed in some areas of each of the prairie provinces; however, correlation between these sites, which will involve primarily detailed subsurface investigations, is incomplete. A primary facet of future investigations should first be the definition of subsurface lithostratigraphic units, based primarily on the petrology, mineralogy, geochemistry, and geophysical log signatures of the till units, and subsequently, their correlation throughout the region.

Throughout the Western Canadian Sedimentary Basin the chronological framework is still very sparse. Paleoenvironmental studies on the stratified sediment lying between the till units is needed in order to provide information on the nonglacial climatic and environmental fluctuations.

The aquifers within the Quaternary succession form an important source of water for agricultural, municipal and industrial users. The presence, extent and amount of this resource must be determined to assist in sustainable resource development. The completion of the Quaternary stratigraphic framework is an essential first step.

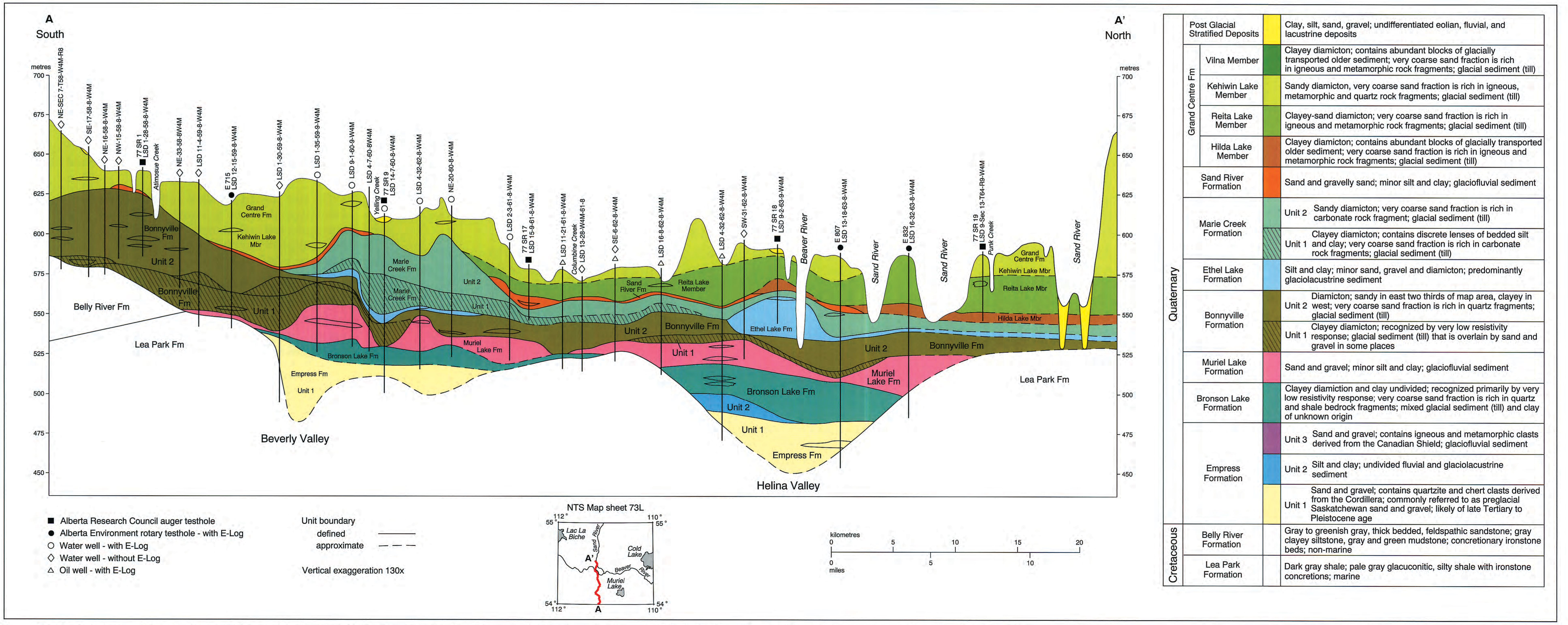

Figure 26.7 Geological cross section showing the distribution of Quaternary and late Tertiary sediment, Sand River area. Sediments consist of a series of interbedded stratified and till (diamicton) layers (from Andriashek and Fenton, 1989).

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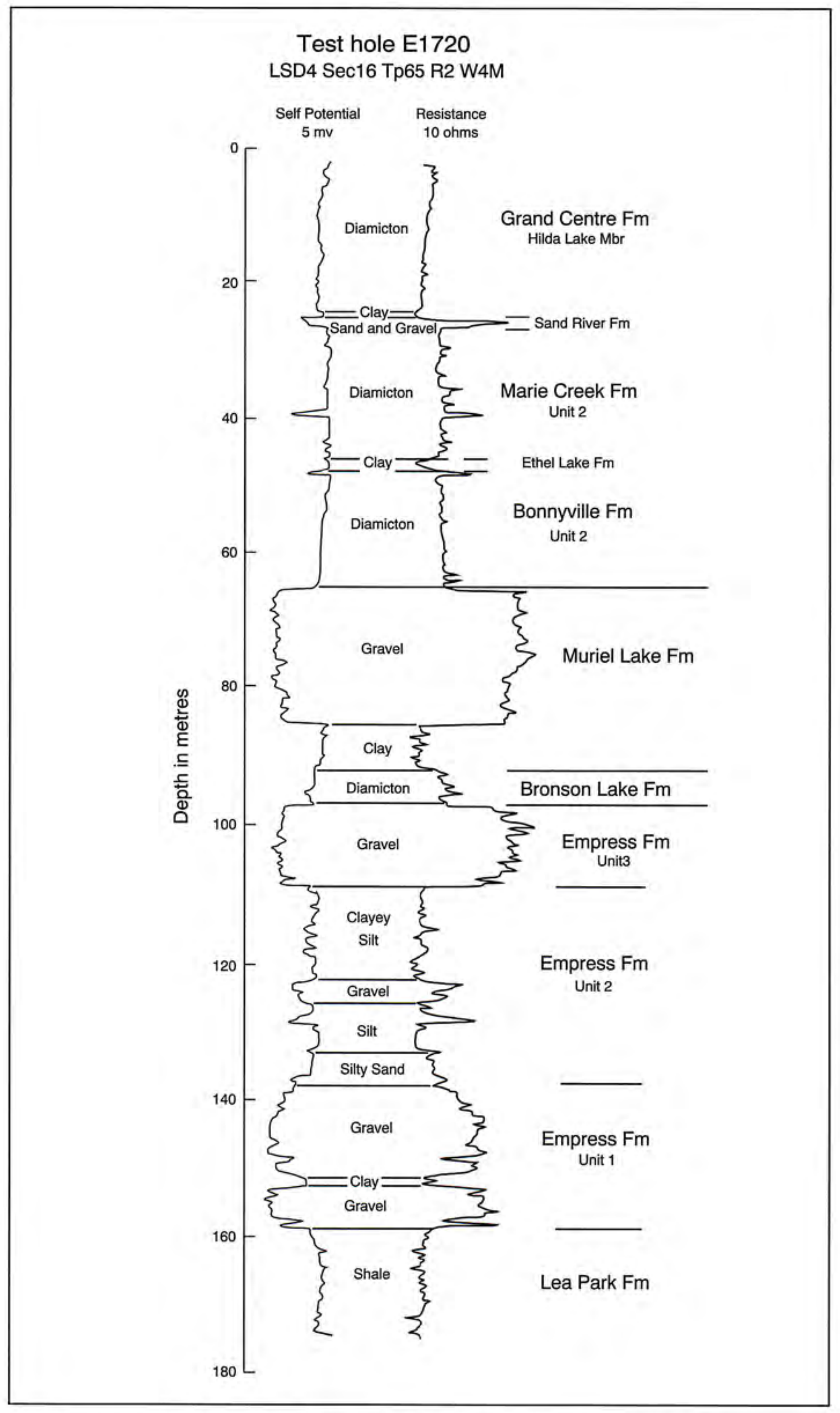

Figure 26.8 Stratigraphy and reference logs for the Sand River area (from Andriashek and Fenton, 1989).

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