GEOLOGICAL REPORT GR80-7

Surficial Geology of the Swan River Area

By E. Nielsen

Manitoba
Energy and Mines
Geological Services

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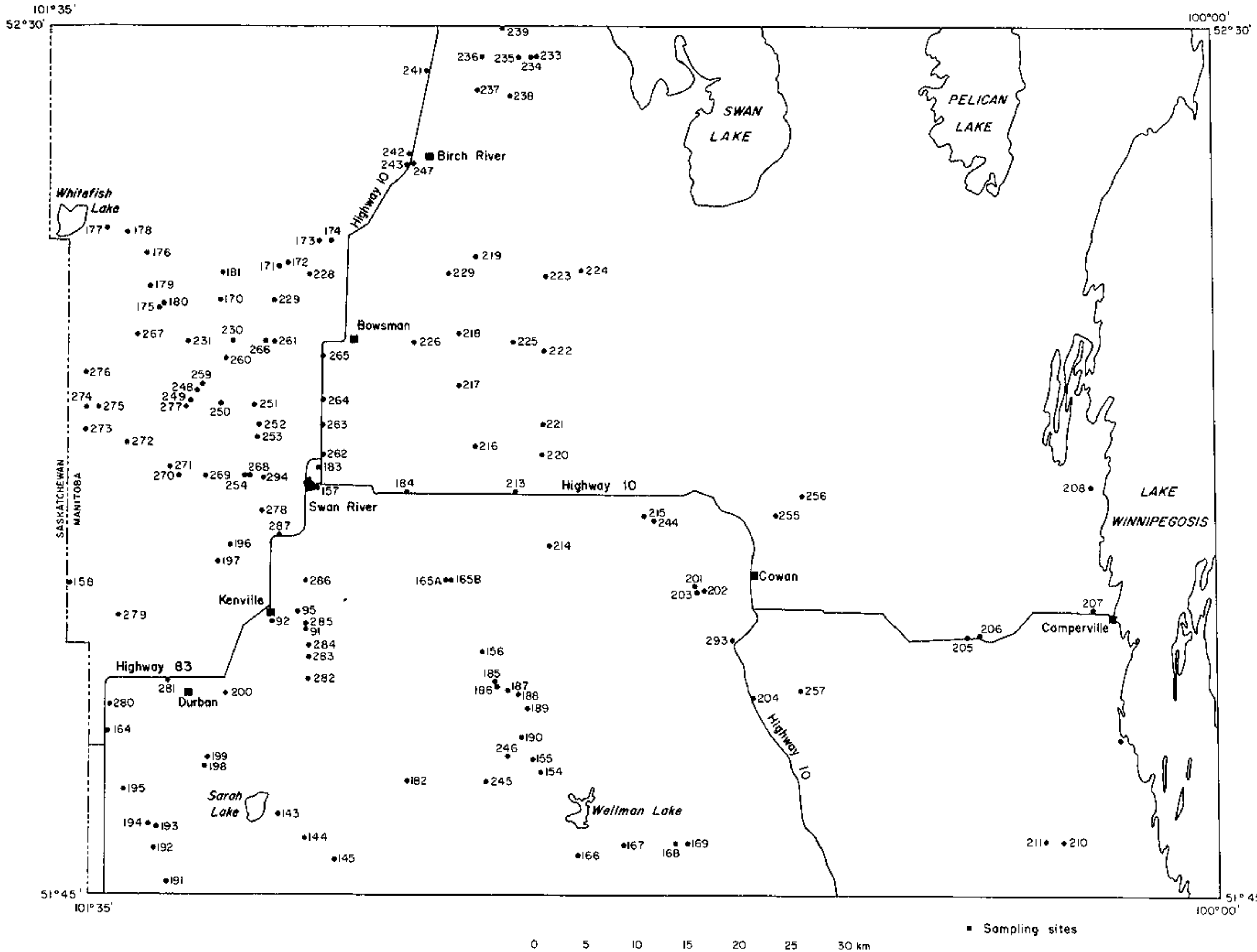


Figure 1: Location map and sampling sites.

INTRODUCTION

This report describes the Quaternary deposits in the Swan River Valley and the adjacent parts of Duck Mountain, Porcupine Hills and the Manitoba Plain (Fig. 1). The area is bounded by the Saskatchewan-Manitoba border, 100°W, 51°45'N, and 52°30'N and comprises 910 km². The town of Swan River with a population (1981) of 3,700 people is the largest community in the area. Road access is good in the Swan River Valley, which is largely a farming area. Road access is limited on Duck Mountain and Porcupine Hills and poor on the Manitoba Plain.

OBJECTIVES

The main objective of the project was to map the surficial sediments and to establish a Quaternary stratigraphy as a basis for future aggregate mapping.

METHODS OF INVESTIGATION

Mapping of the surficial sediments was accomplished by vehicle traverses along roads, and by foot traverses in areas otherwise inaccessible. Airphoto interpretation supplemented the field information in the more remote areas.

Elevations were measured with a barometric altimeter at selected sites. Detailed levelling profiles, obtained from Manitoba Department of Highways, were used to determine the exact elevations of Lake Agassiz beaches.

Sieve and pipette analyses were performed on 65 till samples using the method outlined by Folk (1968). Each till sample weighed approximately 10 kg.

The carbonate content of the less than 0.063 mm (4 phi) fraction of the till samples was determined using the Leco Induction Furnace. Pebble counts of 300 clasts were done on each of the 0, -1, -2 and -3 phi fractions of each till sample.

The fine fraction (< 63 microns) of non-till samples was analyzed by the hydrometer method to determine the percentages of sand, silt and clay.

PREVIOUS WORK

The Cretaceous bedrock of the area was mapped by Wickenden (1945), Bannatyne (1970) and, more recently, by McNeil and Caldwell (1981). Norris et al. (1982) mapped the Devonian bedrock.

Some aspects of the Quaternary geology of parts of the area have been reported by Tyrrell (1888,1891,1892), Johnston (1921,1946) and, more recently, by Elson (1961,1967), Christiansen (1979), Klassen et al. (1967), Klassen (1972,1979), Klassen et al. (1970), Ritchie (1964,1969, 1976), Nichols (1969), and Nielsen et al. (1984).

Little and Sie (1976), Little (1973), and Ehrlich et al. (1962) conducted a groundwater study and a soil survey of the Swan River region; these constitute the only studies that deal exclusively with the area.

ACKNOWLEDGEMENTS

Appreciation is extended to G. Matile and G. Conley for their help in the field and with the textural analysis and pebble counts. Dr. Wes Blake, Jr. of the Geological Survey of Canada supplied one of the radiocarbon dates from the Sclater alluvial fan. Steve Zoltai of the Canadian Forestry Service in Edmonton gave permission for use of an unpublished radiocarbon date from Duck Mountain. The Manitoba Department of Highways supplied highway profiles. The writer is also indebted to Dr. M. Wilson of the University of Calgary for identifying the bison bones, and Dr. W.B. McKillop of the Manitoba Museum of Man and Nature for identifying the molluscs.

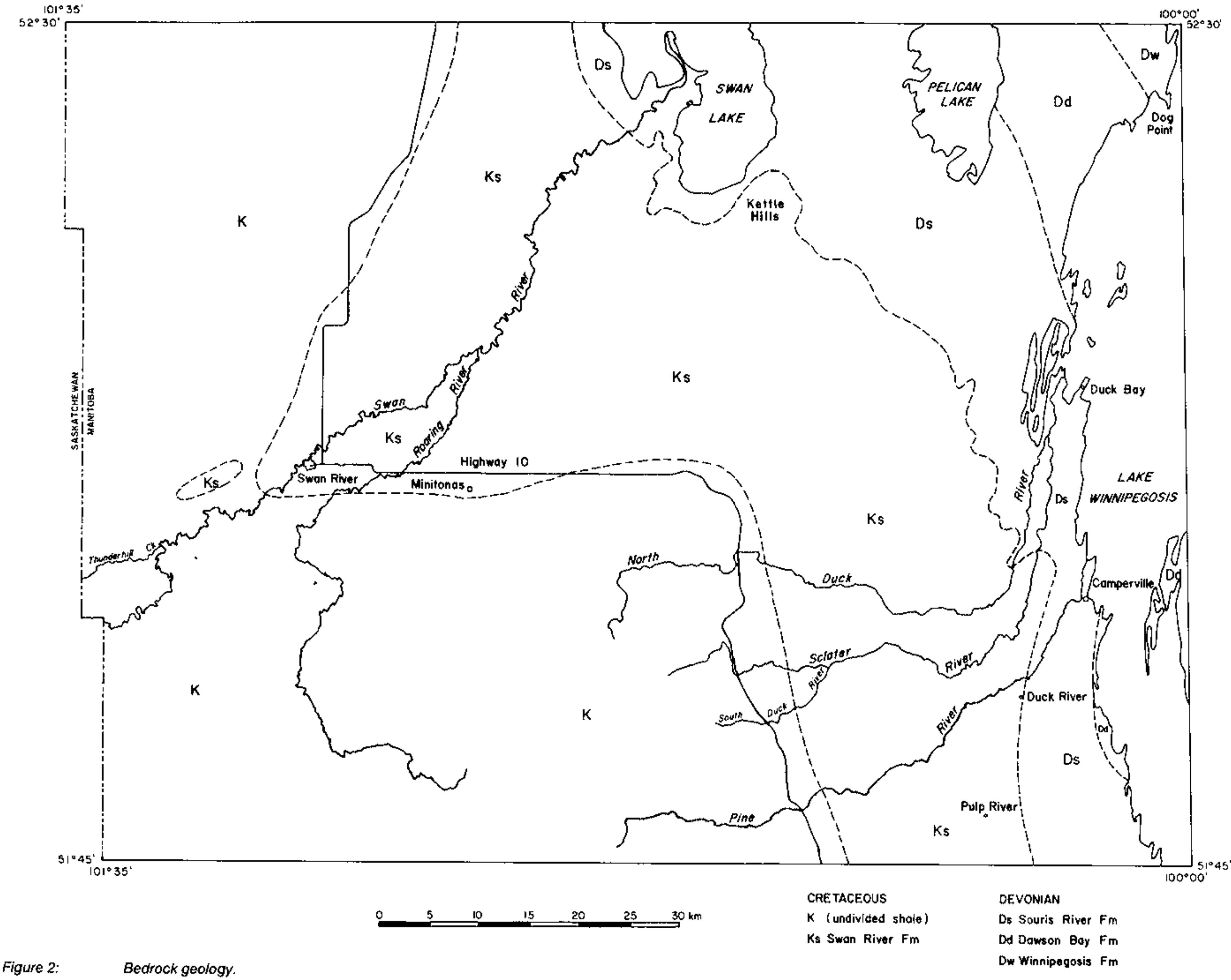


Figure 2: *Bedrock geology.*

BEDROCK GEOLOGY AND PHYSIOGRAPHY

BEDROCK GEOLOGY

The eastern part of the area, including Swan Lake, Pelican Lake and Lake Winnipegosis, is underlain by Devonian carbonate rocks (Fig. 2). The western two-thirds of the area is underlain by Cretaceous sandstone and shale.

The Devonian bedrock consists of a small area of Winnipegosis Formation, north of Dog Point on Lake Winnipegosis. It is overlain by Dawson Bay Formation east of Pelican Lake and, along the west shore of Lake Winnipegosis, south of Camperville. The Dawson Bay Formation is exposed in a quarry along Highway 20, approximately 13 km south of Camperville. Most of the Devonian rocks consist of the Souris River Formation that outcrops along a broad belt on the west side of Lake Winnipegosis. The outcrop belt includes Swan Lake and the western part of Pelican Lake. Outcrops of the Souris River Formation are common 10-14 km east of Pulp River. Outcrops are scattered north of Kettle Hills along the southeast shore of Swan Lake and in a few ditch exposures between Duck Bay and Camperville. The Devonian bedrock comprises a variety of lithologies including limestones, dolomites, and calcareous shales. The detailed Paleozoic stratigraphy and lithologies have been described by Norris et al. (1982).

The Devonian is unconformably overlain by Lower and Upper Cretaceous sandstone and shale. The Swan River Formation, attaining thicknesses of up to 100 m, occurs in a 10-20 km wide belt east of the Manitoba Escarpment and throughout the eastern part of the Swan River re-entrant. Swan River sandstone outcrops at several sites along Swan River, approximately 10 km east of the town of Swan River, on the north side of Kettle Hills, along the river bed where Highway 10 crosses the Roaring River, along Pine River 2.5 km west of the community of Duck River (Watson, 1985) and along Sclater River about 2 km east of Sclater. The Swan River Formation consists primarily of unconsolidated, well sorted, clean quartzose sand. The sand contains less than 1% heavy minerals (primarily magnetite and glauconite) and varying amounts of kaolin. Marcasite concretions and lignite layers are found in some beds. The "kettles" (Fig. 3), exposed for over 100 m along the north side of Kettle Hills, are spectacular carbonate-cemented sandstone concretions and form the only known lithified part of the formation. The extent of this bed is not known although the presence of lithified sandstone pebbles in the till along the west side of Swan Lake indicates the cemented layer may extend outside Kettle Hills.

The Swan River Formation is disconformably overlain by the Ashville Formation, the lowest of a number of marine shale formations outcropping along the Manitoba Escarpment (Fig. 4). The Ashville Formation consists of more than 90 m of non-calcareous dark grey to black shales with some silty and sandy beds and minor bentonite layers.

The Favel Formation, overlying the Ashville Formation, consists of calcareous grey shale, some beds of impure limestone and minor bentonite beds (Fig. 5). The Favel, which attains a thickness of 30 m, outcrops along the east and west branches of Favel River south of Minitonas and along Swan River between Thunderhill Creek and the Saskatchewan border.

The Favel Formation is overlain by the Morden Shale. McNeill and Caldwell (1981) indicate the formation, consisting of uniform, black, non-calcareous shale, is only a few metres thick in the Duck Mountain-Porcupine Hills area. It is poorly exposed except for a few outcrops along East Favel River, south of Minitonas (Wickenden, 1945).

The overlying Niobrara Formation consists of a lower calcareous shale and an upper chalky shale or marlstone. The formation outcrops along the east Favel River and along Birch River on the east side of Porcupine Hills. It is less than 6 m thick.

The Niobrara Formation is overlain by the Pierre Shale. The lower part of the formation, the Pembina Member, is poorly exposed along the edge of the escarpment on both Duck Mountain and Porcupine Hills. Typically, it consists of greyish black carbonaceous shale with numerous bentonite layers.

The middle part of the Pierre Shale, the Millwood Member, is 110 m thick on Duck Mountain (Little and Sie, 1976) and consists of non-calcareous, soft, silty, olive-grey clay. Wickenden (1945) indicates there are several outcrops of the Millwood Member south of Minitonas and along the escarpment on Porcupine Hills.

Tertiary sediments are not known to outcrop in the area. Klassen et al. (1970) and Klassen (1971) reported the occurrence of sandy and silty sediments overlying the Riding Mountain Formation on Duck Mountain, Riding Mountain and the adjacent parts of Saskatchewan. These sediments, named the Wynyard Formation, were assigned a possible Tertiary age. Moran (1969) reported the occurrence of similar sediments in the subsurface of the Lady Lake area, 80 km west of Swan River, and similar sediments are found in the Bredenbury area, southeast of Yorkton,

Figure 3: "Kettle" concretion in the Swan River sandstone on the north side of Kettle Hills. Note the hammer for scale.

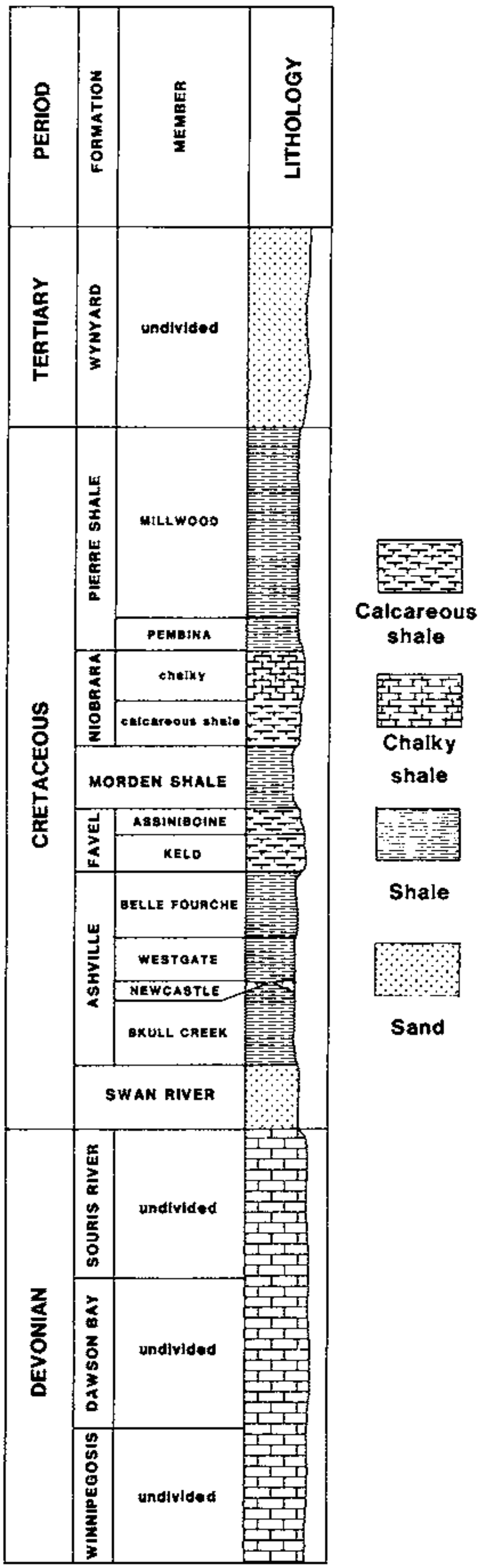


Figure 4: Pre-Quaternary stratigraphy of the Swan River area.

Saskatchewan (B. Schreiner, pers. comm., 1987). Extensive beds of gravel, silt and clay, that are younger than the Odanah Member but older than the glacial sediments, are also found in the Quill Lakes area, 95 km west of Lady Lake, Saskatchewan. These sediments have been assigned a Tertiary age (MacDonald and Broughton. 1980).

Comparable deposits are not known in the Swan River area except for the Wynyard Formation on Duck Mountain. However, an abundance of petrified wood fragments, black chert, toffee coloured quartzite (Fig. 6), and assorted jasper lithologies is found in the Quaternary sediments in the Swan River Valley. These clasts, ranging from less than 1 cm to more than 15 cm in diameter, are well rounded with percussion cones, indicating a high energy fluvial source. They are identical to Tertiary gravels exposed in the Cypress Hills and elsewhere in Saskatchewan indicating the Swan River Valley was cut by eastwardly flowing rivers draining the Rocky Mountains in Tertiary time.

PHYSIOGRAPHY

The Saskatchewan Plain is a broad area between 800 and 275 m a.s.l. (Fig. 7). The plain comprises three areas: the Duck Mountain upland in the south, the Swan River plain in the centre and the Porcupine Hills upland to the north (Fig. 8).

The Duck Mountain upland ranges from 600 to 800 m in elevation, the highest point being in the east near Windy Lake. The Porcupine Hills upland is relatively uniform in elevation from east to west, the highest point being Hart Mountain at an elevation of 795 m. The Swan River plain, which separates the two uplands, is a broad valley 45 km wide and 70 km long. The valley floor rises from an elevation of approximately 300 m in the northeast to about 500 m in the southwest. The western end of the valley extends into Saskatchewan. The valley has little relief except for Thunder Hill, located on the Saskatchewan-Manitoba border, which rises 140 m above the surrounding plain.

The Swan River plain merges with the Manitoba Plain in the east. The Porcupine Hills and Duck Mountain uplands are separated from the Manitoba Plain by the Manitoba escarpment that drops from 600 m to 430 m.

The Manitoba Plain, named the Westlake plain west of Lake Winnipegosis, ranges between 430 and 253 m in elevation. The Westlake plain is characterized by flat terrain throughout south-central Manitoba where it is underlain by Paleozoic carbonate bedrock. Between Duck Mountain and Swan Lake, Kettle Hills is a prominent Cretaceous sandstone rise, 90 m high.

DRAINAGE

The drainage, with one exception, is toward the northeast (see accompanying surficial geology map in pocket). Swan River and its tributaries, the Roaring, Ruby, East and West Favel, and Sinclair rivers, form the largest river system. Originating in Saskatchewan, they drain the north side of Duck Mountain and the southern part of the Swan River valley. The south side of Porcupine Hills and the north side of the Swan River valley are drained by Woody River and its tributaries, the Bowsman and Birch rivers and numerous creeks. The Swan and Woody rivers flow into Swan Lake. The Point, Garland, Pine, South Duck, Sclater, North Duck, Drake and Pelican rivers drain the east side of Duck Mountain and part of the Westlake plain. Pelican River flows into Pelican Lake and the rest flow into Lake Winnipegosis. Only Shell River, in the southwest, drains southward into Assiniboine River.

Three large lakes, Pelican Lake, Swan Lake and Lake Winnipegosis, border on the area. Pelican Lake has a maximum depth of 5 m and Lake Winnipegosis has a maximum depth of 10 m. Swan Lake is less than 3 m deep. There are numerous small kettle lakes on Duck Mountain and Porcupine Hills.

Figure 5: *Dark grey shale of the Favel Formation outcropping 3.25 km west of the community of Birch River. Bentonite beds are indicated by arrows.*

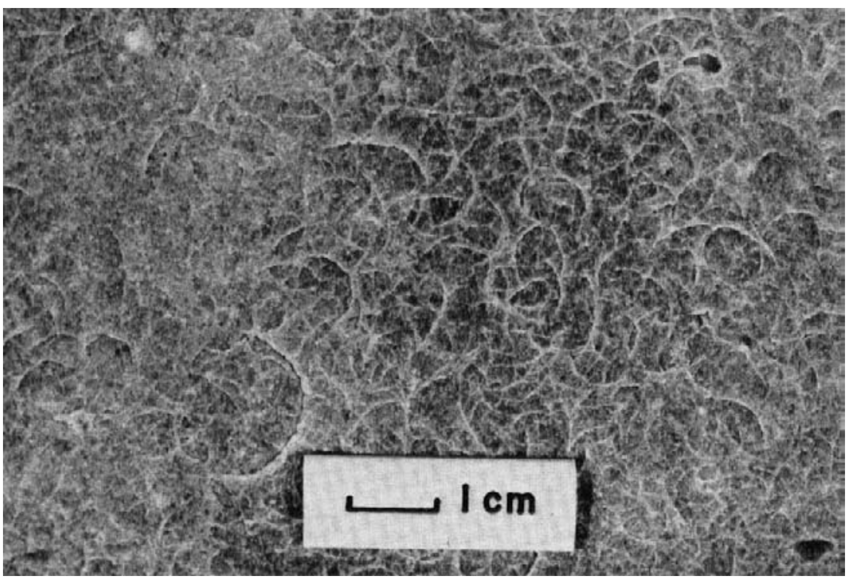


Figure 6: *Close up of a Tertiary gravel clast derived from Cambrian or Precambrian quartzites of the Rocky Mountains showing numerous percussion cones.*

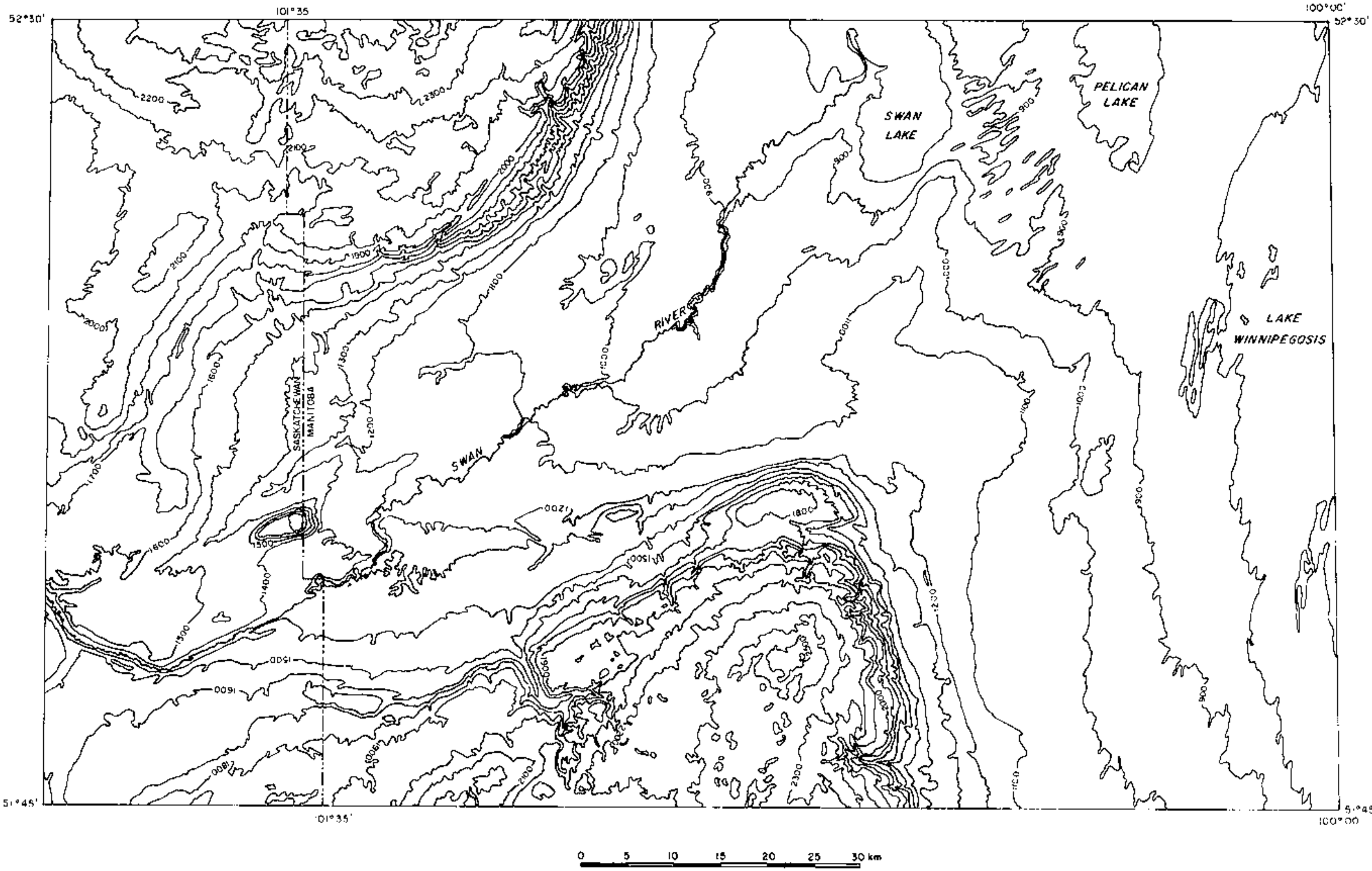


Figure 7: Topography of the Swan River area.

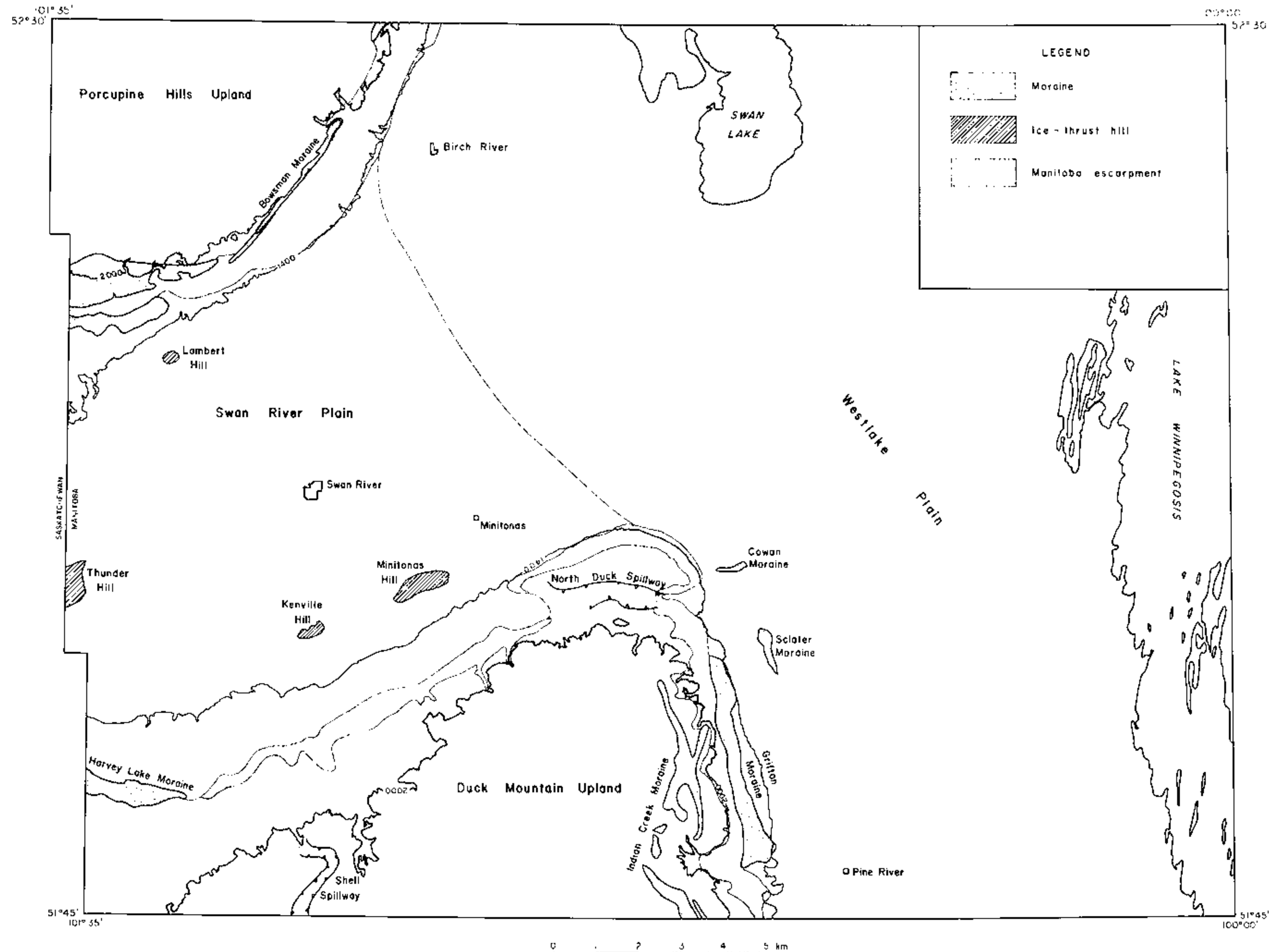


Figure 8: Physiographic regions and major topographic elements.

GENERAL STRATIGRAPHY

The Quaternary stratigraphy of Duck Mountain, Riding Mountain and adjacent areas (Fig. 9) has been established by Klassen (1969, 1971, 1972 and 1979). Klassen (1979) described three pre-Sangamon formations, the Largs, Tee Lakes and Shell formations, in the Swan River map area that do not outcrop. The Sangamon-aged Roaring River Clay, the Wisconsinan-aged Minnedosa, Zelena and Arran formations and a variety of Holocene-aged deposits are widespread.

Largs Formation

This formation consists of dark grey or grey till with a higher shale content than is typical of the area. The carbonate content ($CaCO_3$ equivalent) of the less than 63 micron fraction, as determined by the Chittick method, ranges between 9 and 21%. The textural composition ranges between 25 and 45% sand, 25 and 40% silt, and 30 and 50% clay (Klassen, 1979).

Tee Lakes Formation

The Tee Lakes Formation consists of several tills and intertill sediments found between the Largs Formation and the overlying Shell Formation (Klassen, 1979). The tills are dark grey and the carbonate content is between 20 and 26%. Little is known about the composition or the grain size distribution of the Tee Lakes Formation. The ice flow directions and the ages of the till units are speculative.

TIME UNITS	Duck Mountain upland		Westlake plain		Swan River plain	
	Outcrop	Subsurface	Outcrop	Subsurface	Outcrop	Subsurface
WISCONSIN			Arran F.	Arran F	Arran F	Arran F.
	Zelena F.	Zelena F	Zelena F.	Zelena F		
	Minnedosa Formation	Minnedosa Formation				
	Roaring River Clay					
PRE-WISCONSIN		Shell F				
		Tee Lakes F.				
		Largs F.				

Figure 9: Correlation of Pleistocene formations (after Klassen 1979).

Shell Formation

The Shell Formation generally consists of one till but, in places, may comprise more than one till and intertill sediments (Klassen, 1979). The till is oxidized in the upper part giving it an olive brown or yellowish brown colour. The carbonate content ranges between 24 and 36%. The Shell till is typically sandier than other tills in the area, with sand ranging between 44 and 55%, silt between 27 and 42% and clay between 13 and 25%.

The Shell Till, deposited by westerly flowing ice during the Late Illinoian or, possibly, during the Early Wisconsinan, is followed by at least two major non-glacial intervals beyond the range of carbon dating.

Minnedosa Formation

Till of the Minnedosa Formation is olive grey or dark grey in unweathered borehole samples. Weathered samples, common in exposed sections, are various shades of brown and yellow. The carbonate content ranges between 18 and 32%. Texturally, the Minnedosa till is clayier than the other tills. Klassen (1979) reports 40 to 45% sand, 27 to 32% silt, and 25 to 29% clay for Minnedosa Till from Duck Mountain in sections 16, 20, 19 (the Roaring River section) and 21 (the Zelena section). Only the Roaring River section is in the Swan River map area. Till of the Minnedosa Formation was deposited by southwesterly flowing ice and is of Early Wisconsinan age.

Zelena Formation

The surface till and associated intertill sediments on Duck Mountain were named the Zelena Formation by Klassen (1979). The till ranges in colour between yellowish brown and dark grey, depending on the degree of oxidation. The carbonate content ranges between 26 and 30%. Textural data are available for only three samples from the Zelena and the Roaring River sections on Duck Mountain where Klassen (1979) reports sand values between 38 and 44%, silt between 27 and 31% and clay between 28 and 31%.

Arran Formation

Klassen (1979) named the youngest till and all the overlying stratified sediments on the Westlake and Swan River plains the Arran Formation. In this report however, the Arran Formation includes only the youngest till and associated glaciogenic sediments.

The Arran Till is brownish in colour due to the high carbonate content that ranges between 34 and 65% (Klassen, 1979). The sand content ranges between 10 and 34%, the silt between 25 and 60% and the clay between 28 and 49%, similar to the Zelena Till.

The Arran Till discontinuously overlies the Zelena Formation. It was deposited during a late glacial re-advance approximately 13000 years B.P. (Klassen, 1975).

Late glacial sediments

As the ice margin receded, proglacial lakes in the Swan River valley expanded and became part of Lake Agassiz. A variety of sediments, including supraglacial lacustrine silt, glaciodeltaic gravel and sand, deep water glaciolacustrine silt and clay, beach sediments, spit complexes, and offshore bars, were deposited in the lake.

Postglacial sediments

After the final drainage of Lake Agassiz, the landscape looked much as it does today. Fluvial sedimentation and down-cutting by streams modified the escarpment and fossiliferous alluvial fan sediments were deposited along the base of the escarpment. Similarly, terrace deposits are found along the major rivers and creeks. Poor drainage, impeded by hummocky stagnation moraine on the uplands and fluted till and beach ridges on the plains, resulted in the widespread formation of organic sediments. Sand dunes are common in the eastern end of the Swan River re-entrant.

DUCK MOUNTAIN UPLAND

Drift thickness

Numerous boreholes drilled on the Duck Mountain upland (Klassen et al., 1970; Cherry and Whitaker, 1969; Little and Sie, 1976; Klassen, 1971, 1979) indicate that the highest bedrock elevation is 490 m, at a site approximately 15 km north of Wellman Lake (Little and Sie, 1976). The hole north of Wellman Lake terminated in the Millwood Member whereas some of the other holes terminated in the Wynyard Formation. The maximum drift thickness is 259 m, recorded in a borehole at Wellman Lake (Little and Sie, 1976), but Klassen (1979) indicates that drift thickness exceeds 300 m.

Although the Duck Mountain upland is composed primarily of drift it nevertheless reflects the topography of the underlying bedrock.

Till stratigraphy

Borehole DM31 was drilled 16 km south of Benito in the southwest corner of the map area by Manitoba Water Resources Branch and reported by Little and Sie (1976). The results of the analysis on sediments from other boreholes have been reported by Klassen (1971,1979) and Klassen et al. (1970). Results of the carbonate analyses on core DM31 are shown in Figure 10.

The thickest and most complete stratigraphic succession exposed is in the Roaring River section described by Klassen et al. (1967). The upper 5 m of the section is Zelena Till, overlying 13 m of Minnedosa Till. The two tills are separated by an oxidized horizon interpreted as a paleosol. The grain size distribution of the Zelena Till is similar to that of the upper part of the Minnedosa Till (Fig. 11). The grain size distribution of the lower dark grey part of the Minnedosa Till is strongly bimodal, the result of incorporation of shale. The shale content is highest in the lower, darker part of the Minnedosa Till and decreases toward the top. Shale was not observed in the Zelena Till exposed in the Roaring River section (Fig. 11).

At site 145, on the edge of the Shell Valley, two 2.5 m thick tills are exposed (Fig. 12). The lower till is yellowish with slightly more pebbles than the upper till (Fig. 11). The contact with the overlying brownish till is sharp. The two tills are tentatively correlated with the Zelena and Minnedosa tills exposed in the Roaring River section, based on similarities in grain size and oxidation.

At site 163, 3.5 m of brown clay till overlies coarser textured yellow-brown till. The field relations (Fig. 13) and the similarities in the composition indicate these two till units are facies of the Zelena Till formed when this area underwent large-scale ice stagnation.

Two tills are discontinuously exposed along the road north of Wellman Lake at site 155. The section is composed of 1 m of black till at the base overlain by 5 m of brown clay till (Fig. 11). The black till contains more shale and a higher percentage of carbonate in the matrix than the overlying brown till. The brown till is correlated with the Zelena Till and the underlying black till is correlated with the Minnedosa Till in the Roaring River section.

Section 168 also consists of two tills but, unlike the other sections, the tills are separated by up to 3 m of stratified sand and gravel (Fig. 14). The similarity in colour, texture, degree of oxidation and composition (Fig. 11) suggests these two tills are correlated with the Zelena Till.

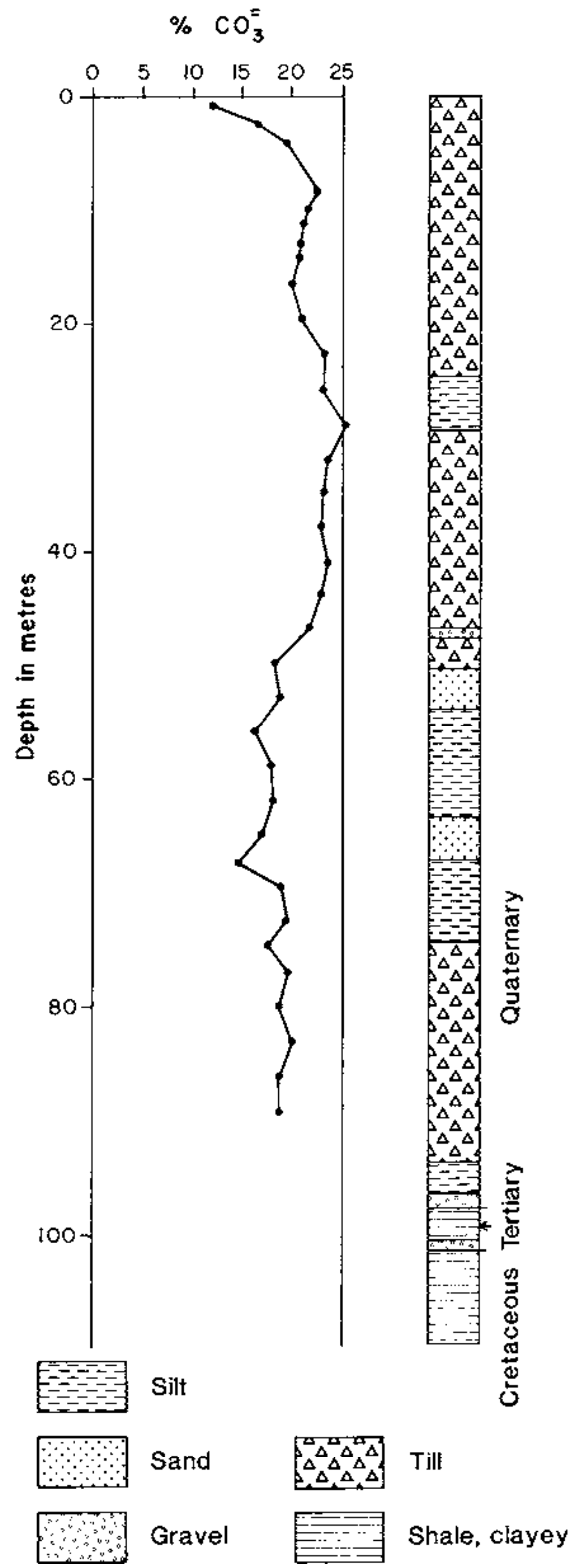
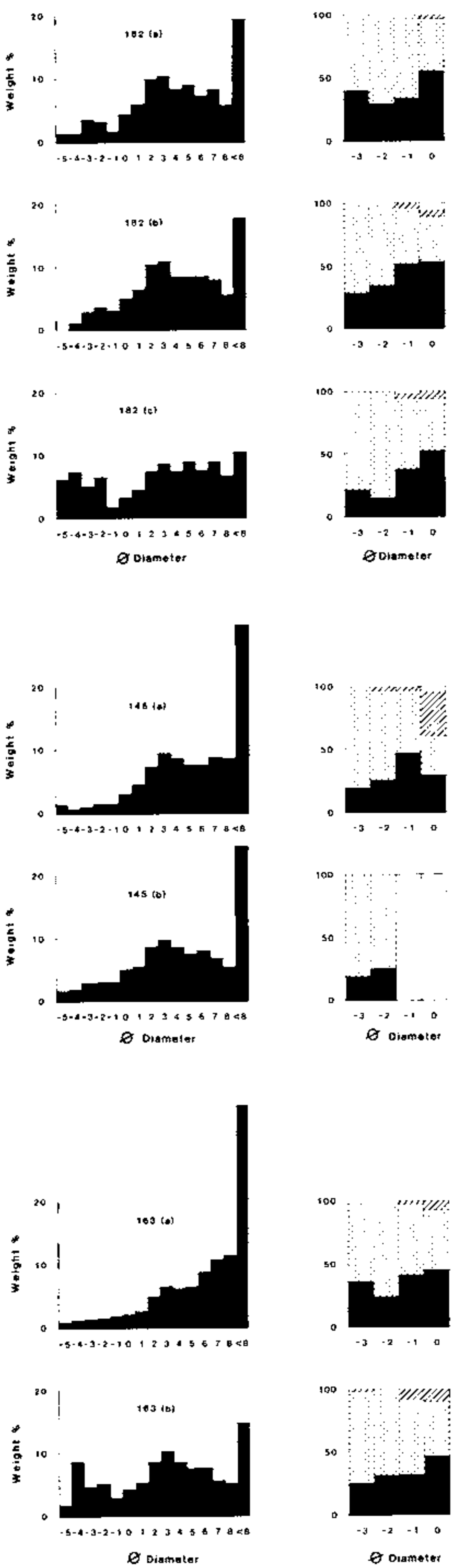


Figure 10: Stratigraphy and carbonate content of the sediments from Manitoba Water Resources borehole DM31 located on Duck Mountain 15 km south of Benito (Little and Sie, 1976).



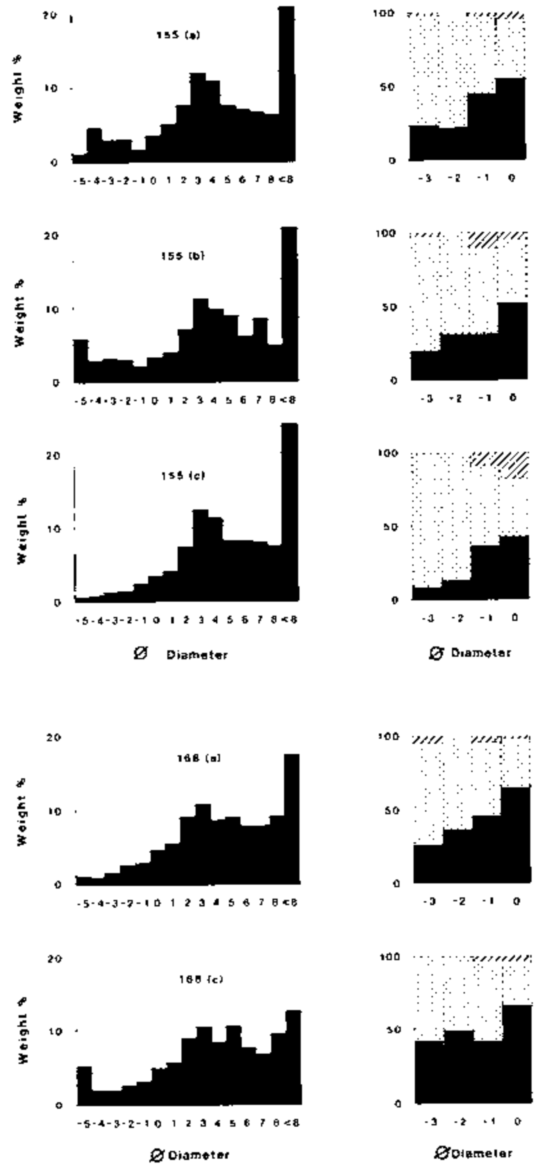


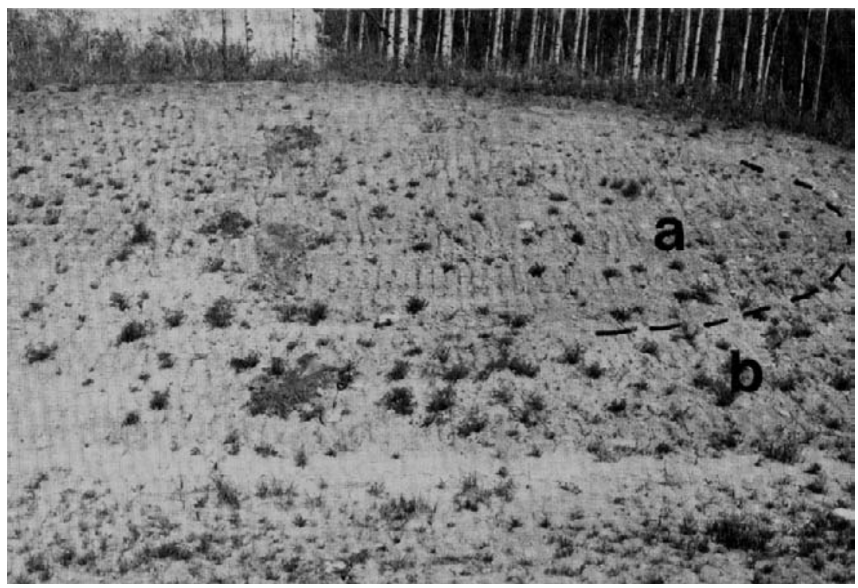
Figure 11: *Grain size distribution and pebble composition of tills from sections on Duck Mountain with multiple tills. See Figure 18 for explanation of symbols.*

Glacial features

Hummocky moraine: Duck Mountain is characterized by widespread hummocky stagnation moraine (Fig. 15). The moraine, covering most of the upland region, can be divided into areas of very high hummocks with relief greater than 10 m and areas of more subdued relief. The highest hummocky stagnation moraine is found along the eastern part of the upland in a zone 10 to 15 km wide and extending the whole length of Duck Mountain. Few exposures in the map area show evidence of ice stagnation. However, south of the area numerous exposures reveal normally faulted sand and gravel deposits capped by thin flow tills. Doughnuts (Fig. 16) are found in places along PR 366 south of Wellman Lake and along PR 271, east of Beaver Lake.

Figure 12: *Zelena Till (a) overlying Minnedosa Till (b) along the Shell River (site 145).*

Figure 13: *Brown clay till (?) (a) overlying sandy till (b) at site 163. Deformation is due to ice stagnation and collapse.*



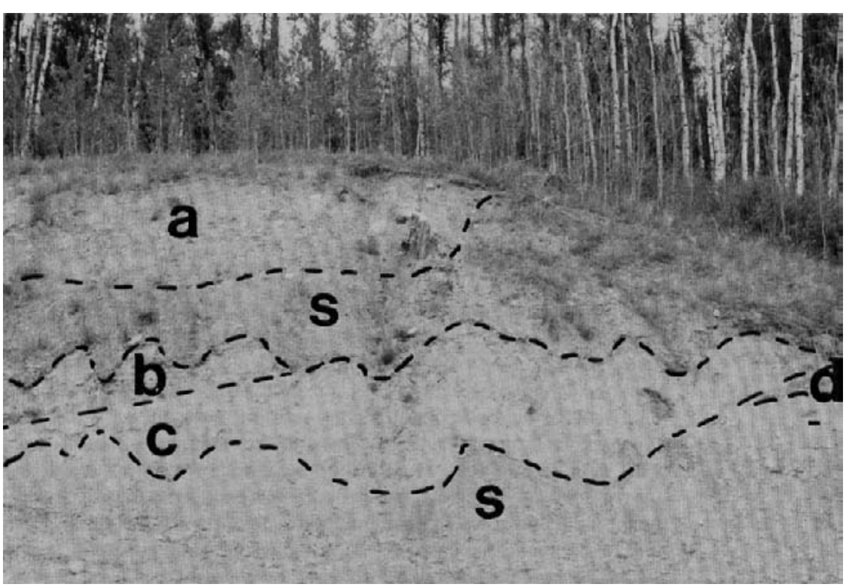


Figure 14: *Zelena Till (a and c) and interbedded gravel (b) overlying flow till and gravel (d) at site 168; (s) is slumped.*

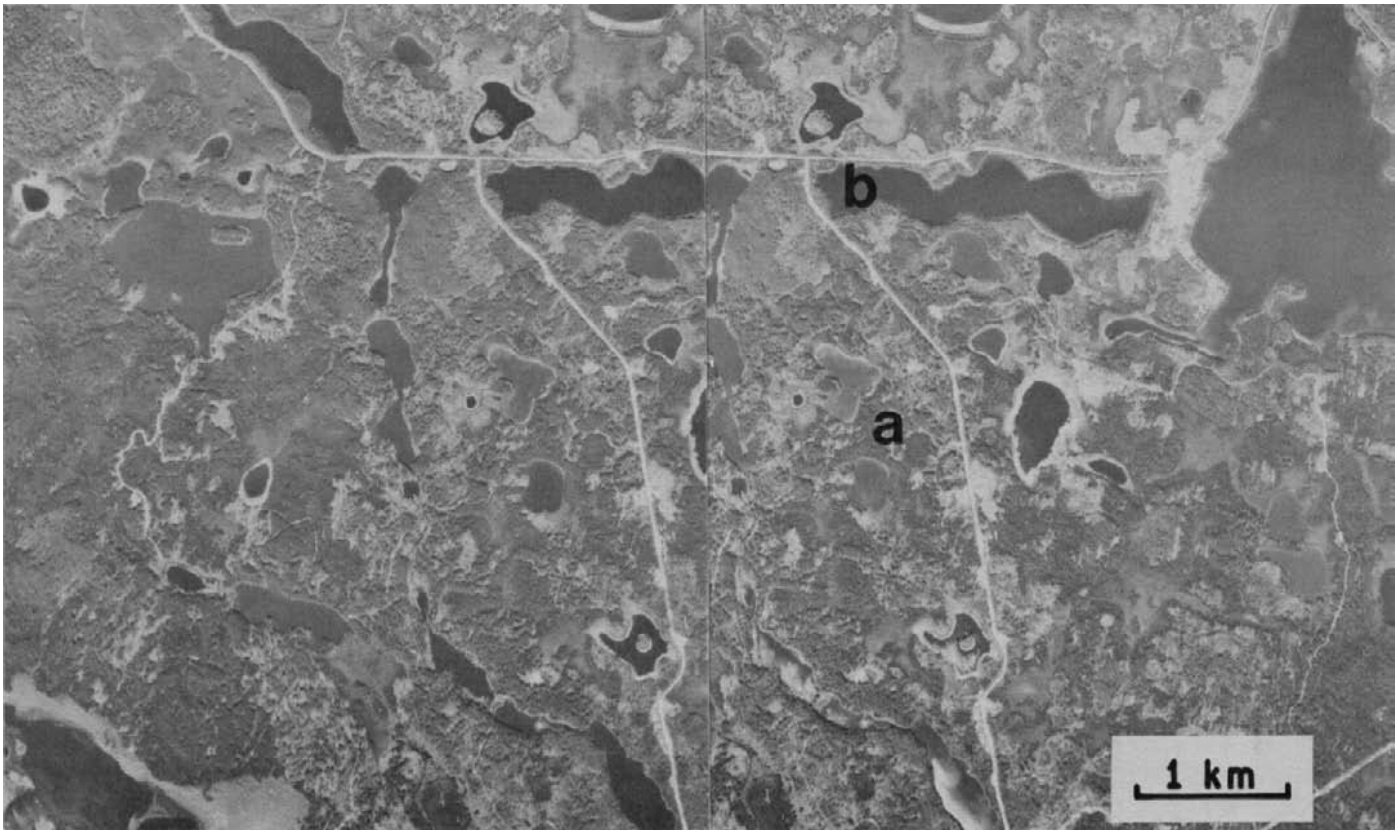


Figure 15: *Stereopair showing hummocky stagnation moraine (a) in the Zelena Till and buried channels (b) on Duck Mountain. North is to the right.*

Textural analysis of the Zelena Till, the surface till across Duck Mountain, shows a wide range of variation (Fig. 17) reflecting the processes of washing, sorting, slumping and mixing that acted on the till during glacier stagnation. The lithologic composition of the Zelena Till (Fig. 18) varies considerably. The carbonate content of the matrix ranges between 19 and 27% (Fig. 19). The low carbonate values (less than 19%) were determined on samples collected near the surface and have consequently been partially leached. The variation in the pebble composition does not appear to be related to the distribution of the high and low hummocky stagnation moraine.

Morainic ridges: Two pronounced 23 km long morainic ridges, named the Indian Creek moraine, are found along the east side of Duck Mountain (Fig. 20 and 21). The 15 to 20 m high ridges are between 0.3 and 1.5 km wide and reach a maximum width of 2 km at a point 7 km north of the Pine River valley, where the two ridges merge. Carbonate determinations on ten till samples collected on the moraine and down the east side of Duck Mountain indicate the ridges are composed of Zelena Till (Fig. 22).

Outwash and glaciolacustrine deposits: Lacustrine clay, silt and sand, draped over the hummocky stagnation moraine, are extensive

Figure 16: *Collapsed hummock or doughnut in the hummocky stagnation moraine at Gallant Lake, 3 km south of Wellman Lake, Duck Mountain.*

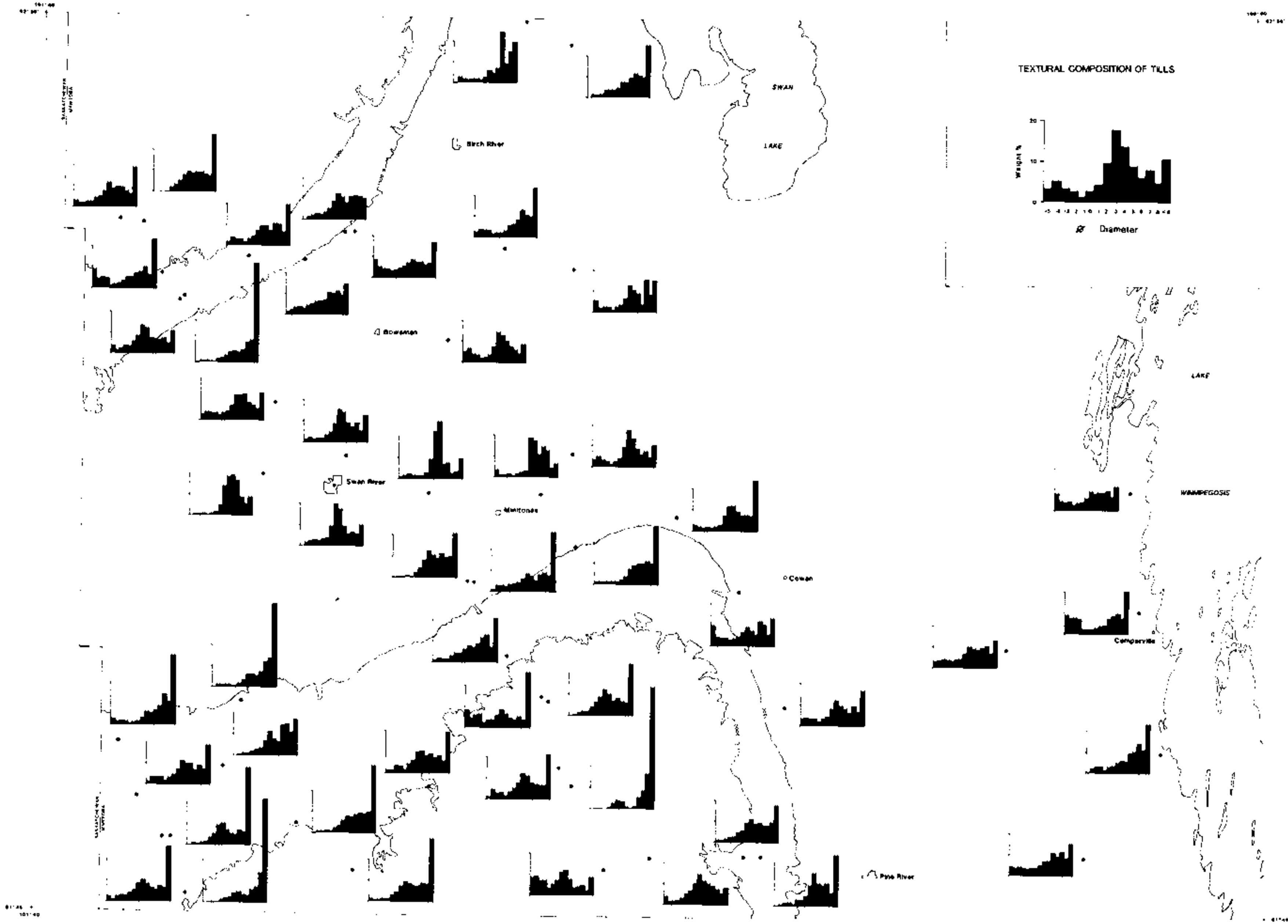


Figure 17: *Textural composition of the surface tills.*

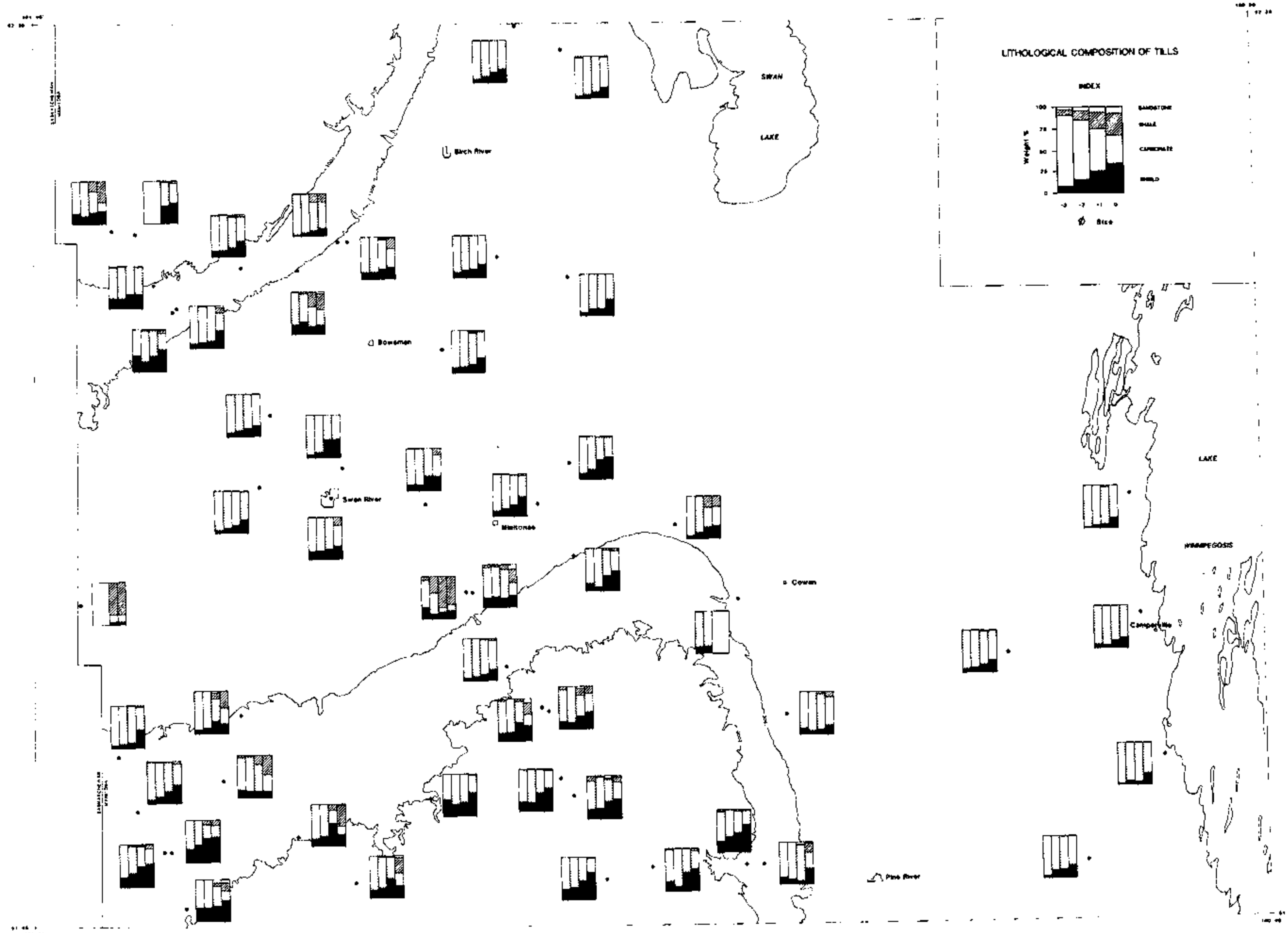


Figure 18: *Lithologic composition of the surface tills.*

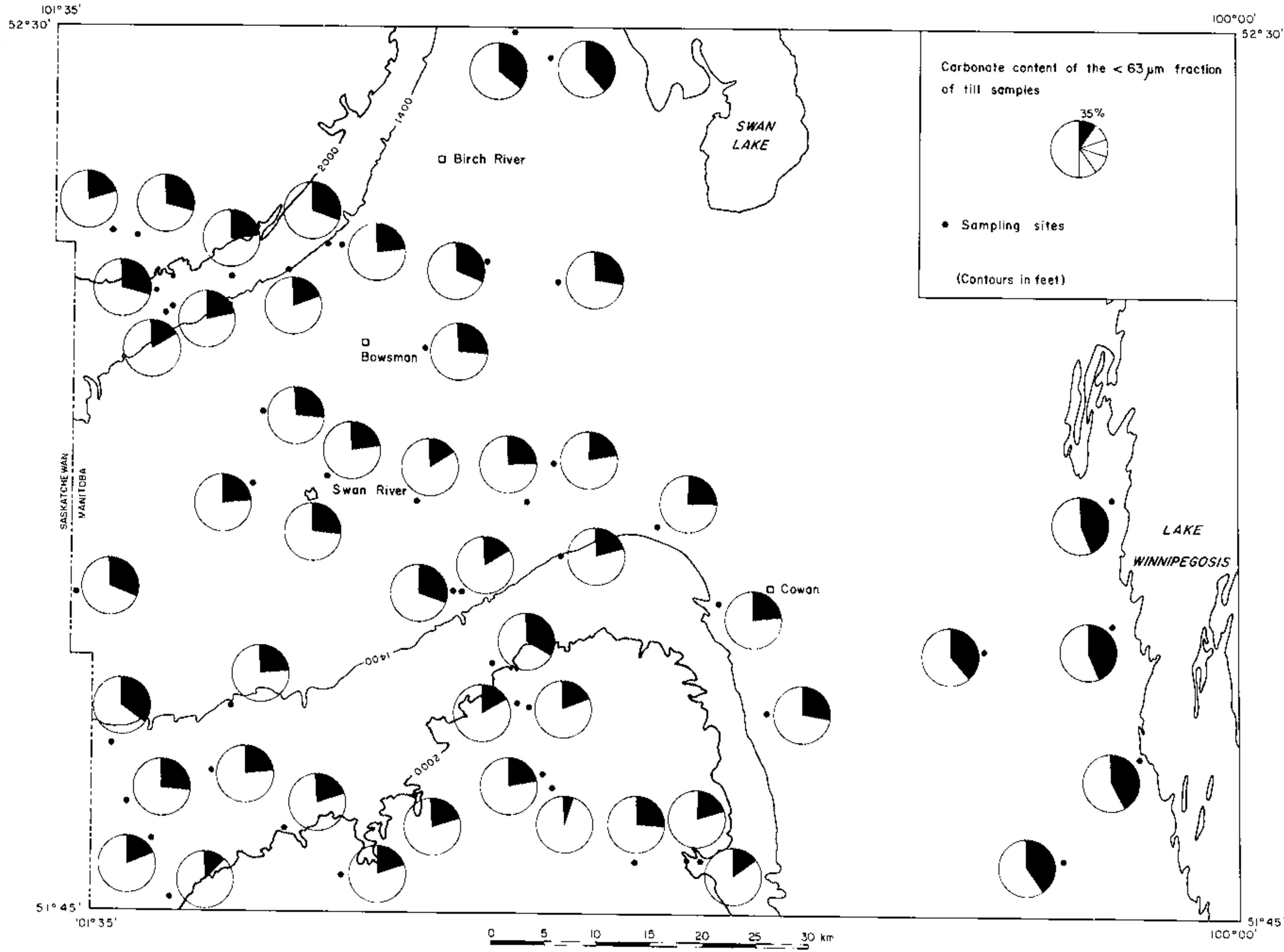


Figure 19: Carbonate content of the less than 63 micron fraction of the surface tills.

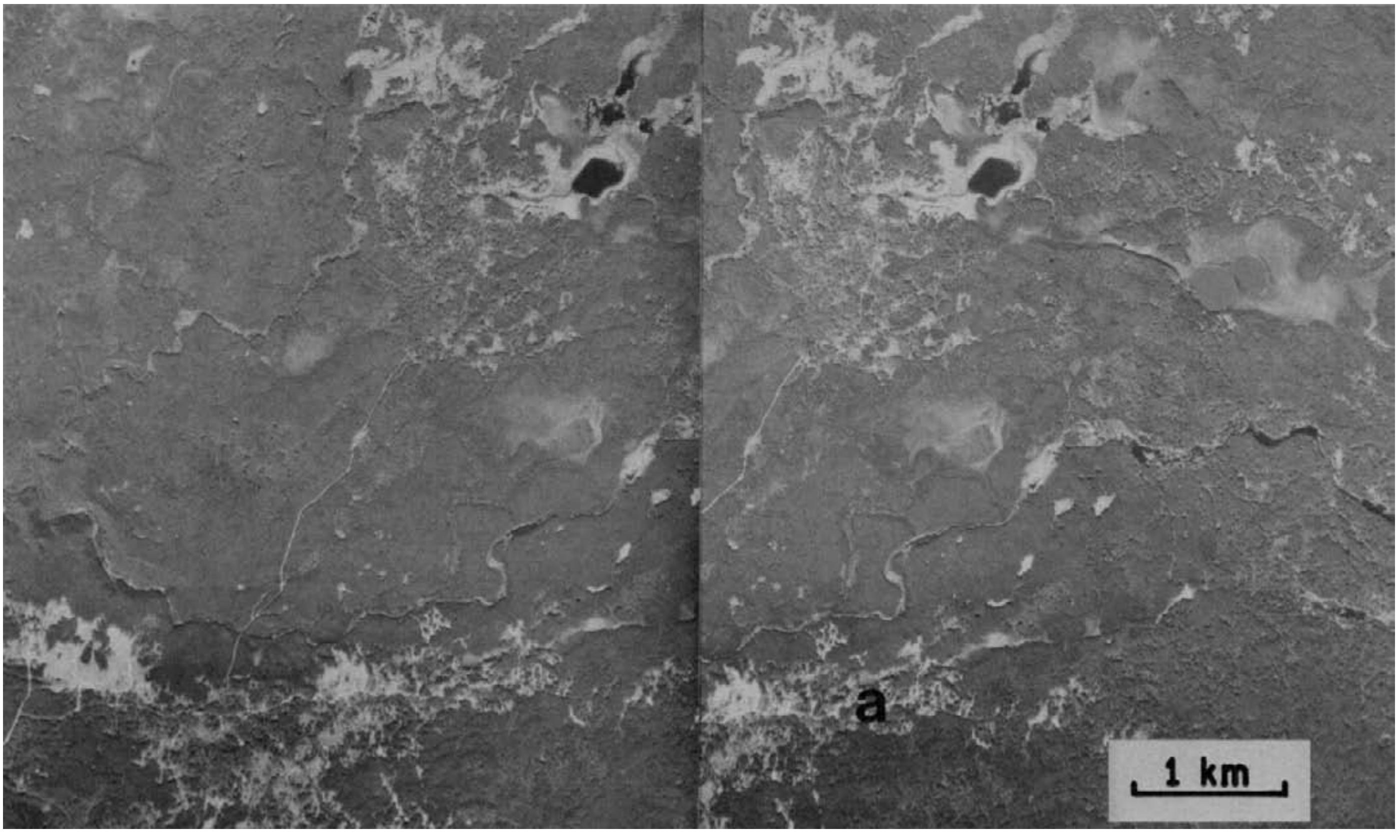


Figure 20: Stereopair showing the Indian Creek moraine (a). North is to the right.

throughout much of Duck Mountain, excluding the highest hummocky moraine. Silt and clay overlying till are exposed along PR 366 north of Roaring River and in some minor exposures south of Wellman Lake (Fig. 23). East and south of Shell River, clay is extensive. In the few exposures of clay examined, lamination or bedding was not noted. Recognizable shoreline features are not associated with this clay and delineation of the unit is tenuous. The irregular topography of the clay blanket and the absence of shoreline deposits suggest deposition in an ice-walled supraglacial lake. The lake was restricted to the Duck Mountain upland.

The clay on Duck Mountain extends eastward to the high hummocky stagnation moraine and is found at some sites within the moraine but not to the east. The relationship between the clay blanket and the Indian Creek moraine is unclear.

A 9 km long sand and gravel ridge striking 35° is situated east of Big Bobs Lake. The ridge extends discontinuously at least 3 km farther northeast and includes glaciofluvial outwash gravel deposits that outcrop along PR 366. The ridge consists of interbedded sand and cobble gravel. The top of the ridge is flat and smooth, indicative of wave wash-

Figure 21: The crest of the Indian Creek moraine composed of Zelena Till, 10 km west of Wellman Lake.

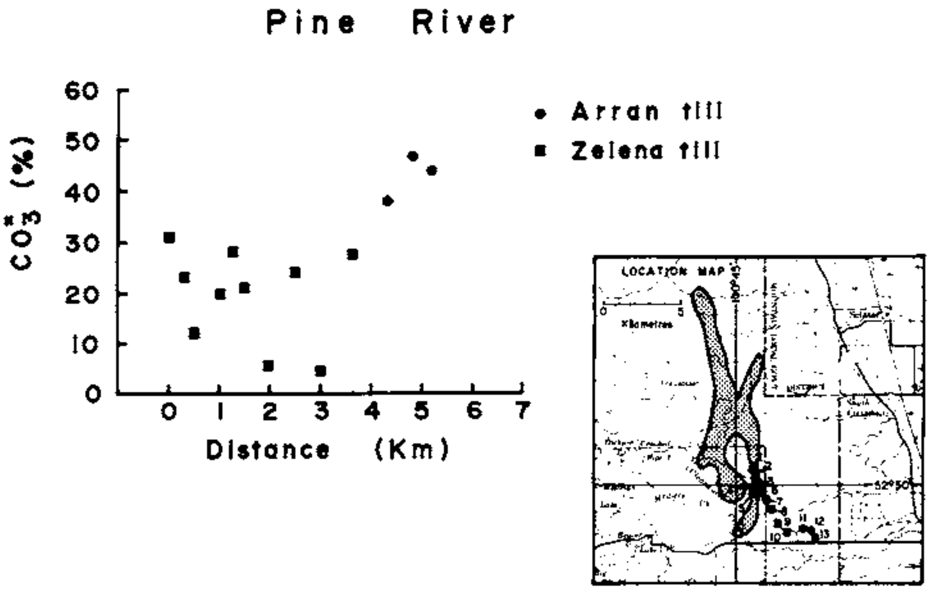


Figure 22: *Carbonate content of till samples from the Indian Creek moraine and the eastern slope of Duck Mountain.*

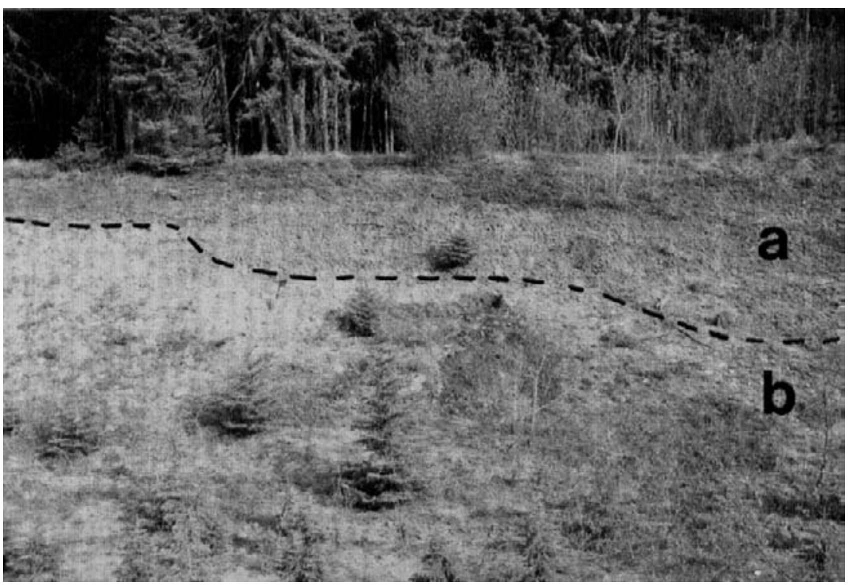


Figure 23: *Clay (a) overlying Zelena Till (b) north of Wellman Lake.*

ing. Though poorly exposed, proximal-distal relations, indicated by grain size variations, suggest the current direction was toward the northeast. The fan-like shape of the ridge, which is narrow in the southwest and wider in the northeast, also suggests a northeast current direction.

Glacial spillways and buried channels: The most prominent valley on Duck Mountain is the Shell River spillway (Fig. 24 and 25). The spillway has a maximum width and depth of 1.5 km and 30 m respectively. The present-day drainage is north by way of Brush Creek, a tributary of Roaring River. Sedgewick Lake, situated in the bottom of the spillway, is the source of West Shell River that drains into Assiniboine River. The head of the spillway is situated about 4 km southeast of Sarah Lake where it opens toward the Swan River plain. The spillway is floored by Recent organic accumulations. Minor terrace deposits occur southeast of Robinson Lake. Fluvial gravel outcrops in places on the valley floor but is generally buried under the organic deposits.

Duck River drains a large valley on the northern part of Duck Mountain. The valley is at an elevation of 534 m (1750') and is approximately 15 km long, 2 km wide, and 30 m deep; it is open both to the east and the west. The valley is flat bottomed as is typical of glacial spillways. A large delta is situated at the eastern end and a smaller delta at the western end of the valley. These deltas are modified by Lake Agassiz beaches. The valley is floored by deltaic topset sand and gravel in the eastern end and by Zelena Till in the west. The channel is believed to have been cut by a meltwater stream draining an ice-marginal lake in the Swan River valley. The stream drained east across Duck Mountain into another ice-marginal lake when the Swan River plain and the Westlake plain were, in part, still occupied by ice. As the ice receded and the lakes joined, the water level dropped and the drainage in the western part of the valley was reversed.

Buried channels are most conspicuous in the area of the high stagnation moraine. They are recognized by the chains of lakes now occupying the old channels (Fig. 15). Sand and gravel were deposited in the ice-walled glaciofluvial channels. As the stagnating ice melted, the walls and floor of the channels collapsed and flow till spread out across the channel bottom giving it an irregular surface capping the sands and gravels.

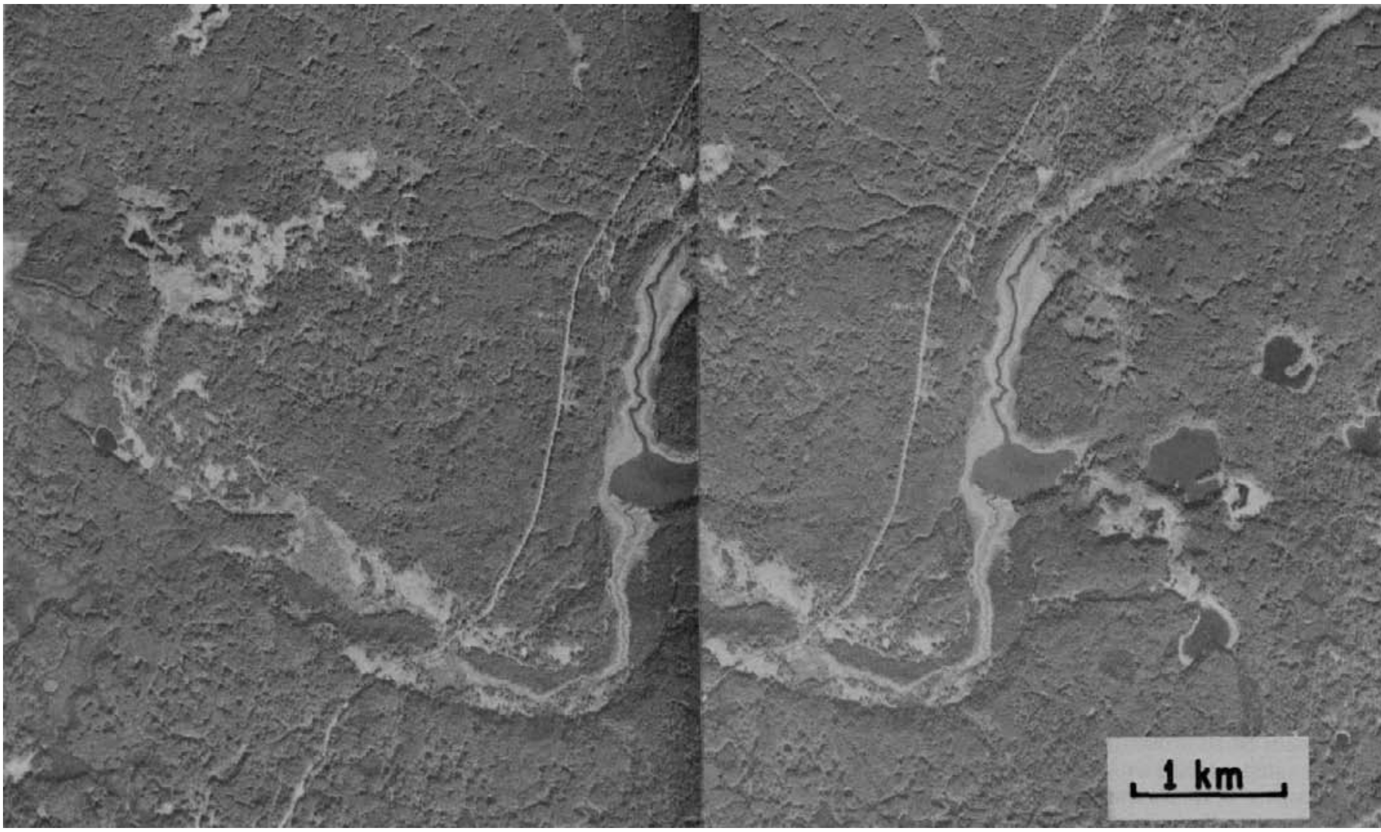


Figure 24: *Stereopair showing the Shell River spillway at Robinson Lake. North is to the right.*

Examples are found on the north side of Copernicus Hill and at the east end of Beaver Lake (Fig. 26). The lakes that occupy the channel bottom are sites of melted ice blocks.

Recent deposits

Kettle lakes and bogs are common features of the landscape on Duck Mountain. The lakes and bogs occupy depressions that are a result of ice stagnation. Recent sediments are typically fossiliferous although exposures are rare. For example, at site 188 Holocene fossiliferous sand and silt overlie post-glacial unfossiliferous clay. Fossil molluscs, including *Gyraulus parvus*, *Stagnicola reflexa*, *Stagnicola caperata* and *Pisidiurn nitidum*, are common in these deposits. Radiocarbon dating of bottom sediments from a bog situated east of Highway 366 and 2.5 km southwest of Godin Lake (51°57'N and 100°58'W) indicates organic productivity began 10 140 ± 455 years B.P. (S-2478) (S. Zoltai, pers. comm., 1984). The area was deglaciated possibly 2000-3000 years before then.

Figure 25: *Shell River spillway floored by swamp and minor gravel. Looking north from site 145.*

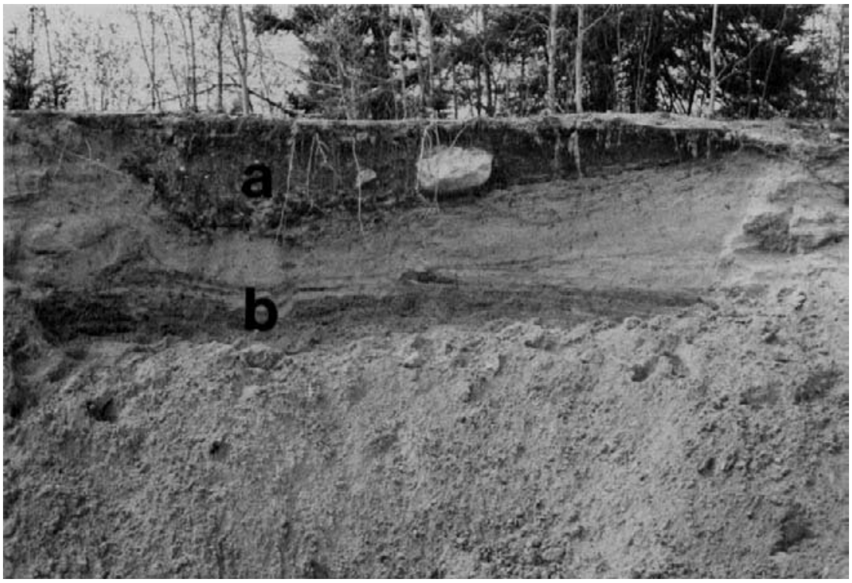


Figure 26: *Flow till (Zelena Till) (a) overlying buried channel sand (b) at the east end of Beaver Lake on Duck Mountain (site 167).*

PORCUPINE HILLS UPLAND

Drift thickness

To date, two boreholes have been drilled in the Porcupine Hills. One hole was located about 2.5 km east of Cross Lake near the southern margin of Porcupine Hills (Little and Sie, 1976). The elevation at the top of the hole is 622 m (2041 ft.) and Cretaceous shale was intersected at 464 m (1521 ft.). Assuming the top of the bedrock is at an elevation of approximately 464 m, there may be up to 300 m of Quaternary sediments, as the highest point on Porcupine Hills, Hart Mountain, is at 762 m (2500 ft.).

Till stratigraphy

Little is known of the stratigraphy of the Quaternary sediments that form Porcupine Hills. There are no known river sections or roadcuts that expose more than the surface till. Backhoe pits dug on Porcupine Hills (Nielsen and Gale, 1983) intersected brown clay till correlated with the Zelena Till on Duck Mountain, calcareous till correlated with the Arran Till on the Westlake plain and, in a few holes, an older till, not previously described, underlying the Zelena Till.

Glacial features

Hummocky moraine: Hummocky stagnation moraine is ubiquitous across Porcupine Hills (Fig. 27). High hummocky stagnation moraine, with relief greater than 10 m, is found near the centre of Porcupine Hills. Brown clay till is widespread on both the high and low parts of the stagnation moraine. The low areas are swampy and brown silt or clay locally overlies till. Elsewhere, the brown clay till overlies brown silt (Fig. 28; Nielsen and Gale, 1983) and, at site 177, 2 m of brown clay till overlies at least 3 m of poorly sorted gravel.

Unlike the northern part of Duck Mountain, moraine plateaus and linear disintegration moraine are common in Porcupine Hills. Moraine plateaus, 0.25 to 0.5 km across, are found primarily in the high stagnation moraine (Fig. 29). There are no exposures in the moraine plateaus but clay overlying brown clay till was found in one backhoe pit (Nielsen and Gale, 1983), and is a common feature of moraine plateaus (Stalker, 1973).

Linear stagnation moraine, up to 1 km wide and 10 km long, occurs along the east side of the high hummocky stagnation moraine and is transitional to the lower hummocky stagnation moraine. There are no exposures in the linear stagnation moraine but some deposits of brown silt are found between the ridges.

Figure 27: *Hummocky stagnation moraine composed of Zelena Till, 2 km west of Hart Mountain, Porcupine Hills.*

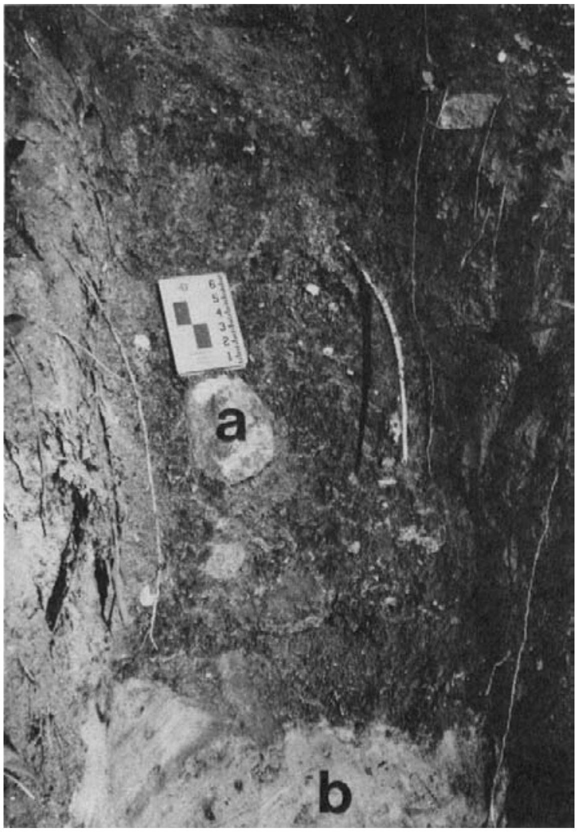


Figure 28: *Zelena Till (a) overlying deformed sand (b) in the hummocky stagnation moraine on Porcupine Hills.*

The widespread thick accumulation of hummocky stagnation moraine on Porcupine Hills, like that of Duck Mountain, is attributed to deposition of till transported englacially. Basal till was not identified in near-surface exposures in either of these upland areas.

The carbonate content of the matrix of the Zelena Till on Porcupine Hills ranges between 16.5 and 24.1%. The textural composition of the Zelena Till on Porcupine Hills is shown in Figure 17. The variation in the texture of the till is consistent with the post-depositional modification of the till during ice stagnation. The lithologic composition is shown in Figure 18.

Morainic ridges: A prominent morainic ridge is situated along the southeast and east side of Porcupine Hills. The ridge is defined by a series of closed contours at the northern edge of the map area. In the southeast it diverts the Bowsman River to the southwest for a distance of 12 km before the river descends from the uplands. As the ridge is well defined along the Bowsman River it is named the Bowsman moraine. Between the Bowsman River and the Saskatchewan-Manitoba border, the moraine is poorly defined, but is approximately coincident with the limit of the highly calcareous Arran Till that is widespread in the Swan River and Westlake plains. Elsewhere, the moraine is at, or close to, the limit of the Arran Till and is mapped as Arran Till. Along Whitefish Lake Road and Hart Mountain Road, the limit of Arran Till is approximately coincident with the moraine as it is at the headwaters of Maple Creek. At site 181 and at the northernmost part of the moraine it is composed of Zelena Till. The Bowsman moraine is tentatively assigned to the Arran readvance.

The other prominent morainic ridge on Porcupine Hills is a 5 km long arcuate ridge located on the north side of Bubble Lake. Although the ridge is in an area of very high hummocky stagnation moraine, similarly oriented ridges located northwest of the area in Saskatchewan suggest that it may have been deposited by an ice advance from the north-northeast. Alternatively, the ridge may be the product of glacier stagnation, although the orientation of streamlined hills and corrugation moraine around Wapsim Lake and Danbury, Saskatchewan, 50 km to the west of the area, suggests formation of the ridges by southerly flowing ice (Moran, 1969).

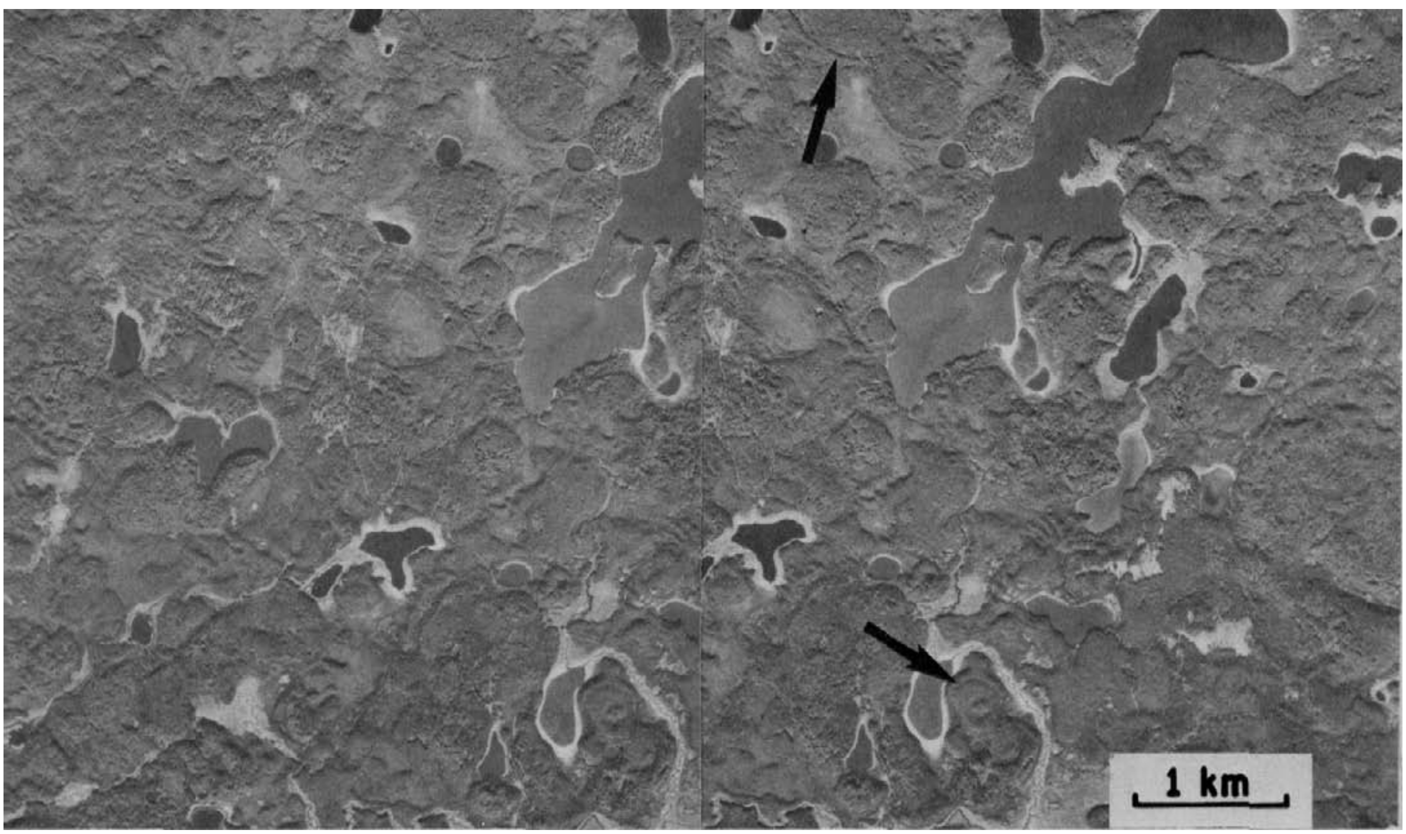


Figure 29: *Stereopair showing moraine plateaus (arrows) around Stanton Lake, Porcupine Hills. North is to the right.*

Figure 30: *Deformed Cretaceous shale overlain by Arran Till, 5 km west of Cowan on North Duck River.*

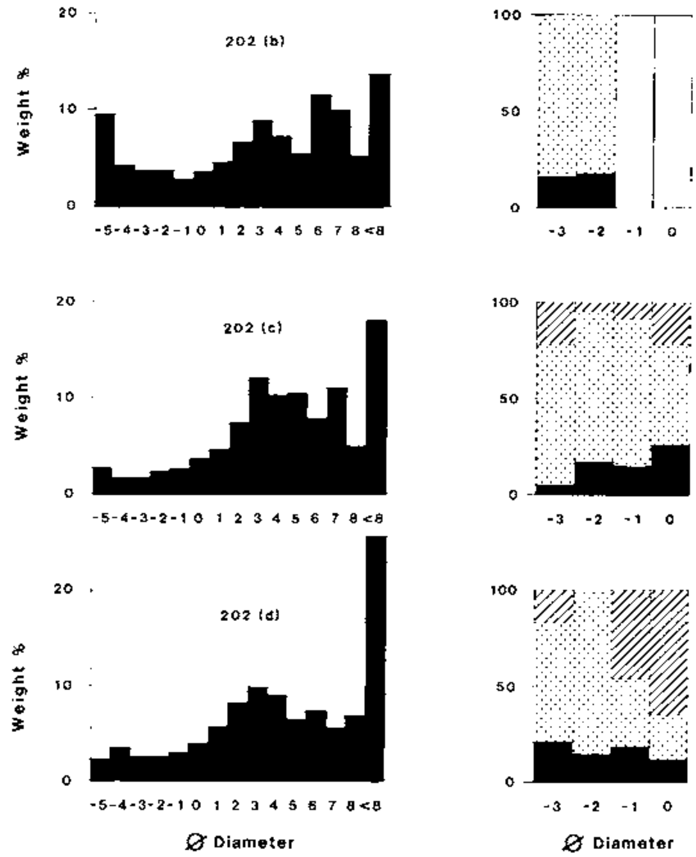


Figure 32: *Texture and pebble composition of the three Arran Till phases shown in Figure 31. See Figure 18 for explanation of symbols.*

Outwash and glaciolacustrine deposits: Near the source of Maple Creek and at isolated locations along Hart Mountain Road, lacustrine silt and clay outcrop at the surface. Unlike Duck Mountain, there is little evidence of glaciolacustrine sedimentation on Porcupine Hills. The isolated occurrences of glaciolacustrine silt and clay are considered to have formed in the hummocky stagnation moraine, as stagnating ice melted.

Recent deposits

The abundant kettle hole depressions on Porcupine Hills have resulted in poor drainage and an abundance of lakes and bogs. Large bogs occur in the low hummocky stagnation moraine and are particularly well developed immediately west of the Bowsman moraine.

Figure 31: *Arran Till exposed along North Duck River at site 202, 5.5 km west of Cowan. The colour differences (a, b and c) are due to the variable shale content.*

The only radiocarbon dates from Porcupine Hills are those of Nichols (1969). A bog bottom date of 6770 ± 70 years BP (WIS-271) demonstrates the problems inherent in dating material from kettle holes. This date probably records the final disappearance of buried glacier ice, which may have taken two or three thousand years, and the onset of organic accumulation (Clayton, 1967; Wright and Watts, 1969). Alternatively, the date could reflect a climatic change or could suggest that possibly the sample is not from the bog bottom. The area probably became ice-free between 11 000 and 12 000 years BP, shortly after Duck Mountain.

WESTLAKE PLAIN

Drift thickness

Klassen (1979) mapped the Westlake plain east of Duck Mountain as rolling bedrock plains, locally veneered with till. There is, however, little bedrock exposed in the area and drift thicknesses range between 0 and 30 m. Little and Sie (1976) indicate from 10 to more than 30 m of overburden is present east of Duck Mountain. North of 52°N, information on the overburden thickness is sparse. Little (1973) showed the overburden thickness to be 30 m north of Lenswood and 25 m northeast of Renwer and indicated that the drift is probably less than 30 m thick in most of the Swan Lake-Pelican Lake area. Drilling indicated that the Cretaceous Swan River Formation is less than 10 m from the surface at Kettle Hills (Watson, pers. comm., 1985).

Till stratigraphy

There are few exposures on the Westlake plain because of the low rolling topography. However, along the Manitoba escarpment, several river cuts expose the near surface stratigraphy; several small exposures occur along Duck River, west of Cowan. A gentle fold in the Cretaceous shale at the base of one of these sections strikes 355°, suggesting ice flow toward the west. The bedrock is overlain by black till grading up into brown till, that is capped by 1 m of sandy gravel (Fig. 30). A similar stratigraphic sequence is exposed in adjoining sections (Fig. 31) where black till grades into brown till that, in turn, grades into tan coloured till, capped by 1 m of sand and silty sand. The grain size distribution of the black till and the overlying brown till is similar to that of the Zelena Till on Duck Mountain (Fig. 32). The overlying tan coloured till has a similar grain size distribution but is somewhat more gravelly and silty, a characteristic of till derived from the Paleozoic carbonate terrain to the east. The upper tan coloured till contains 82% carbonate clasts in the 4-16 mm fraction and 24% in the matrix. The underlying brown and black tills contain 77% and 74% carbonate clasts in the 4-16 mm fraction, respectively, and 26% in the matrix. There is 9% shale in the black till, 12% in the brown till, but only 2% in the tan till. The brown till is correlated with the Zelena Till and the black till is possibly correlated with the Minnedosa Till. The upper tan till is correlated with the Arran Till.

Glacial features

The till plain, east of the Manitoba escarpment, is divided into two broad areas. To the east, at elevations below 275 m a.s.l., till is highly fluted. Above 275 m a.s.l., the till sheet is flat with little evidence of fluting. From Kettle Hills south to the edge of the map area, the transition from fluted till to flat till plain is approximately coincident with the contact between the Devonian Souris River Formation and the Cretaceous Swan River Formation. The transition, from hard impermeable carbonate bedrock to highly permeable unlithified sandstone along the ice flow direction, resulted in the change from fluted to non-fluted till. West and southwest of Swan Lake, the Swan River sandstone may have been buried and, consequently, not exposed to the advancing Arran sublobe. The transition from fluted till to till plain is, therefore, less distinct than in other areas.

Fluted till: The flutes of the Westlake plain are composed of highly calcareous compact till. The till forms elongated ridges typically 2 to 3 km long, 0.5 km wide (Fig. 33) and generally less than 6 m high. The flutes are accentuated by widespread swamps due to low relief and poor

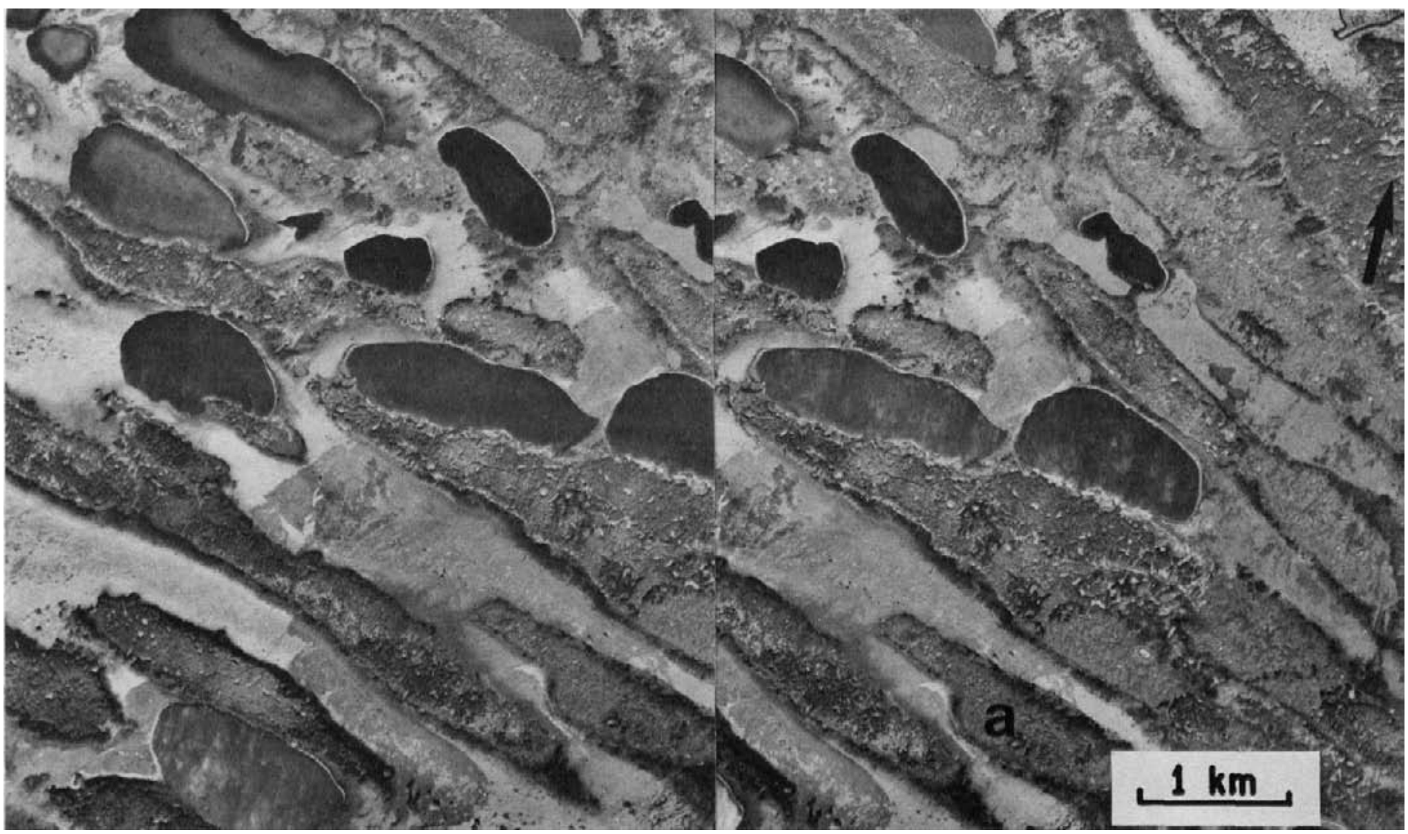


Figure 33: Stereopair showing fluted till (a) on the Westlake plain, 5 km south of Pelican Lake. The ice flow was towards 215°. Note the iceberg furrows indicated by an arrow. North is to the right.

drainage. The orientation of the flutes is variable: at Duck Bay the flutes trend toward 205°, west of Sagemace Bay the flutes trend toward 185° and around Swan Lake they trend toward 235°. The orientation of the flutes was controlled by the topography; Duck Mountain and the northeast extension of the Cretaceous Swan River Formation, including Kettle Hills, diverted the ice flow southwest into the Swan River valley. The southerly trend of the flutes around Sagemace Bay is consistent with the orientation of the flutes farther east and throughout much of the northern Interlake.

The till comprising the flutes is highly calcareous, being derived primarily from the comminution of Paleozoic carbonate bedrock. Along the shore of Lake Winnipegosis, southwest of Duck Bay (Fig. 19), the matrix of the fluted till typically consists of 40% or greater carbonate. The high carbonate content of the matrix is also reflected in the pebble composition (Fig. 18). The granulometric composition of the till also reflects its carbonate bedrock origin with high proportions of silt-sized material (Fig. 17).

The fluted till, west of Swan Lake, is similar in pebble composition to the till east of Swan River but the carbonate content of the matrix is below 40%, reflecting the incorporation of non-calcareous sediment, possibly from the Swan River Formation.

Till plain: The till plain is a broad flat area rising gently toward Duck Mountain. The bedrock is Cretaceous sandstone and shale of the Swan River and Ashville formations. Exposures on the till plain are poor because of widespread swamps impounded by beach ridges. The transition from fluted till to till plain is accentuated by wave washing on the till plain. Lake Agassiz raised beaches are scarce on the fluted till but widespread on the till plain. In places, such as 5 km northeast of Pine River, areas of poorly developed but slightly fluted till occur within the till plain.

The granulometric composition of till in the till plain is similar to that of the fluted till (Fig. 18). Paleozoic carbonate clasts constitute the largest component of the pebble fraction (Fig. 34). The high sand content and the 28% carbonate content of the till sample from Sclater reflect the contribution of the Swan River sandstone to the composition of the till. Samples collected adjacent to Indian Creek moraine have carbonate values of more than 40% in the matrix, indicating their composition was not affected by the local shale and sandstone bedrock. The variation in the composition and texture of this till may be governed by the mode of transport and other factors.

Deltas: Large deltas are situated along the east side of Duck Mountain and Porcupine Hills where major rivers drain the upland. Two large deltas are associated with Pine and North Duck rivers on the east side of Duck Mountain and a small delta is associated with Birch River on Porcupine Hills.

The Pine River and North Duck River deltas are modified Gilbert deltas, consisting of a gently sloping proximal surface and a more steeply sloping distal surface or delta front. The delta fronts have been extensively modified by Lake Agassiz shoreline processes and downcutting by rivers. The smaller delta on Birch River is, however, a well developed river-dominated Gilbert-type delta with a steep delta front. Although there are no well exposed sections, the deltas on the east side of Porcupine Hills appear coarser grained than those on Duck Mountain. The steep foreset slope of the coarser grained Porcupine deltas is characteristic of Gilbert-type deltas. The Duck Mountain deltas may not be true Gilbert-type deltas as they are generally sandy and have lower profiles.

Using the top of the foreset slope as the approximate contact between the topset and foreset beds, the water level at the time of the formation of the Birch River delta was at an elevation of about 366 m. On North Duck River, the change in slope at the topset-foreset contact is at 427 m (Fig. 35). On Pine River the change in slope is at 419 m but, because of the low profile due to post-depositional erosion, this is only an approximation.

The deltas formed as meltwater from the stagnating ice on the upland flowed into ice marginal lakes confined between the Manitoba escarpment and an ice lobe situated in the Interlake. Overflow from an ice marginal lake in the western part of the Swan River valley, through the North Duck spillway, also contributed to the formation of Duck River delta.

Moraines: Three moraines are identified on the Westlake plain: the Cowan moraine, described by Elson (1961); the northward extension of the Grifton moraine, mapped by Klassen (1979); and a small newly identified moraine remnant, named the Sclater moraine (Fig. 8).

The Cowan moraine is a low, west-trending ridge, 2.5 km long and 0.5 km wide, situated 2 km northwest of Cowan. The ridge is composed of highly calcareous till attributed to the Arran re-advance. The upper surface of the moraine is wave washed and covered with a boulder lag and minor gravel deposits, up to 1 m thick.

The northern part of the Grifton moraine, trending north from North Pine River for 20 km, is situated along the edge of the Manitoba escarpment. The moraine is well defined south of the map area in the Grifton-Kulish area, but north of Pine River it is difficult to differentiate it from the hummocky topography characteristic of the escarpment. The morainic belt is 1 to 3 km wide and till knolls and ridges are in places more than 10 m high. The moraine, extending to an elevation of 580 m on the flank of the escarpment, is in places coincident with the most westerly extent of the Arran Till. Along North Pine River, the moraine reaches an elevation of about 490 m, whereas Arran Till rises westward to an elevation of 580 m.

The Sclater moraine situated 3 km north of Sclater, along the edge of the Upper Campbell scarp, is 4 km long. The moraine, forming a singular ridge over 30 m high, is up to 1 km wide and composed of till. A boulder lag, gravel, or other evidence of wave washing is not associated with the

Figure 34: *Large Precambrian erratic in the Arran Till exposed at Pulp River on the Westlake plain. Note the quarter for scale.*

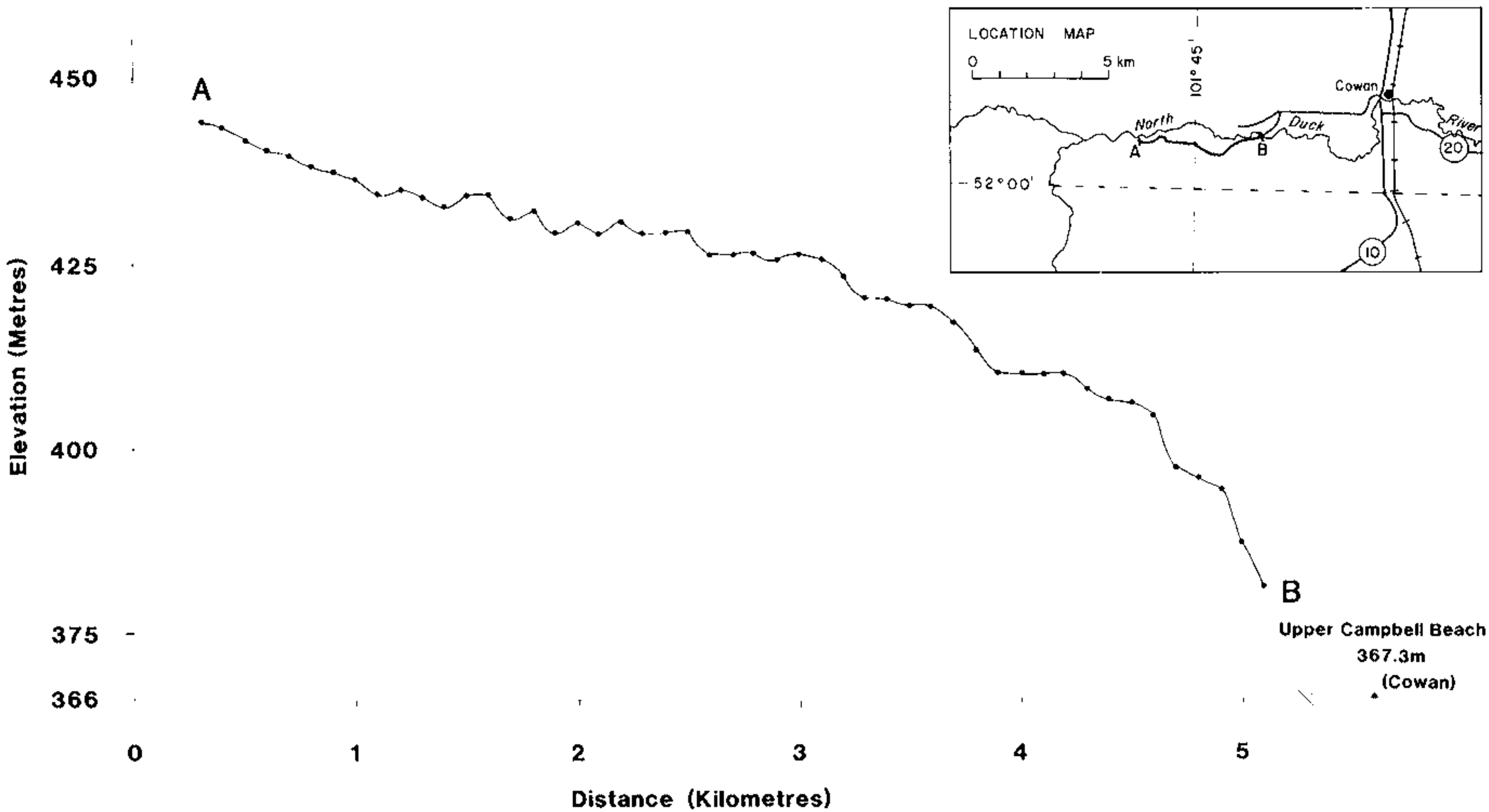


Figure 35: Profile along the North Duck River delta. Note the river and beach terraces that have modified the profile.

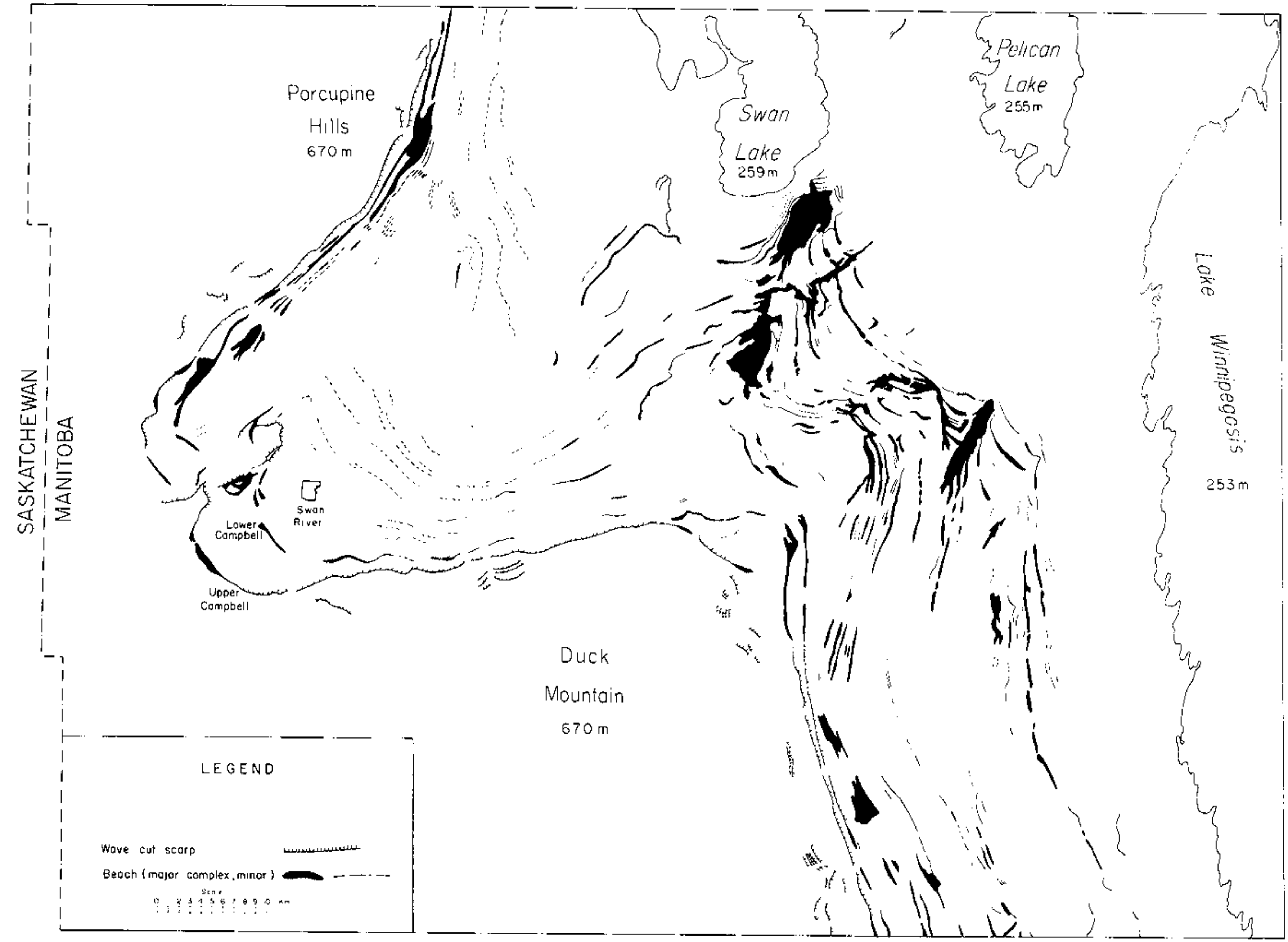


Figure 36: *Lake Agassiz strandlines.*

Figure 37. *Upper Campbell wave-cut terrace, 5 km north of the community of Pine River.*

ridge. The Sclater moraine is correlated with the Cowan moraine; the northward extension of it joins the Cowan moraine at approximately right angles, 1 to 2 km north of Cowan. These moraines are recessional features that formed shortly after the Arran lobe retreated from the Grifton moraine.

Lacustrine sediments and abandoned beaches

Deep water lacustrine sediments are scarce on the Westlake plain. West of Sagemace Bay, to an elevation of about 305 m, drained sloughs are floored by clayey silt of variable thickness. Texturally, the sediment consists of 12% sand, 67% silt and 21% clay. The sediment is poorly exposed and its origin is problematic. The absence of fossils and the occurrence of Lake Agassiz beach levels cut into the sediment suggest deposition in Lake Agassiz. However, the occurrence of similar sediments along valleys on the lowlands east of the alluvial fans at the base of the escarpment suggests some of these sediments may be distal alluvial fan deposits.

In the Birch River area, widespread accumulations of tan silt are found downslope or basinward of Lake Agassiz beaches. The bedding is poor but in places it is accentuated by manganese oxide staining. Dropstones are present, but scarce.

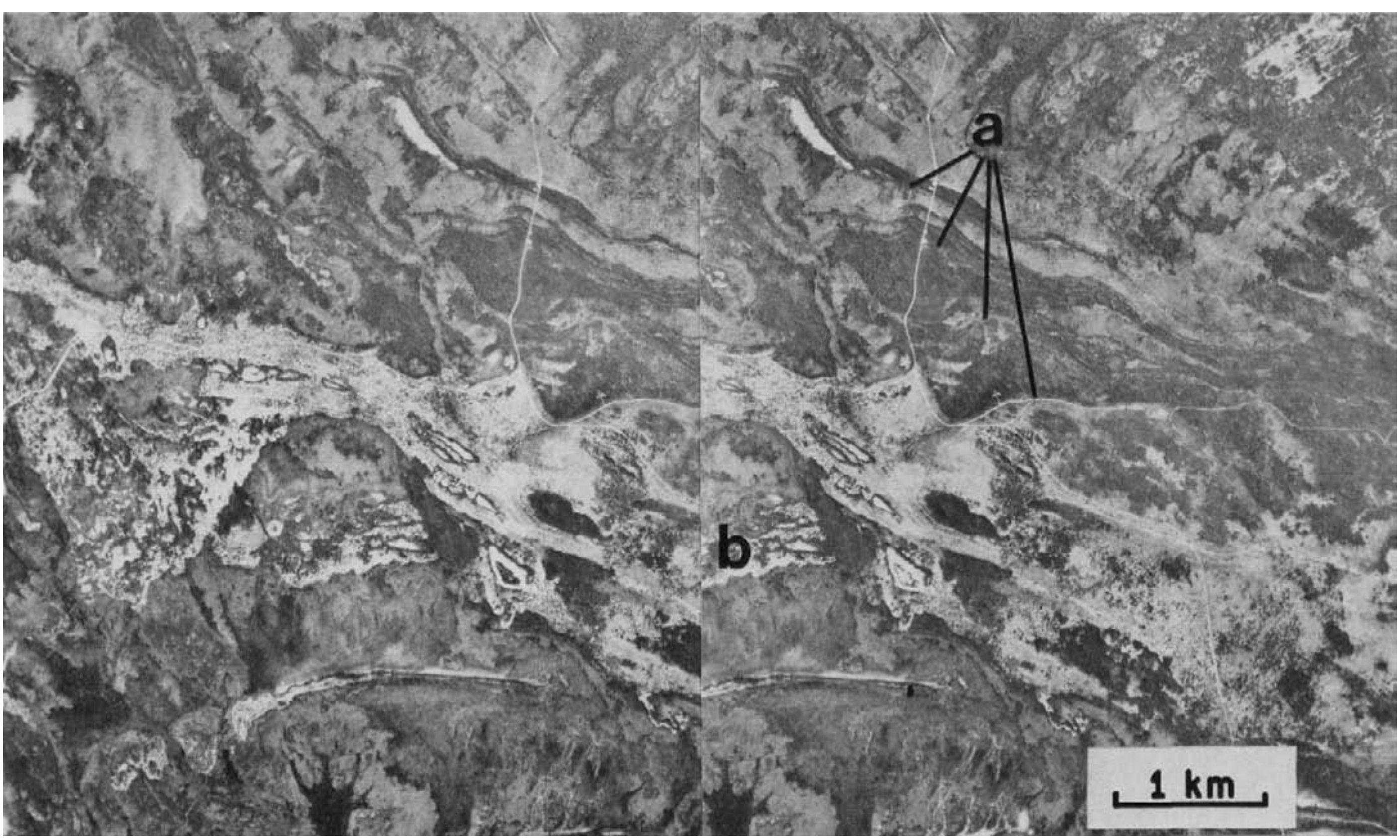


Figure 38: *Stereopair showing Lake Agassiz beaches (a) and sand dunes (b) on the Kettle Hills. North is to the right.*

Abandoned strandlines, related to the stepwise draining of glacial Lake Agassiz, are a common feature of the Westlake plain. The highest beaches are found on the North Duck River delta, west of Cowan, at an elevation of 427 m, 60 m above the crest of the Upper Campbell beach. Wave-cut scarps and minor beach segments can be traced south to the edge of the map sheet.

The most prominent strandlines which can be traced uninterrupted through the map area are those of the Upper and Lower Campbell levels (Fig. 36). The Upper Campbell strandline is a wave-cut scarp along the east side of Duck Mountain (Fig. 37). In the Cowan area, it is a beach at an elevation of 367 m. On the east side of Porcupine Hills, the Upper Campbell strandline is also a wave-cut scarp. The Lower Campbell strandline is a continuous, well developed beach ridge. East of the Lower Campbell beach, a succession of lower beaches extends almost to Lake Winnipegosis.

In the Kettle Hills-Spence Lake area and east of Spence Lake, 22 beach ridges can be discerned (Fig. 38). Although some of these ridges are composed of well sorted sand and have low cross-sectional profiles (Fig. 39), their lateral extent suggests they are related to specific water levels. Other less continuous sand ridges may be offshore bars that do not mark water planes. The beach ridges occur at elevations between 274 m and the Lower Campbell beach, with elevations of 350 m at Pine River and 360 m west of Bowsrnan.

The beach ridges below the Lower Campbell beach, west of Birch River, are noteworthy because of their number and good exposure. The prominent ridge on which Highway 10 is situated is only one of this series of well formed ridges. This beach, at an elevation of 349 m, approximately 11 m below the Lower Campbell beach, is correlated with the McCauleyville level defined by Johnston (1946). Ridges east and west of the highway are related to storm beaches, as indicated by the washover crossbeds overlying foreshore gravel facies (Fig. 40). The Lower Campbell and McCauleyville beaches typically consist of low angled foreshore bedding, dipping 8°-10° toward the east (95°-135°).

Postglacial features

Alluvial fans: Alluvial fans are found along the base of the Manitoba escarpment where rivers draining the uplands descend to the Westlake and Swan River plains. The alluvial fans are easily discernible on aerial photographs, showing typical fan shapes with distributary channels radiating from the apex (Fig. 41).

Only the Sclater alluvial fan was investigated in detail. This fan is forming at the base of the Upper Campbell terrace; it extends east for more than 4.5 km and drops 12 m in elevation. The section investigated is situated 2 krn east of the Lower Campbell beach. The lowest 1 m of the 4 m section consists of structureless greyish white sand. A weakly developed

Figure 39: Beach ridge (indicated by arrow) on the Kettle Hills. Note the glacial erratics in the foreground.

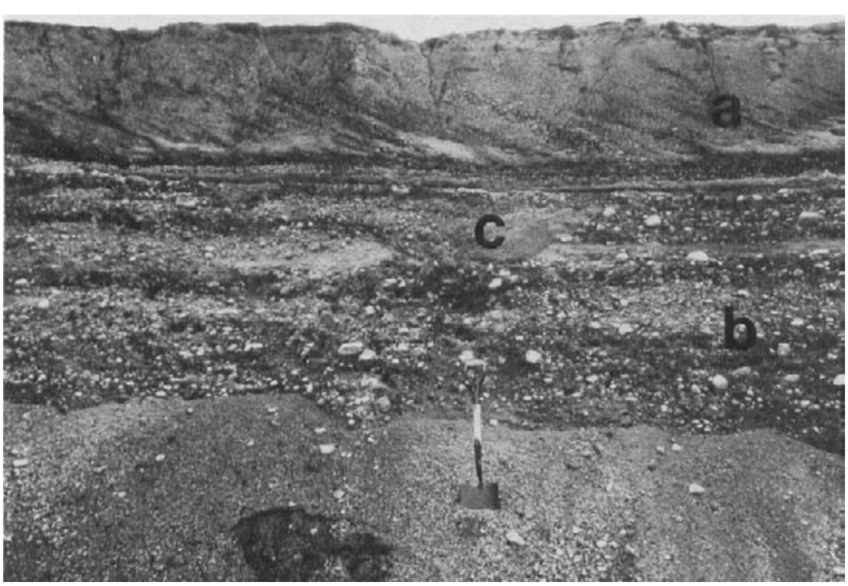


Figure 40: Washover crossbeds (a) overlying foreshore gravel (b) in the McCauleyville beach, 2 km southwest of Birch River. Lakeward (left) dipping crossbeds (c) are present in the channel cut in the foreshore facies.

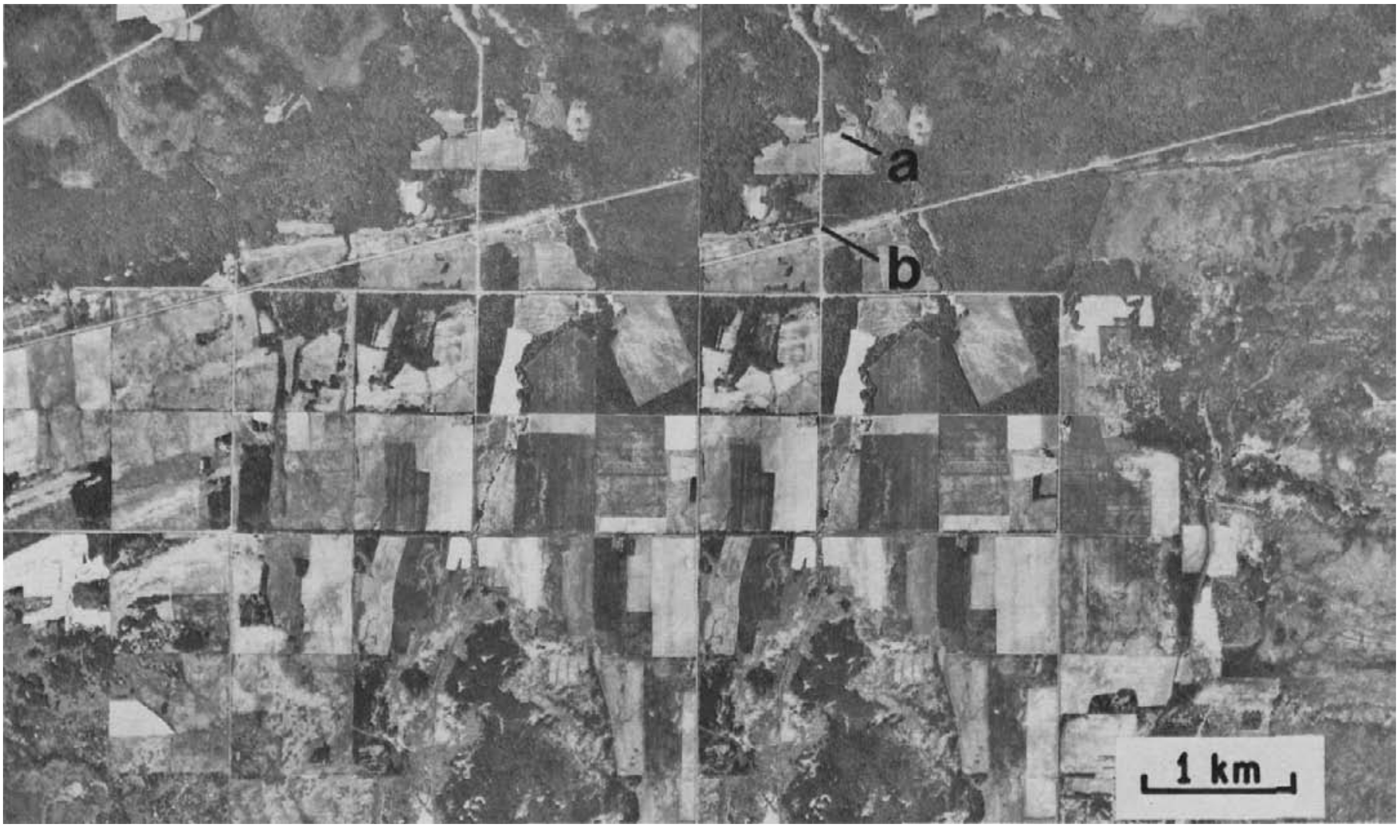


Figure 41: *Stereopair showing the Sclater alluvial fan, partly outlined by cleared farmland. Note the Upper Campbell wave-cut terrace (a) and the Lower Campbell beach (b). North is to the right.*

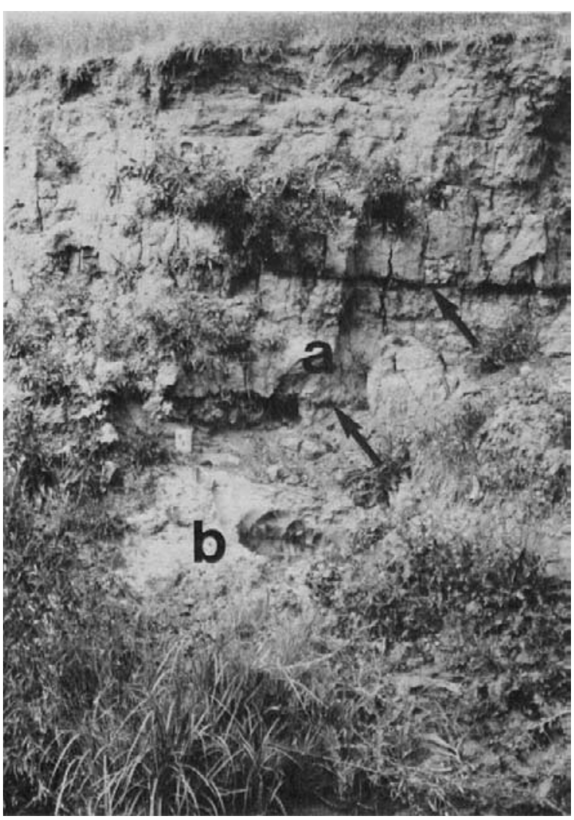


Figure 42: *Exposure in the Sclater alluvial fan 2.2 km east of Sclater showing alluvium (a), Swan River sandstone (b). Two prominent paleosols are indicated by arrows.*

paleosol with minor organic and rust coloured oxidation occurs at the contact with the overlying greyish silty sand. The sorting of the lower white sand indicates it is probably the Cretaceous Swan River Formation (Fig. 42). The overlying sediments are finer textured, more poorly sorted and are attributed to alluvial fan deposition. The texture of the sediments is shown in Figure 43. The fine textured clayey silt and sandy silt that constitute the alluvial fan are thinly bedded and show some crossbedding. Prominent paleosols, composed of organic accumulations 5 cm thick, are found 1.7 m and 2.7 m from the surface (Fig. 42 and 44). Two minor

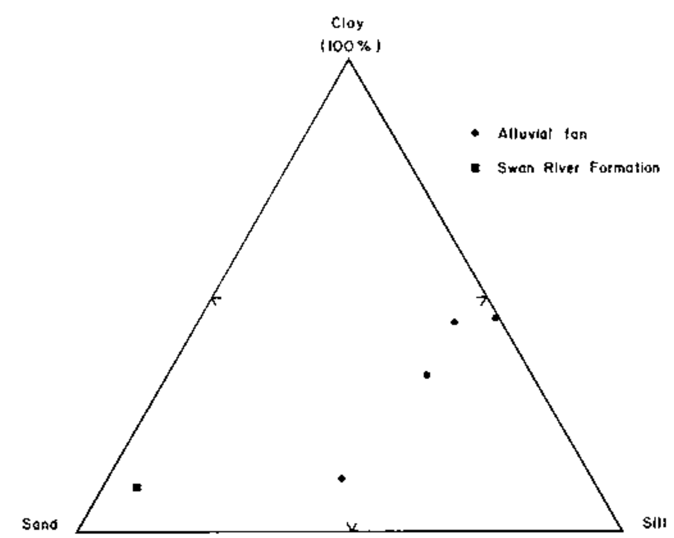


Figure 43: *Grain size distribution of alluvial sediments and Swan River sandstone from the Sclater fan.*

paleosols occur between the two prominent paleosols, and another occurs 20 cm above the upper paleosol. The uppermost paleosol is associated with large, rooted, black spruce tree stumps, that have been radiocarbon dated at 225 ± 75 years BP (BGS-1116) (Fig. 44). The prominent paleosols 0.2 m and 1.2 m below the stumps have been radiocarbon dated at 840 ± 50 years BP (GSC-2761) and 3830 ± 125 years BP (BGS-726), respectively.

The alluvial sediments are fossiliferous, with mammals represented by *Alces* (moose) and *Lepus americanus* (snowshoe hare), and molluscs represented by *Promenetus umbiculatus*, *Retinella electia*, *Lymnaea parva* and *Helisoma trivolvis*. The environment suggested by this fauna is consistent with the geomorphological and stratigraphic evidence of semi-permanent standing water.

Sand dunes: Sand dunes, common over a wide area south-southeast of the Kettle Hills, are underlain by the Cretaceous Swan River Formation. Most dunes are stabilized by vegetation, and only a few areas show evidence of being active. One area where dunes are still active, 6.5 km northeast of Cowan, has some blowouts (Fig. 45). The area, however, has been modified by human activity and the blowouts could be natural or due to truck traffic, wood cutting, dirtbikes, etc.

The dune-covered area is relatively flat, with a maximum relief of 2 m. On aerial photographs the dunes appear as ribbons, closely parallelling Lake Agassiz beach ridges, indicating formation by reworking of beach sediment (Fig. 46). Some dunes are parabolic with horns extending toward the west indicating formation by westerly winds. The internal structure was not examined as there are no known sections. The dunes, although classified as parabolic, comprise both blowout and parabolic dunes and are largely stabilized.

Landslides: A large landslide in the form of rotational slumps on the east side of Porcupine Hills, 11 km north of Birch River, is part of a very extensive landslide area located to the north (Scott and Brooker, 1968; Wickenden, 1945; and Nielsen and Watson, 1985). The slide covers many tens of square kilometres and the toe comprises over 20 m of mixed Cretaceous shale, sandstone and a variety of Quaternary sediments (Fig. 47). The slide truncates Lake Agassiz beach ridges, indicating a maximum age of about 9500 years BP (Nielsen et al., 1984). Wood from the Bellsite area, buried by the slide, was radiocarbon dated at 340 ± 70 years BP (BGS - 1040) indicating the slide area was active in historic times (Nielsen and Watson, 1985).

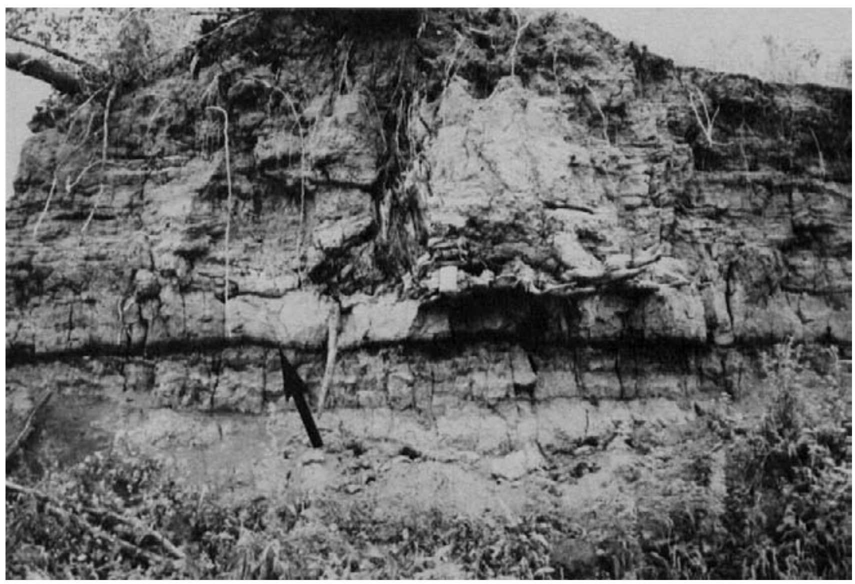


Figure 44: Buried spruce stump (Picea sp.) radiocarbon dated at 225 ± 75 years BP (BGS- 1116). The underlying paleosol (arrow) dated at 840 ± 50 years BP (GSC — 2761).

Figure 45: Blowout dune, 1.5 km south of Spruce Lake.

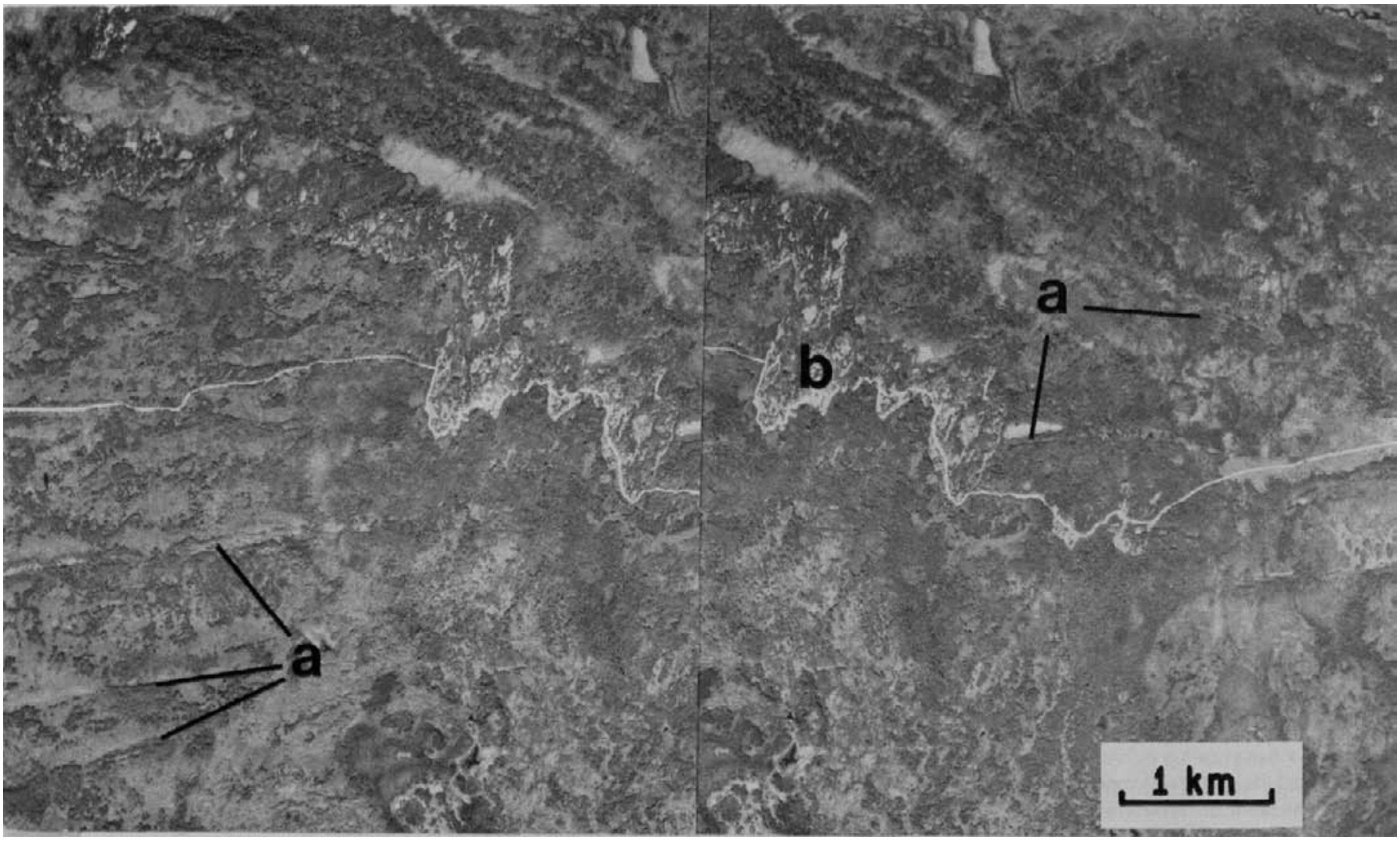


Figure 46: *Stereopair showing parabolic dunes (a) along Lake Agassiz beach ridges (b), 20 km east of Cowan. The wind was blowing from the west (top). North is to the right.*

SWAN RIVER PLAIN

Drift thickness

Little (1973) mapped the drift thickness in the Swan River plain using available borehole information. Throughout most of the valley, the overburden is less than 30 m thick. However, along the centre of the valley, from Lenswood to Thunderhill, there is a narrow trough where drift thicknesses exceed 30 m, and west of Swan River drift thicknesses greater than 45 m are common. The deep drift fills a valley carved by the ancestral Swan River during the Tertiary. Two boreholes, 8 km and 11 km west-southwest of Swan River, record overburden 68 m and 88 m thick, respectively. Several holes in the Minitonas area, and one hole 13 km west of Bowsman, also record anomalous overburden thicknesses of over 38 m. These areas of anomalously thick drift are found adjacent to large ice-thrust bedrock hills.

Figure 47: *Cretaceous shale (a) overlying till (b) in the toe of the landslide, 12 km north of Birch River.*

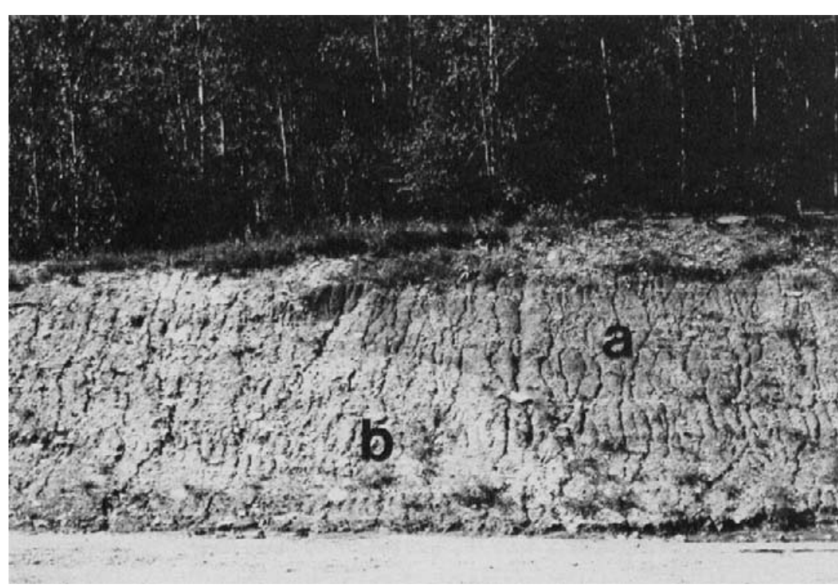


Figure 48: *Arran Till (c) and (e) and interbedded non-glacial sand (d) at site 183 in Swan River. The till is overlain by glaciolacustrine silt (b) and wind-blown silt (a). Note the deformation in unit (d).*

Till stratigraphy

Multiple till sections are exposed at several sites along Woody River and, in places, along Swan and Roaring rivers. A 6 m section is exposed where Highway 10 crosses Swan River (Fig. 48). The base of the section consists of 1.5 m of dark grey clay till (Fig. 49). Black shale clasts are common and the till is jointed with manganese staining and associated selenite crystals. The fabric of the pebbles indicates ice flow toward the southwest (Fig. 50). The texture of the till is clayey and shale constitutes up to 50% of the coarse sand fraction (Fig. 51). This till is overlain by a 1 m thick bed of silt and sandy silt. The lower part of this silty unit shows horizontal laminations that grade upward into coarser climbing ripples with a current direction toward 005°. The upper part of the unit is highly deformed. Faults in the sandy silt strike 140° and dip 25°-30° to the west indicating compression from the northeast (050°).

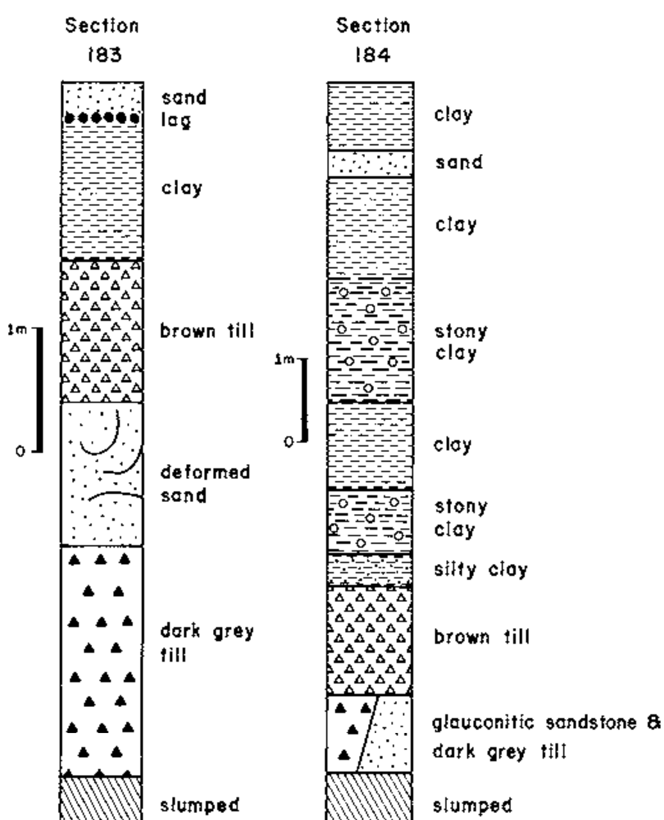


Figure 49: *Stratigraphy at sites 183 and 184 on the Swan River plain.*

The deformed bed of sandy silt is overlain by brown or "buff" till between 0.5 and 1.5 m thick. The lower contact is straight and sharp, but the upper contact is irregular, with up to 1 m of relief (Fig. 48). Shear planes, represented by boulder pavements, are present. Texturally, this till is sandier than the underlying clay till and contains numerous large dolomite erratics, some over 1 m in diameter. Shale clasts are absent but marcasite concretions, from the Swan River Formation, are common. The fabric is southwesterly, identical to that of the lower till. The sandy texture, the marcasite concretions, and the fabric indicate this till was derived from the comminution of Swan River sandstone and deposited by southwesterly flowing ice. Both tills are correlated with the Arran re-advance. One metre of tan coloured clayey silt overlies the brown till, filling the irregular upper surface of the till that, in places, forms almost vertical pinnacles (Fig. 48). The preservation of these features indicates instantaneous transgression into deep water as the ice sheet retreated. The clayey silt was deposited immediately after deglaciation in an early pro-glacial lake which occupied the western part of the Swan River plain. As deglaciation proceeded, the lake spread northeastward and became part of Lake Agassiz. Where the till was exposed to wave attack, a boulder lag formed during the regression of Lake Agassiz caps the glaciolacustrine clayey silt (Fig. 48).
Up to 1 m of Holocene eolian sand overlies the lag and forms the upper unit in the section.

A similar stratigraphy is exposed in a highly slumped section (site 184) outcropping where Highway 10 crosses Roaring River (Fig. 49). At the base of the section dark grey shaly till overlies glauconitic sandstone of the Swan River Formation. The dark grey till is overlain by sandy brown till that, in turn, is overlain by a thick sequence of glaciolacustrine silt and clay. During deposition of the glaciolacustrine silt and clay, icebergs deposited two beds of stony lake clay. The stony lake clays show conformable contacts at the top and at the bottom and are texturally similar to the underlying till (Fig. 52). The stony lake clay can be differentiated from till by the absence of shearing. This site overlies the Swan River Formation, resulting in both tills being sandy compared to the tills at site 183.

Two poorly exposed tills outcrop along West Favel River where it crosses Provincial Road 485. Approximately 1 m of dark grey shaly-rich till overlies the Favel Formation. Although the till is clayey, it shows a slight enrichment in sand, attributed to the addition of sand from the Swan River Formation (Fig. 53). The overlying 2 m thick brown till contains relatively fewer shale clasts and more sand derived from the Swan River Formation. The upper brown till is correlated with the Arran Till. The underlying

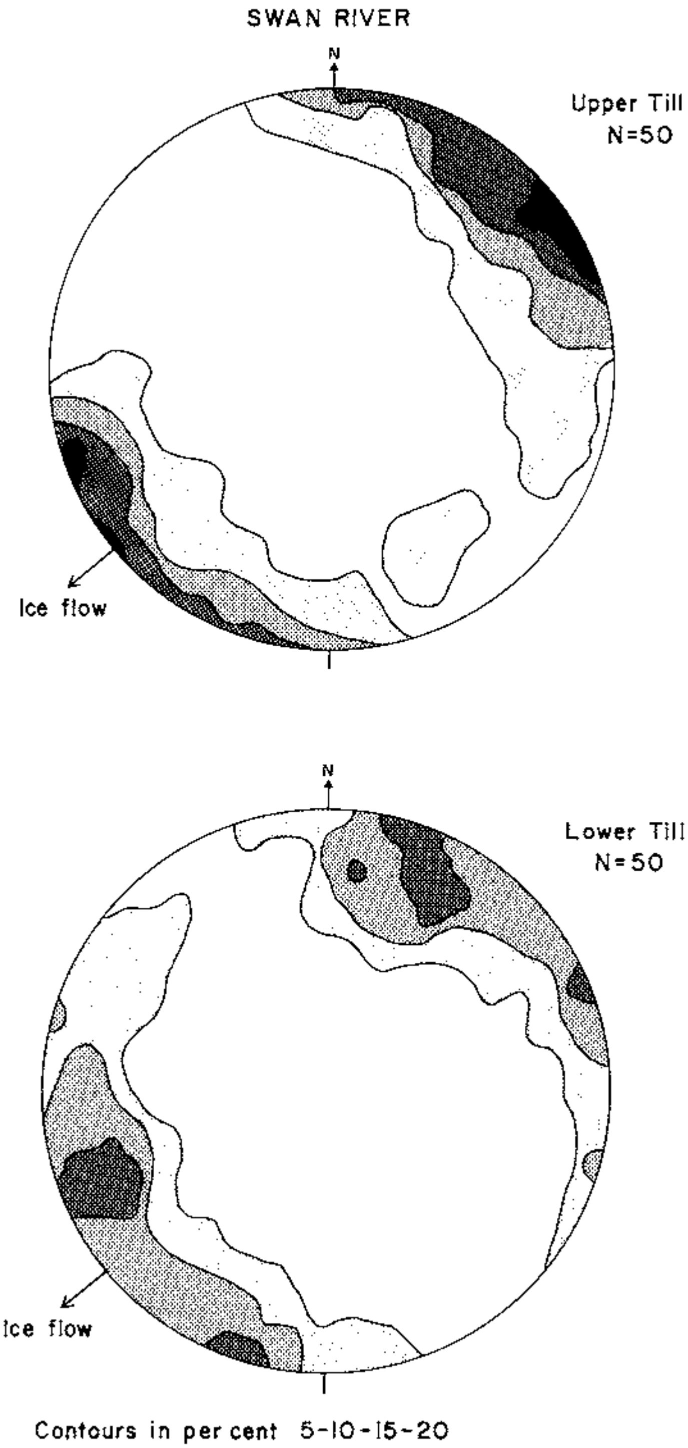


Figure 50: *Pebble fabrics of the tills exposed at site 183.*

shale-rich till may be the bottom of the Arran Till where it comes into contact with the shale bedrock or, alternatively, it may be correlated with the Zelena Till.

Sections exoosed in backhoe pits along Mudlin and Maple creeks, on the south side of Porcupine Hills, show brown Zelena Till overlain by light brown, highly calcareous Arran Till (Nielsen and Gale, 1983). The texture and composition of the Arran and ZelenaTills in this area are more typical of the Westlake plain and Porcupine Hills because they have not been influenced by the addition of sand from the Swan River Formation.

Glacial features

Till plain: Till is common at the surface in the southwestern part of the Swan River plain and on the flanks of Porcupine Hills and the Duck Mountain upland. In the northeastern part of the plain, the till is overlain by glaciolacustrine sediments. Glaciodeltaic sediments are common in parts of the southwestern plain. Fluted till similar to that of the Westlake plain outcrops east of Bowsman and ice-thrust hills are scattered about the valley; otherwise, the till plain is flat with little relief.

The carbonate content of the matrix of the surface till ranges from 16 to 37% (Fig. 19). Similarly, the carbonate content of the pebble fractions and coarse sand fraction is higher than in the surrounding areas (Fig. 18) except in the Westlake plain.

The texture of the surface till is variable and ranges from sandy to silty (Fig. 17). Over and immediately down-ice from the Swan River Formation, the till is very sandy. By contrast, the till overlying the shale of the Ashville and Favel formations is silty and clayey. Some samples, for example 173 and 199, with modes in both the sand and silt fractions, indicate incorporation of both sandstone and shale bedrock.

Ice flow indicators: The most conspicuous ice flow directional indicators are the ice-thrust blocks dominating the valley. Of the four prominent hills — Thunder Hill, Minitonas Hill, Kenville Hill and Lambert Hill – Thunder Hill is the largest. It is 7 km long, 4 km wide and rises over 150 m above the surrounding plain (Fig. 54). Thunder Hill, oriented toward 250°, is drumlinoid in shape, being higher and wider toward the northeast. The internal structure of Thunder Hill was mapped by Moran (1969,1971). Drilling by Wickenden (1945) and Moran (1969) showed that the Cretaceous sediments are repetitive and interbedded with Pleistocene sediments, indicating glacial thrusting and stacking (Fig. 55A). The orientation of the thrust blocks composing Thunder Hill, as well as the orientation of the hills and streamlined forms in the surrounding area, indicates emplacement by west-southwesterly flow. The site of decollement is not certain but may be a southwesterly oriented bedrock depression located 6.5 km west of Swan River (Little, 1973). This depression, although defined only by two drill holes, appears to have the same general dimensions as Thunder Hill. If this is the source, the thrust block(s) have been transported a distance of about 17 km.

The stratigraphy of the other three thrust blocks is less well known. Three Shell Oil exploratory wells on Kenville Hill indicate some repetitive Cretaceous sequences indicative of stacking (Fig. 55B). Lambert Hill and Minitonas Hill are unexplored but bedrock depressions to the northeast of both hills suggest a similar origin. The orientation of all four ice thrust hills indicates ice flow was toward the southwest, parallel to the axis of the valley.

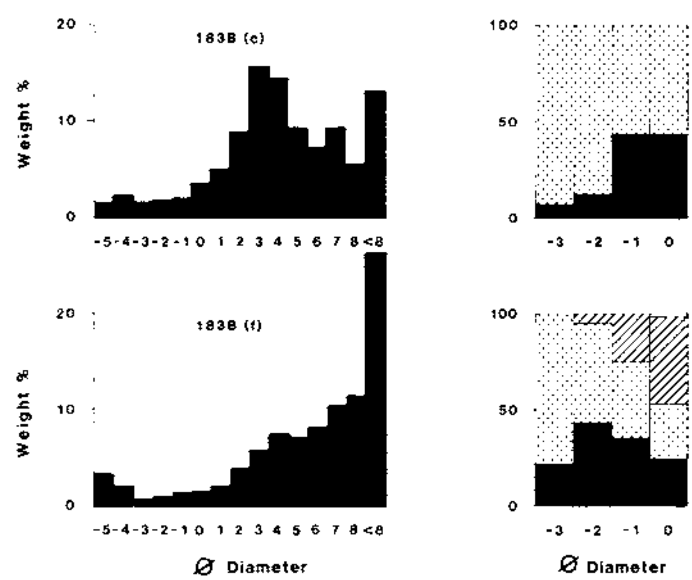


Figure 51: *Grain size distribution and pebble composition of the tills exposed at site 183.*

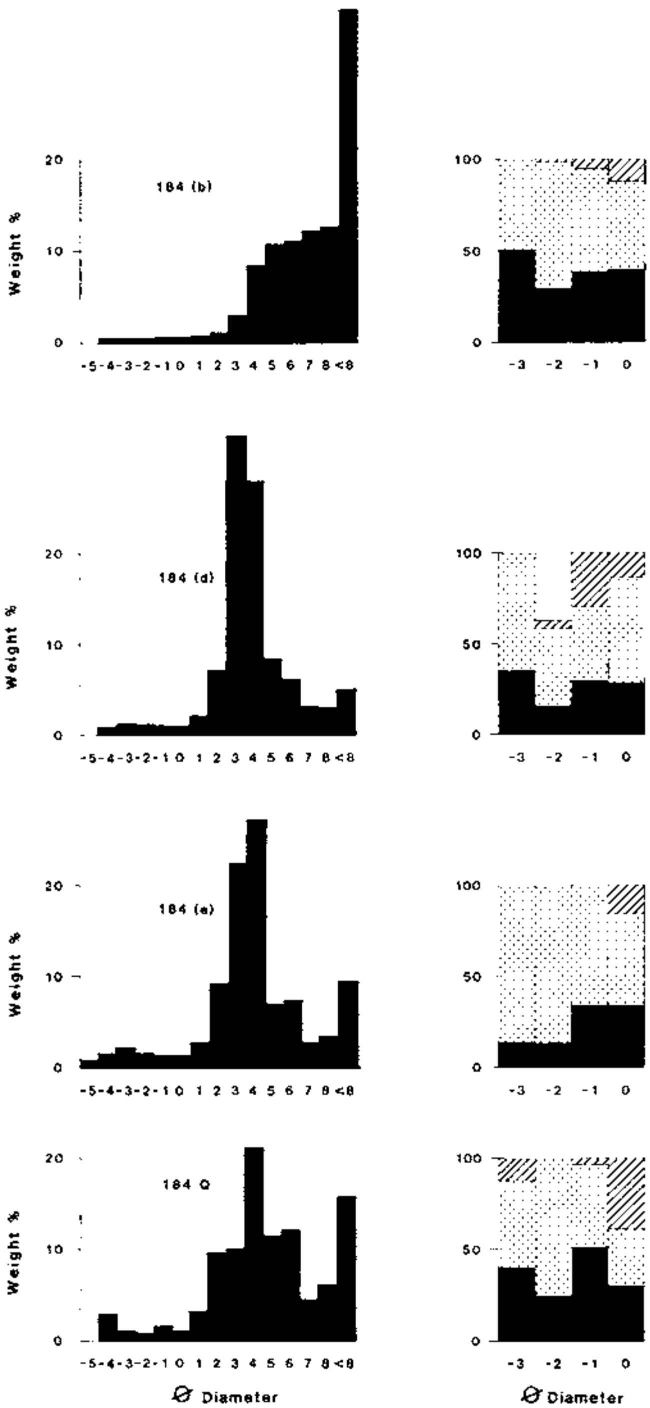


Figure 52: *Grain size distribution and pebble composition of the tills exposed at site 184.*

The carbonate content (31%) of a single till sample from the top of Thunder Hill indicates Arran Till forms the youngest sediment. At several sites, notably 183 and 195 (Fig. 56), the Arran Till shows glaciotectonic deformation indicating it was the last ice advance that was responsible for the thrusting.

Deformation structures produced by glacier overriding of sediments were noted at two locations. At site 215, 2 km southeast of Renwer, folded blocks of shale in the till indicate ice flow towards 210° (Fig. 57). Recumbently folded till with low angled shears on the north side of the valley at site 175 indicates ice flow toward 290° (Fig. 58). Fluted till east of Bowsman indicates ice flow towards 220°.

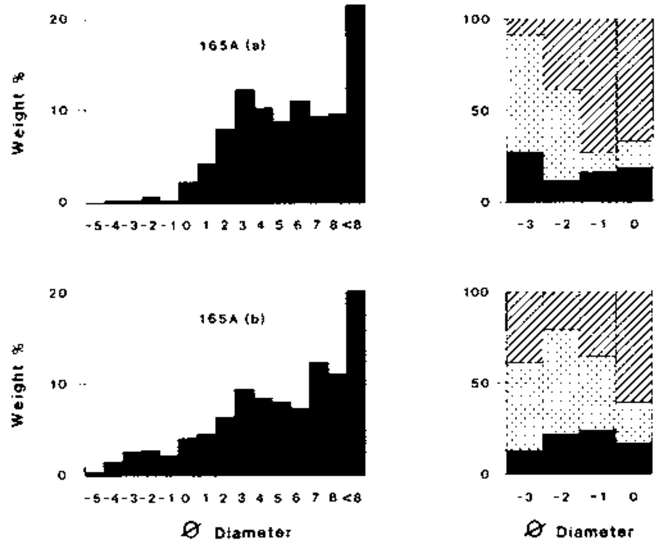


Figure 53: *Grain size distribution and pebble composition of the tills exposed at site 165.*

The orientation of the ice thrust blocks, flutes, deformation structures and the till fabric indicate the last ice advance to affect the area flowed southwestward along the axis of the valley. This ice advance is correlated with the Arran readvance described by Klassen (1979).

Ice marginal features: Ice marginal indicators are scarce in the Swan River valley. Klassen (1979) mapped the Harvey Lake moraine located between 6 and 7 km south of Benito. This moraine, marking the maximum limit of the Arran readvance, is well formed in the adjacent part of Saskatchewan but is barely discernible in Manitoba. Similarly the western part of the Bowsman moraine, on the north side of the valley, is also poorly defined. The highly calcareous Arran Till, comprising the ice marginal sediments in this area, forms a hummocky stagnation moraine similar to that on Porcupine Hills (Fig. 59). The deltaic deposit, found 10 km north of Big Woody on the south side of Porcupine Hills, is of uncertain origin. The steep eastern scarp, the distal fining toward the west, and the presence of kettle hole depressions in the north (E. Gryba, pers, comm., 1982) indicate the deposit might have been laid down as a kame delta, with ice abutting the east side. Alternatively, the deposit may have been laid down as a delta in an early ice marginal lake by glacial meltwater flowing south from Porcupine Hills along the ancestral Hubbell Creek. Deltas similar to this are common where rivers and creeks drain the escarpment. The steep eastern side of the deposit may have been eroded subsequently.

Outwash and glaciolacustrine deposits: The western end of the Swan River valley in Saskatchewan is composed of extensive sand and gravel deposits (Moran, 1969 and Klassen, 1979). As the Arran sublobe retreated eastward into the Manitoba Plain, the ancestral Swan River drained south of Thunder Hill into a late glacial, ice-marginal lake, termed Glacial Lake Swan, occupying the western part of the Swan River valley. Gravel deposited in Saskatchewan grades eastward into sand, silt and clay between Benito and Minitonas in Manitoba. North of Thunder Hill, the ancestral Bowsman River formed similar, although not as extensive, deposits as along Swan River. The outwash along Swan River forms a large flat plain, sloping gently to the east. A prominent wave-cut scarp was eroded into the plain during the Upper Campbell stand of Lake Agassiz. The scarp, cut into silt deposits of the distal outwash fan, can be traced for 43 km along the north side of Duck Mountain. The western part of the outwash above the Upper Campbell strandline consists of poorly exposed crossbedded sand (Fig. 60). This sandy area has undergone extensive Holocene erosion and is dissected by numerous dry creeks, giving this area a gently rolling topography (Fig. 61). Below the Upper Campbell level, the silty sediments of the outwash have undergone extensive reworking by Lake Agassiz.

Figure 54: *Thunder Hill as seen from the south.*

Glacial meltwater, flowing north from Duck Mountain and south from Porcupine Hills, deposited outwash sediments along the sides of the Swan River valley. A large outwash deposit is found where Roaring River enters the Swan River valley and minor similar deposits are situated where Hubbell Creek and Bowsman River descend to the valley floor (Fig. 62). The Bowsman, Hubbell and Woody deposits in the northwest are flat-topped and in places terraced suggesting they were deposited as river-dominated deltas, possibly in a small restricted ice-marginal lake. The Swan River and Roaring River deposits have gently sloping profiles and were deposited probably as wave-dominated deltas.

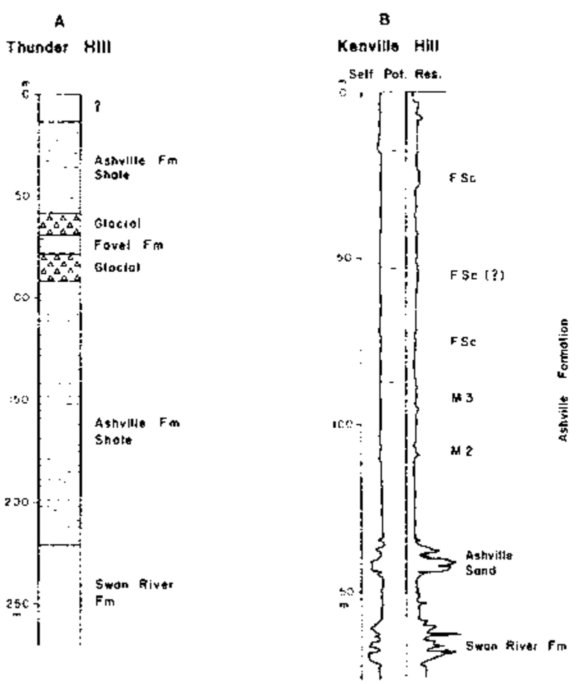


Figure 55: *Stratigraphy of Thunder Hill (a) and Kenville Hill (b) showing repeated Cretaceous bedrock sequences and interbedded till. The Thunder Hill section is drawn from the description by Wickenden (1945). The Kenville Hill section is based on Shell Oil structure test holes.*

Another notable outwash deposit is located 8 km southeast of Minitonas, on the north side of Duck Mountain. This outwash is poorly sorted, shale-rich gravel, ranging between 5 and 10 m in thickness (Fig. 63). Large-scale crossbedding in the upper part of the gravel indicates a paleocurrent direction between 40° and 60°, parallel to the edge of the escarpment. The outwash is capped by deep water stony lake clay and flow till. This deposit, at an elevation of 410 m, is believed to have formed as a kame terrace, by glacial meltwater flowing eastward into Lake Agassiz from the ice marginal lake in the western end of the Swan River valley, when ice occupied most of the valley. This kame terrace is at approximately the same elevation as the Woody, Hubbell and Bowsman deltaic outwash deposits. The apices of the Swan River and Roaring River deltas are higher than the kame delta and must have been graded to an initially higher water level. The floor of the Swan River spillway in Saskatchewan was cut to approximately 410 m (Fig. 64), whereas the top of the Swan River delta is at an elevation of 473 m (1550'). The down-cutting of the delta may be correlated to the formation of the kame terrace southeast of Minitonas.

Glaciolacustrine plains and abandoned beaches: Much of the eastern half of the Swan River valley is blanketed with silt and fine sand deposited in Lake Agassiz. The littoral sand and silt is of variable thickness and fills depressions in the underlying till surface, resulting in a generally flat plain. The sediment below the Upper Campbell level of Lake Agassiz was derived largely by the reworking of previously deposited, fine textured, glaciodeltaic outwash and Arran Till.

Beach ridges, including offshore bars, spits and wave-cut terraces are common throughout the Swan River valley and are especially numerous below the Upper Campbell level (Fig. 36). Minor beach ridges are found south of Minitonas, above 396 m (1300 ft.). Johnston (1946) measured the highest of these beaches at about 420 m (1380 ft.) and correlated them with the Herman levels of Lake Agassiz.

The Upper Campbell level forms a prominent wave-cut scarp (Fig. 65) that can be traced continuously along the north side of Duck Mountain, northwest to the south side of Porcupine Hills, and northeast past Birch River to beyond the map area (Fig. 36). The only beaches associated with this level are found where the Upper Campbell strandline crosses the Swan and Woody rivers.

The Lower Campbell level marked by beaches that can be traced almost continuously throughout the valley, parallel to the Upper Campbell terrace. The beaches, composed of sand and gravelly sand, show a variety of sedimentary structures indicative of a high energy nearshore environment (Fig. 66). Nielsen et al. (1984) showed from the orientation of spits, spit platform cross-stratification and chenier ridges that the Upper and Lower Campbell beaches and wave-cut scarps were formed by anti-clockwise circulating currents in the Swan River embayment.

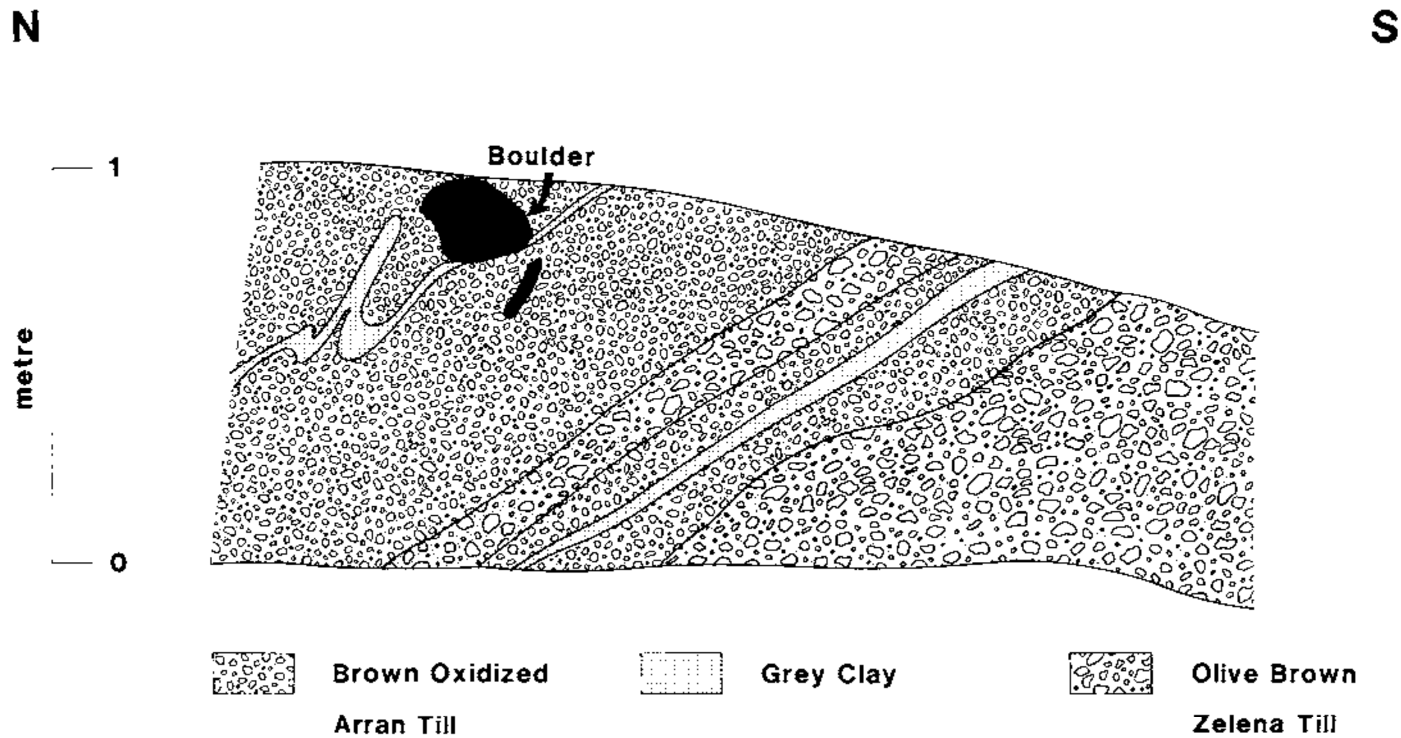


Figure 56: The contact between the Arran Till and Zelena Till striking 285° and dipping 25°N at site 195.

Radiocarbon dates of 10300 ± 200 years BP (BGS — 617), 9500 ± 150 years BP (BGS — 840) and 9400 ± 125 years BP (BGS — 887) on bison bone, from a spit between the Upper and Lower Campbell levels, 14 km northwest of Swan River, indicate these features were formed during the Emerson Phase of Lake Agassiz (Nielsen et al., 1984; Teller and Thorleifson, 1983).

Beaches below the Lower Campbell level, with the exception of the McCauleyville beaches in the Birch River area, are composed mainly of sand and in places minor pebbly sand. Many of these lower levels though discernible on aerial photographs are not obvious on the ground. These lower beaches extend to the Burnside level at an elevation of about 290 m (950').

Levelling across the almost continuous Upper and Lower Campbell strand lines, at a number of sites within the Swan River valley (Fig. 67), indicates the former water planes have been deformed substantially in the last 9500-10 000 years. The results of these surveys are listed in Table 1.

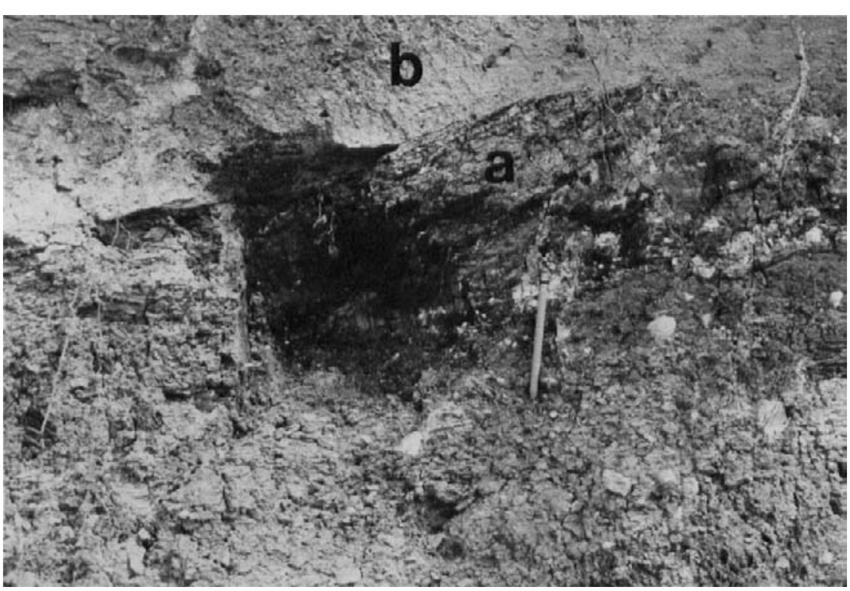


Figure 57: Folded shale inclusion (a) in Arran Till (b) at site 215. Ice flow was toward 210° (right).

Figure 58: *Deformed flow till (a) and interbedded sand and gravel (b) at site 175. Ice flow was toward 290° (right).*

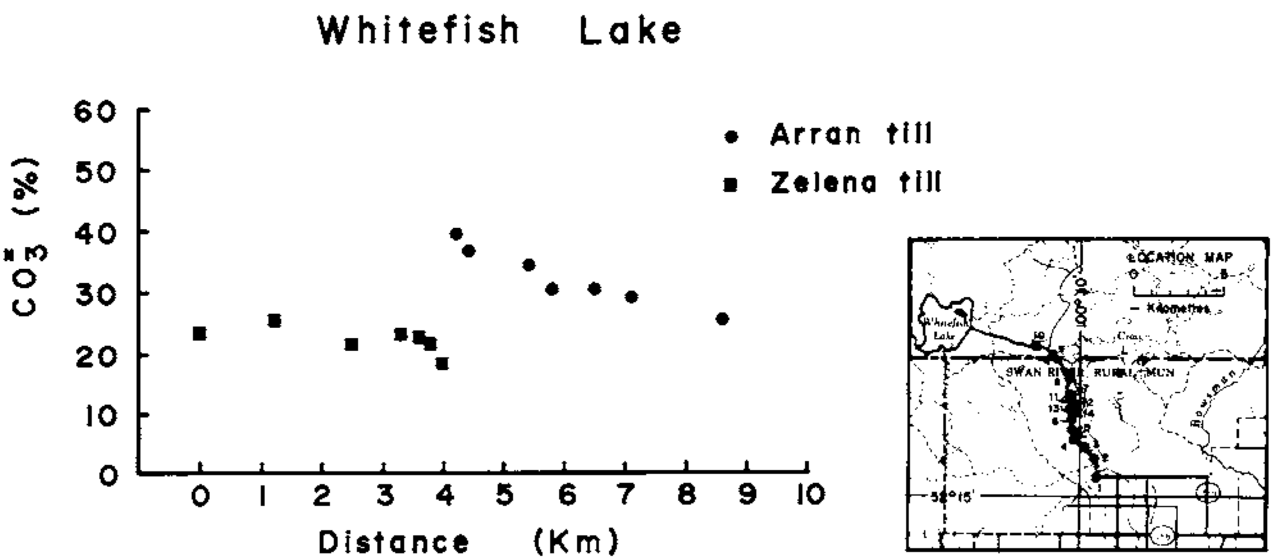


Figure 59: *Carbonate content of the less than 63 micron fraction of till samples from the south side of the Porcupine Hills.*

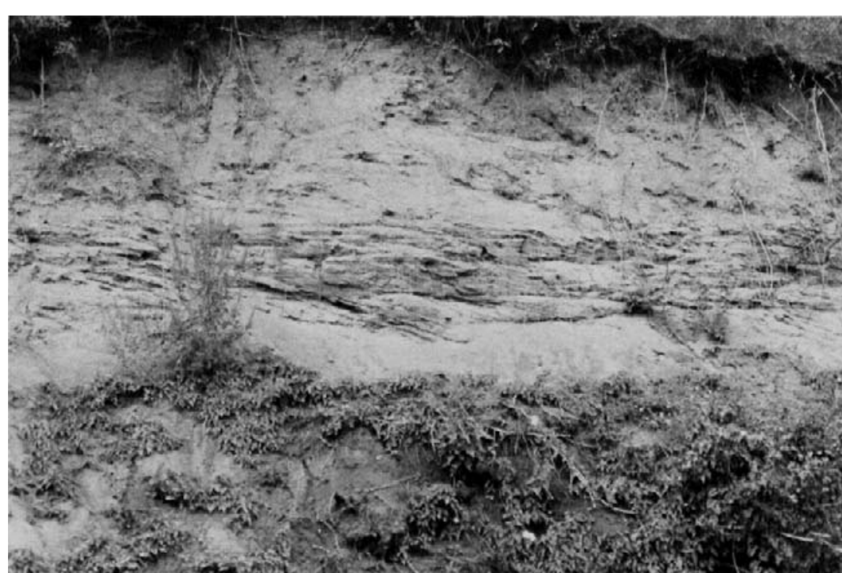


Figure 60: *Fluviodeltaic sand of the Swan River delta, 6 km north of Benito.*

Figure 61: *Eroded fluviodeltaic surface southeast of Thunder Hill.*

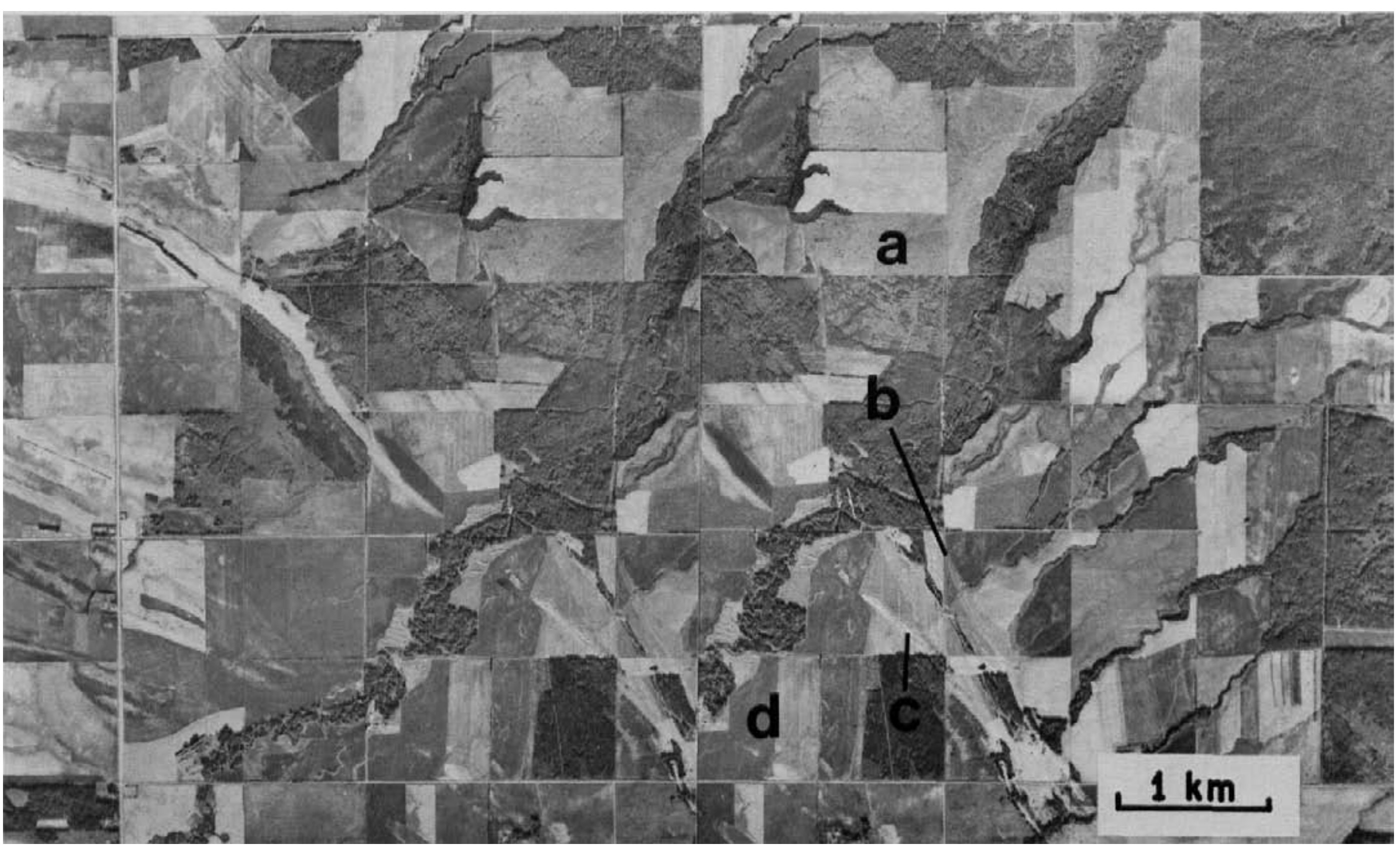


Figure 62: *Stereopair showing the Bowsman delta (a), the Upper Campbell terrace (b), the Lower Campbell beach (c) and an alluvial fan (d) on the south side of Porcupine Hills. North is to the right.*

Figure 63: *Flow till (a) overlying kame terrace gravel (b) at site 214 on the north side of Duck Mountain. The current direction was northeasterly (left). Flow till (a) is 1 m thick.*

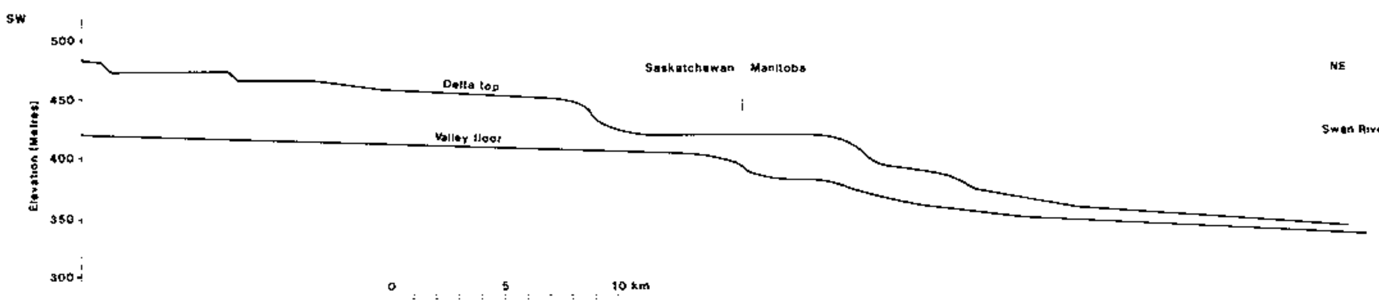


Figure 64: *Longitudinal profile of Swan River and the Swan River delta.*

Figure 65: *The Upper Campbell wave-cut terrace. Looking southwest from PR 279, 13 km west of Bowsman.*

Figure 66: *Washover crossbeds (a) and low angle beachbedding (b) in the Lower Campbell beach at site 228. Lake Agassiz was to the right (southeast).*

TABLE 1

Strandline	Location	Feature	Elevation
Upper Campbell	3 km south of Minitonas	scarp	359.8 m (1180 ft.)
	10 km southwest of Swan River	scarp	353.7 m (1160 ft.)
Lower Campbell	5 km southwest of Swan River	beach	346.0 m (1135 ft.)
	11.5 km west of of Bowsman	beach	349.1 m (1145 ft.)

Lake Agassiz drained from the area before 8300 years BP when it stood at the Ponton level in northern Manitoba (Ringrose, 1975).

Postglacial features

Alluvium: Rivers descending Duck Mountain and Porcupine Hills deposited alluvial fans at the base of the escarpment in several parts of the Swan River valley. The Kemulch Creek alluvial fan, on the southeast side of Porcupine Hills, is particularly well formed. A similar fan is situated on Bowsman River and small alluvium accumulations are found at the base of the Upper Campbell terrace throughout the valley. The sediment in the fans is generally fossiliferous silt and clay. In 1978, bison bones were found exposed in the alluvial fan along Bowsman River 7 km west of Bowsman at a depth of 1 m (Fig. 68). A left calcaneum and an incomplete atlas vertebra from the site, typical for mid- to late Holocene female bison (M. Wilson, pers. comm., 1986), gave a radiocarbon date of 5350 ± 120 years BP (BGS-728). A sedimentation rate of about 1 m/5000 years can be inferred for this part of the alluvial fan.

River terraces are common along the major rivers draining the Swan River valley (Fig. 69). The terraces are particularly well formed along Swan River where two sections were investigated in detail. The first site, 9 km

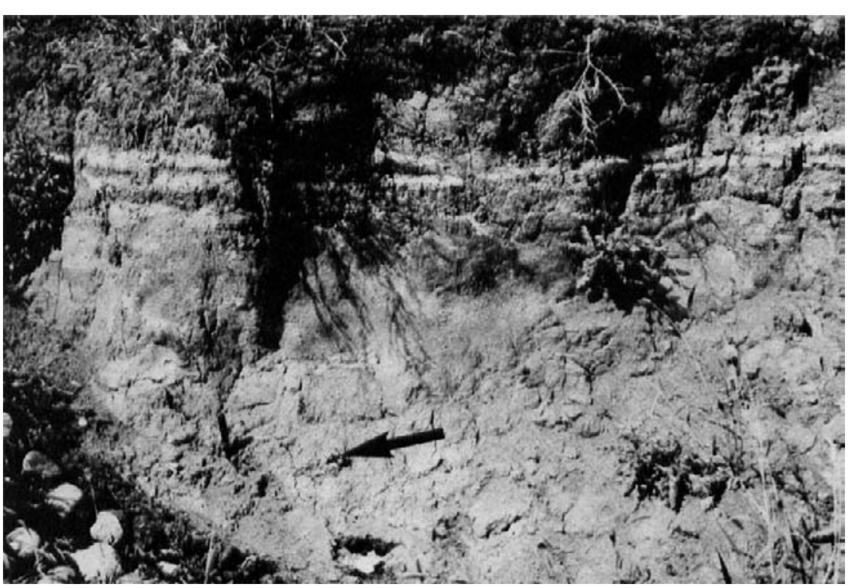


Figure 68: *Alluvial fan sediments along Bowsman River, 7 km west of Bowsman. Bison bones (indicated by arrow) dated at 5350 ± 120 years BP (BGS – 728). Note the pen knife for scale.*

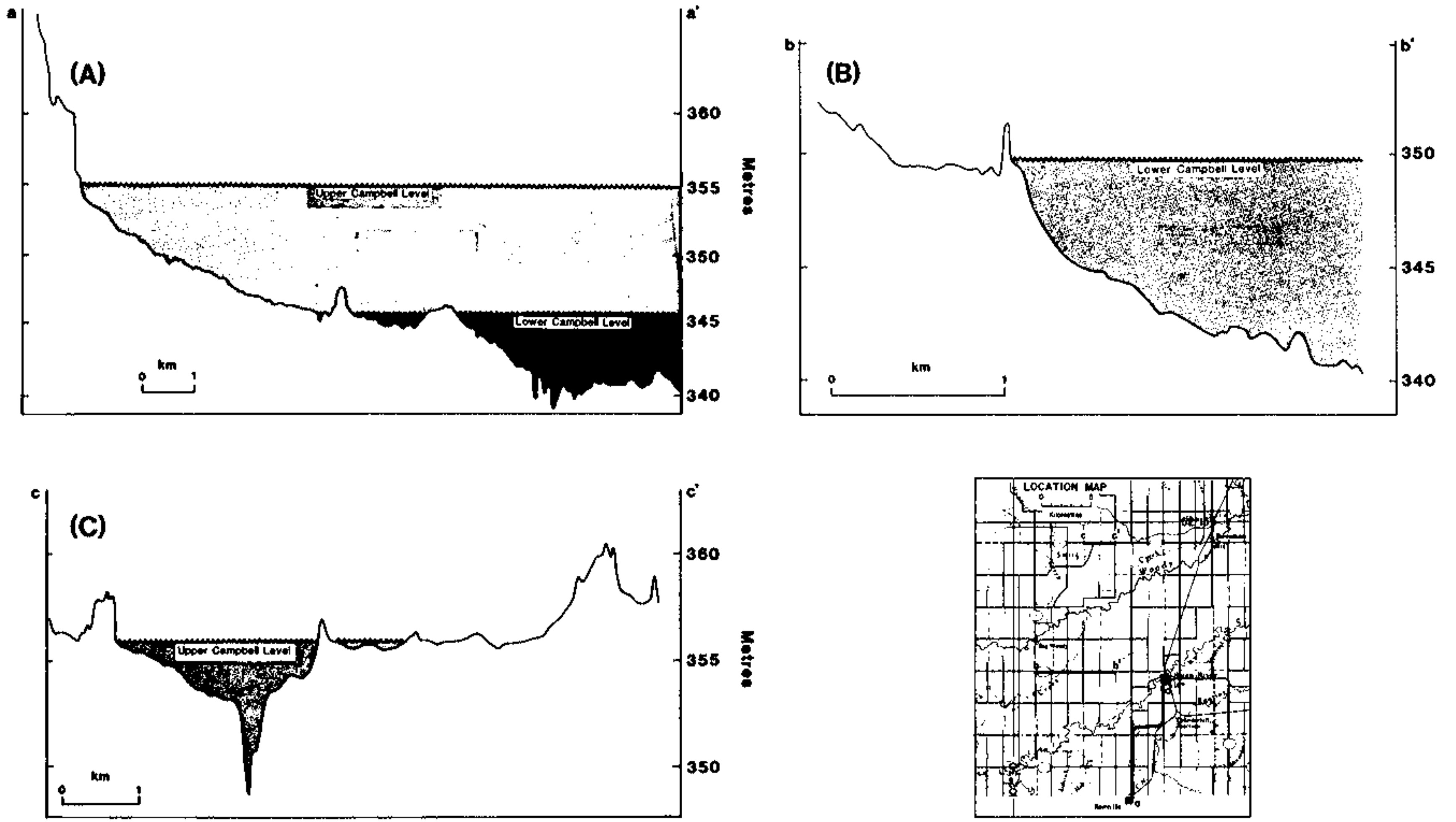


Figure 67: *Profiles across Lake Agassiz strandlines.*

Figure 69: Terrace of the Swan River. Looking south from a point 8 km south of the town of Swan River.

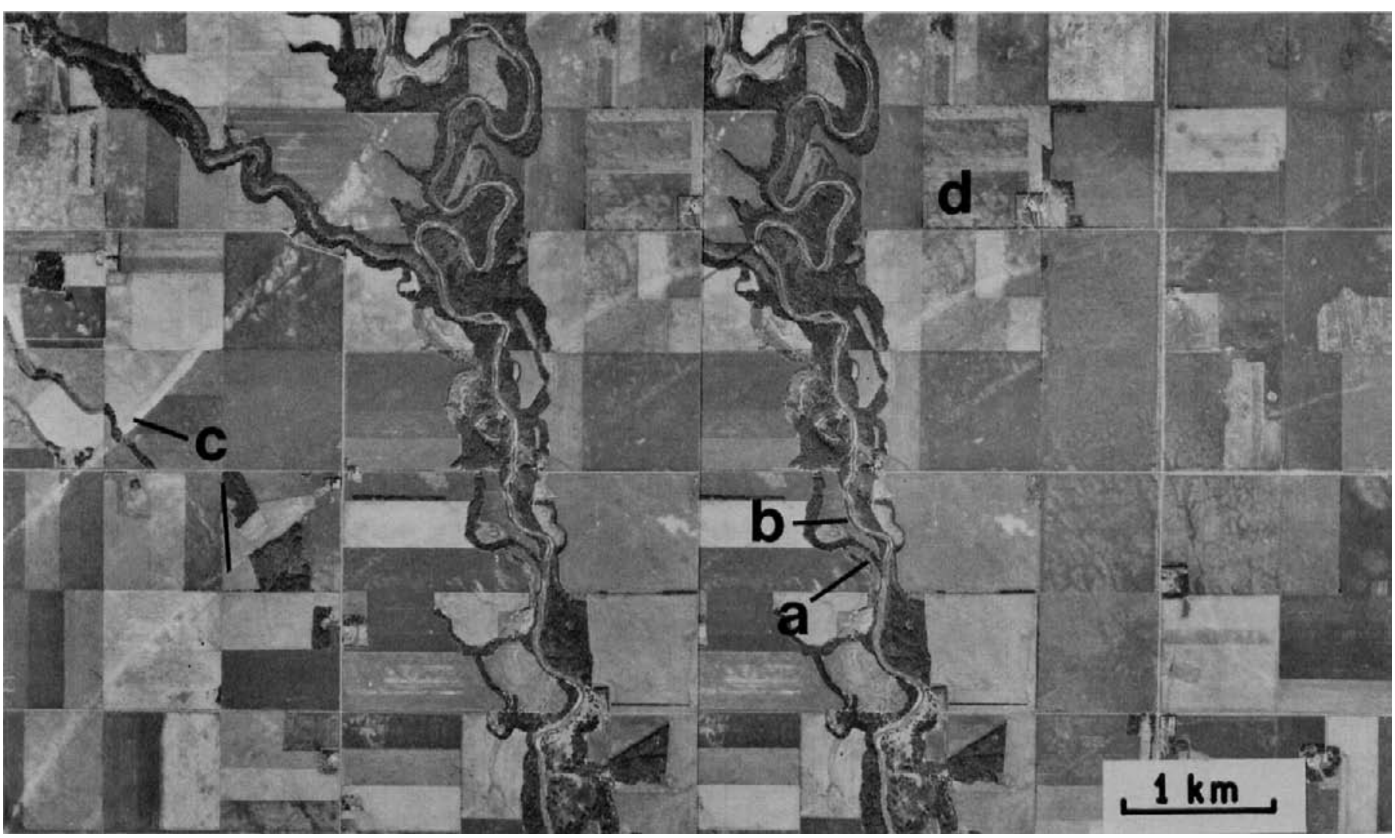


Figure 70: Stereopair showing river terraces along the Swan River, 8.5 km downstream from Swan River. The high terrace (a) is of unknown age. The lower terrace (b) was radiocarbon dated at 3040 ± 80 years BP (BGS — 1041). Note the Lake Agassiz beaches (c) and the lacustrine plain (d). North is to the right.

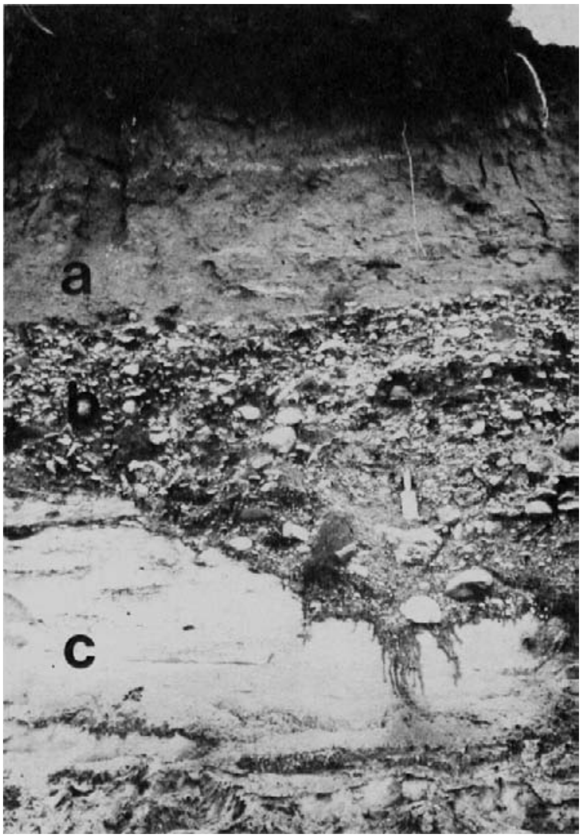


Figure 71: Details of the stratigraphy of the lower terrace shown in Figure 70. Swan River sandstone (c) is overlain by bed load gravel (b) and fine textured overbank sediment (a).

downstream from the community of Swan River, shows 2 terraces, one well formed, 4.5 m above the present river bed and 15 m below the surrounding prairie level and an older, higher terrace, poorly preserved and of unknown elevation (Fig. 70). The lower terrace comprises 0.5-1.5 m coarse, poorly sorted fossiliferous gravel overlying Swan River sandstone and is capped by 1.5 m of rhythmically bedded fossiliferous silt and clay (Fig. 71). The gravel and overlying fine sediment indicate point bar deposition when the river was several metres higher than at present. Fossils recovered from the gravel include a right proximal fragment of a bison femur. The specimen, though highly abraded during fluvial transport, is not large and is typical for late Holocene female bison. Other fossils include two species of pelecypod, *Sphaerium nitidum* and *Lampsilis radiata siliquoidea* and two species of gastropod, *Valvata tricarinata* and *Helisoma anceps*. Radiocarbon dating of a large pelecypod shell (*Lampsilis radiata siliquoidea*) indicates the gravel was deposited 3040 ± 80 BP (delta C-13 = 12.57‰) (BGS - 1041) when the river bed was 2.5 m higher than present.

The top of the terrace at the second site, located 2.5 km southwest of Harlington on Swan River, is approximately 4 m above the present river and 7 m below the prairie level. The terrace consists of laminated silt and clay, with a well developed paleosol preserved about 2 m from the top (Fig. 72). The sediment is believed to have accumulated from overbank deposition during periods of flooding. A left metacarpal and a complete ungual phalanx were recovered 3 m from the surface of the terrace (1 m below the paleosol) (Fig. 73). The bones from a mid- to late Holocene female bison were dated at 6960 ± 100 years BP (BGS - 1100). This radiocarbon date indicates the western part of Swan River in Manitoba was downcut in early Holocene time and that the valley fill has slowly accumulated since that time.

Sand dunes: Wind-blown sand deposits of variable thickness are widespread but are generally not mappable (Fig. 74). Stabilized dunes are found in a small area 11 km northwest of Swan River. The sand is well sorted and structureless. Individual dunes now stabilized by vegetation stand about 1.5 m high. A paleosol of unknown age in a small roadcut in one of the dunes at site 250 (Fig. 75) indicates eolian activity has been periodically active in the past.

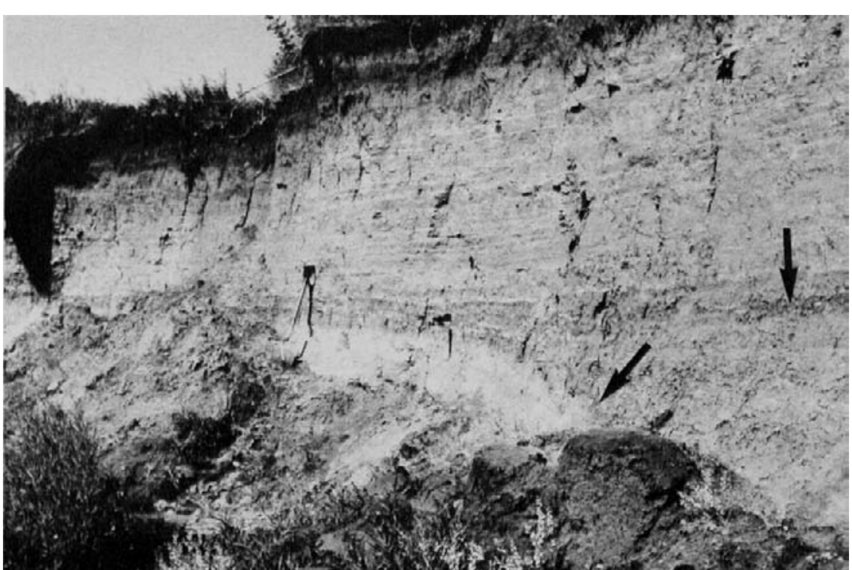


Figure 72: Fine textured floodplain (overbank) sediments in the terrace along Swan River, 2.5 km southwest of Harlington. Prominent paleosols are indicated by arrows.

Figure 73: Details of bison bone dated at 6960 ± 100 years BP (BGS - 1100) and the floodplain deposits in Figure 72.

Figure 74: Windblown sand (a) overlying glaciofluvial gravel (b) at site 252, 7 km northwest of Swan River.

Figure 75: Buried paleosol in a stabilized sand dune, 5.5 km northeast of Big Woody.

QUATERNARY HISTORY

PRE-LATE WISCONSINAN

Little is known about the early Quaternary history of the area. The first identifiable event was the deposition of the Roaring River sediments on Duck Mountain. The ostracods, pollen and molluscan fauna from these sediments indicate deposition in an environment similar to the environment found in the area today. The Roaring River sediment is correlated with the Sangamon Interglacial (Klassen et al., 1967). The close of the Sangamon Interglacial came when ice inundated the area from the northeast and deposited Minnedosa Till. This interval may have lasted from 75 000 to 40 000 years BP. Glaciation was interrupted during the Mid-Wisconsinan between approximately 40 000 and 22 000 years BP when silt was deposited in an ice-free environment on the southern part of Duck Mountain (Klassen, 1979). Glacier ice once again inundated the area at the beginning of the Late Wisconsinan, 22 000 years ago.

LATE WISCONSINAN

Late Wisconsinan ice flow from the north deposited Zelena Till (Fig. 76A). On Duck Mountain and the Porcupine Hills Zelena Till was deposited as hummocky stagnation moraine. A basal till facies of this till is not recognized. Deposition of the hummocky stagnation moraine was by meltout of englacial sediment, in an area with ice flow transitional between the southeasterly ice flow, characteristic of the Lennard Till (Battleford Formation in Saskatchewan) in southwestern Duck Mountain, and the more northerly derived Zelena Till. The great thickness, the relatively high carbonate content (compared to the Lennard), the abundance of erratics from the Shield, and the general absence of basal till, suggest the hummocky moraine formed over a long period of time in an ice marginal or possibly an interlobate position.

The timing of deglaciation of the Manitoba escarpment and adjacent parts of the Manitoba plain is a moot point. The minimum age for deglaciation of Duck Mountain is based on a radiocarbon date of 10 140 ± 455 years BP (S-2478) on wood from a small lake. As trees were already present at that time the area must have been deglaciated considerably earlier, possibly as much as 2000 to 3000 years before. Porcupine Hills probably became ice-free about the same time (Fig. 76B-76C). The Swan River and Westlake plains remained ice-free for only a short time. The ice retreated into northern Manitoba, possibly to The Pas moraine, before readvancing to an unknown position in southern Manitoba while depositing the Arran Till (Fig. 76D). The ice margin of the Swan River sublobe lay across the southeastern part of Porcupine Hills, possibly at the Bowsman moraine, and at the Harvey Lake and Indian Creek moraines along the north and eastern side of Duck Mountain. Duck Mountain and most of Porcupine Hills remained ice-free during this time, although stagnant ice was still present in places.

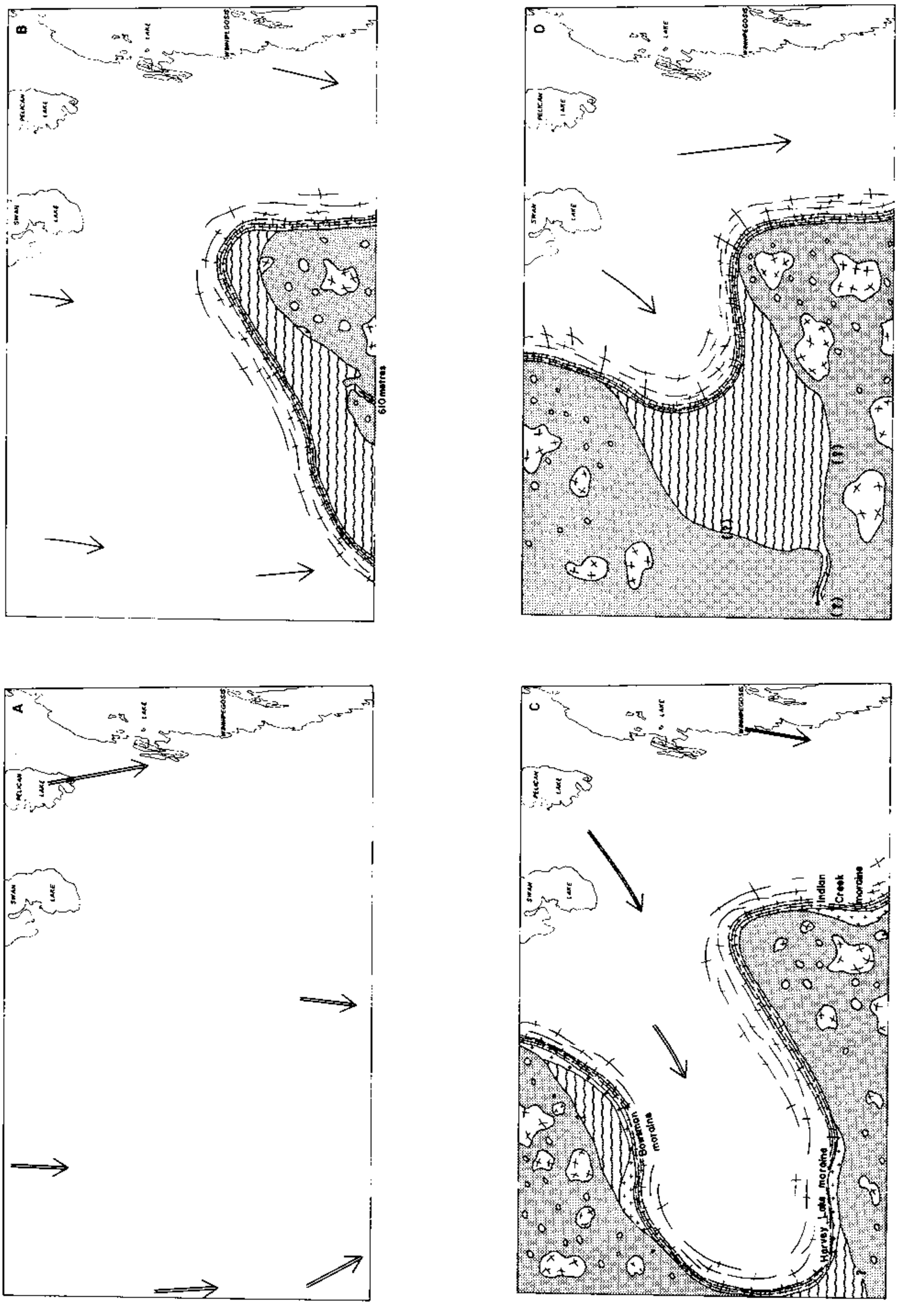
A large ice marginal and supraglacial lake formed on the north side of Duck Mountain. The lake was bounded by stagnant ice to the south, east and west and by ice in the Swan River valley to the north. As the stagnant ice in the south melted the lake partially drained through the Shell River spillway (Fig. 76D). The lake became a narrow ice marginal lake along the southern edge of the Swan River sublobe. Drainage continued through the Shell River spillway until the sublobe gradually melted back and the water escaped through the North Duck spillway, into Lake Agassiz (Fig. 76E). The ice margin in the Westlake plain lay at the Sclater and Cowan moraines. Meltwater continued flowing into Glacial Lake Swan at the western end of the valley forming the large deltas at the western end of the Swan River valley.

Continued retreat of the ice margin resulted in the lake draining north of Duck Mountain; it stabilized at the 410 m (1345ft.) level (Fig. 76F). Lake Agassiz was at one of the lower Herman levels or possibly the Norcross level at that time. The Swan River sublobe continued to retreat and glacial Lake Swan merged with Lake Agassiz. The timing of these events is uncertain but they are related to the Pre-Moorhead Phase of Lake Agassiz which ended about 10 800 years BP (Teller and Thorleifson, 1983). By 10 800 years BP (the beginning of the Moorhead Phase) Lake Agassiz had fallen at least to the Ojata level and much of Swan River valley became subaerially exposed for the first time since the beginning of the Late Wisconsinan.

HOLOCENE

At the beginning of the Emerson Phase (9900 years BP), the eastern outlets of Lake Agassiz were blocked by a readvance of the ice margin in the Nipigon basin and brought the water level back at least to the Upper Campbell level (Fig. 77A). The Upper and Lower Campbell beaches formed between 9900 and 9300 years BP (Nielsen et al., 1984). The apparent change in water level during this time was due to isostatic uplift of northern Manitoba, relative to southern Manitoba. When the Nipigon outlets of Lake Agassiz opened for the last time at the beginning of the Nipigon Phase, 9300 years BP, the water level fell in a series of steps that correlate with the opening of successively lower outlets in the Lake Nipigon area (Teller and Thorleifson, 1983). it was during the Emerson and Nipigon phases that the beaches below the Upper Campbell level in the Swan River area formed (Fig. 77 B, C, D). Lake Agassiz drained from the area shortly after the water plane dropped below the Burnside level.

The rapid dewatering of the Manitoba escarpment during the Emerson and Nipigon phases of Lake Agassiz initiated large-scale landslides along the east side of Porcupine Hills and parts of Duck Mountain. Alluvial sedimentation also began at that time. The last major event was the eolian activity that reworked littoral sediments during the relatively warmer period between 9500 and 3500 years BP. Dry grassland vegetation was prevalent on the Westlake and Swan River plains during that time (Ritchie, 1976). The prevailing westerly winds that blew through the Swan River valley caused dune formation. Alluvial sedimentation continues along the rivers and at the base of the escarpment.


A
B
C
D
SWAN LAKE
PELICAN LAKE
WINNIPEGOSIS
LAKE
610 metres
Bowsman moraine
Harvey Lake moraine
Indian Creek moraine
(1)
(2)
(3)

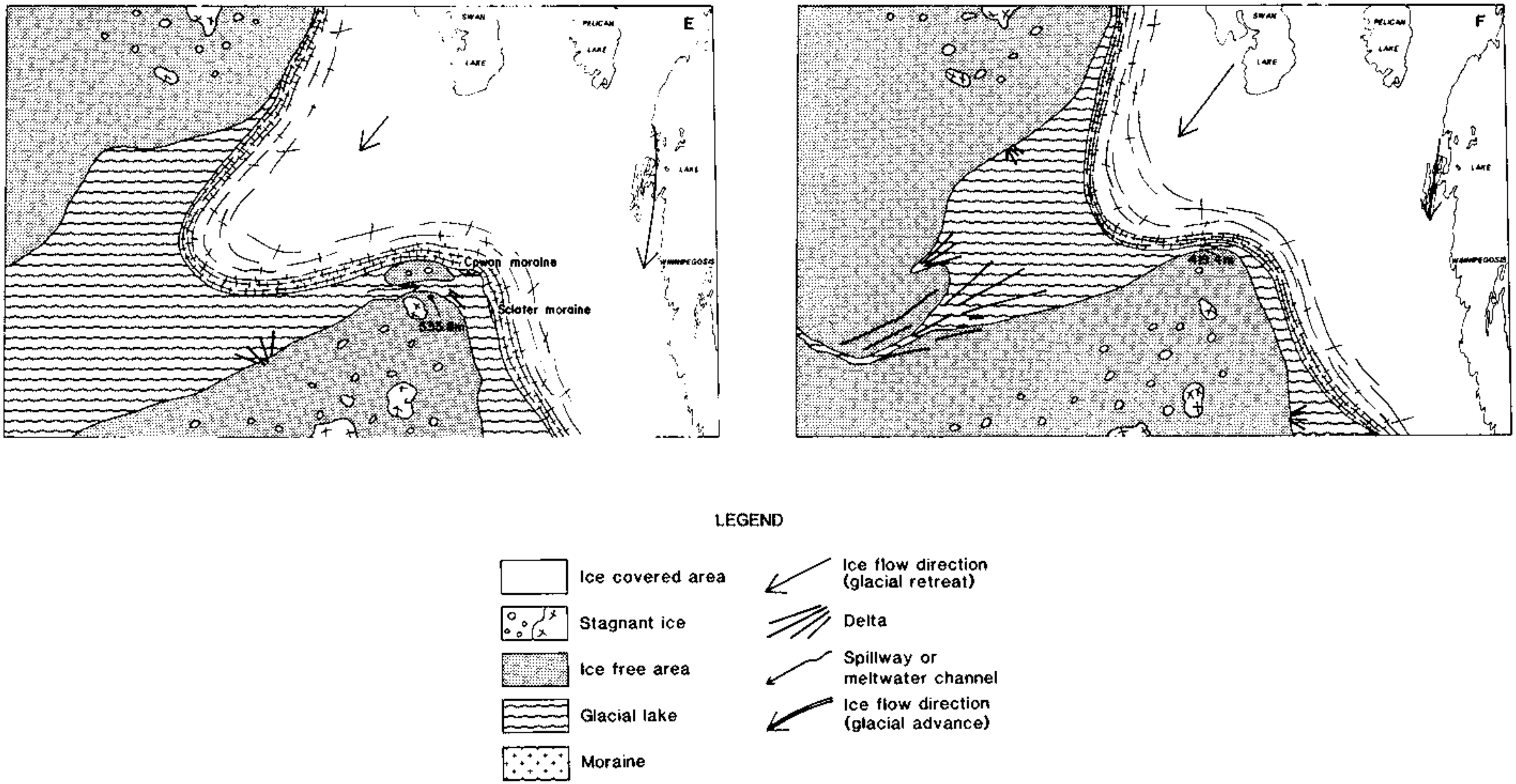
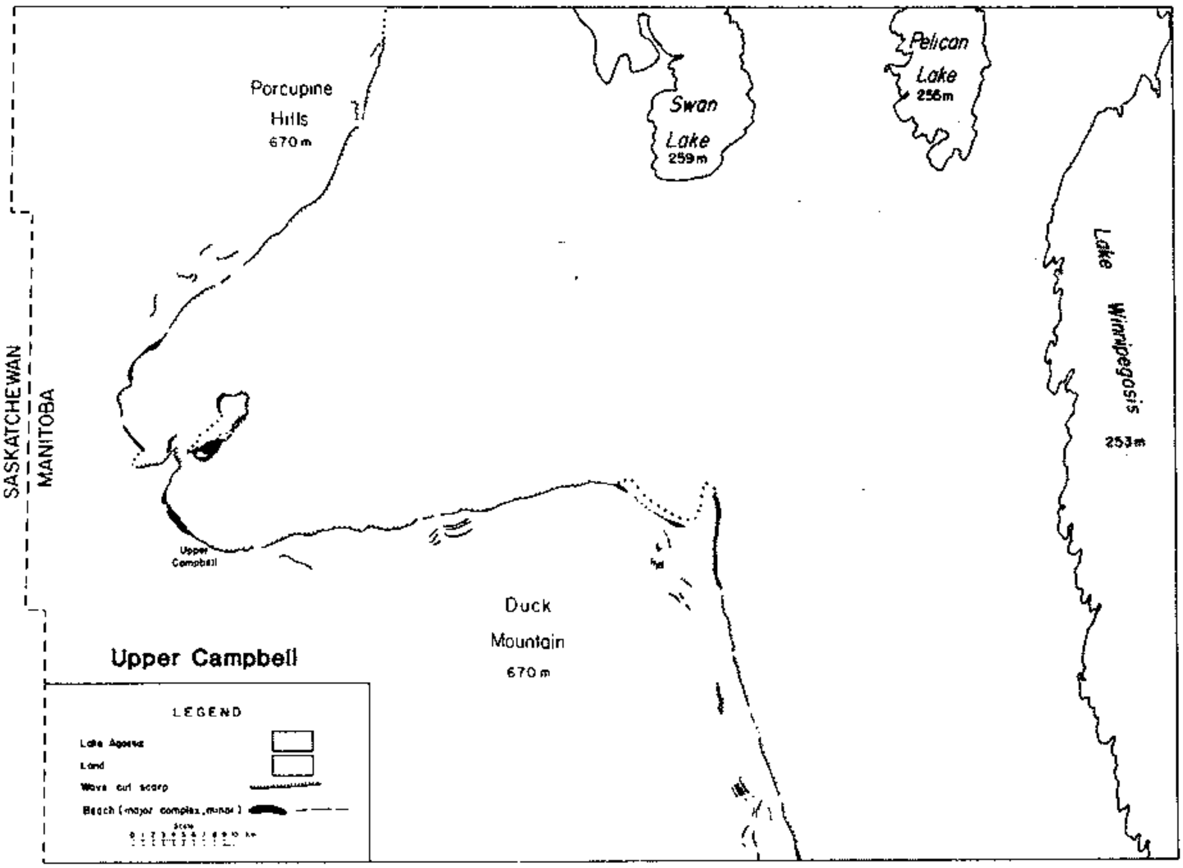
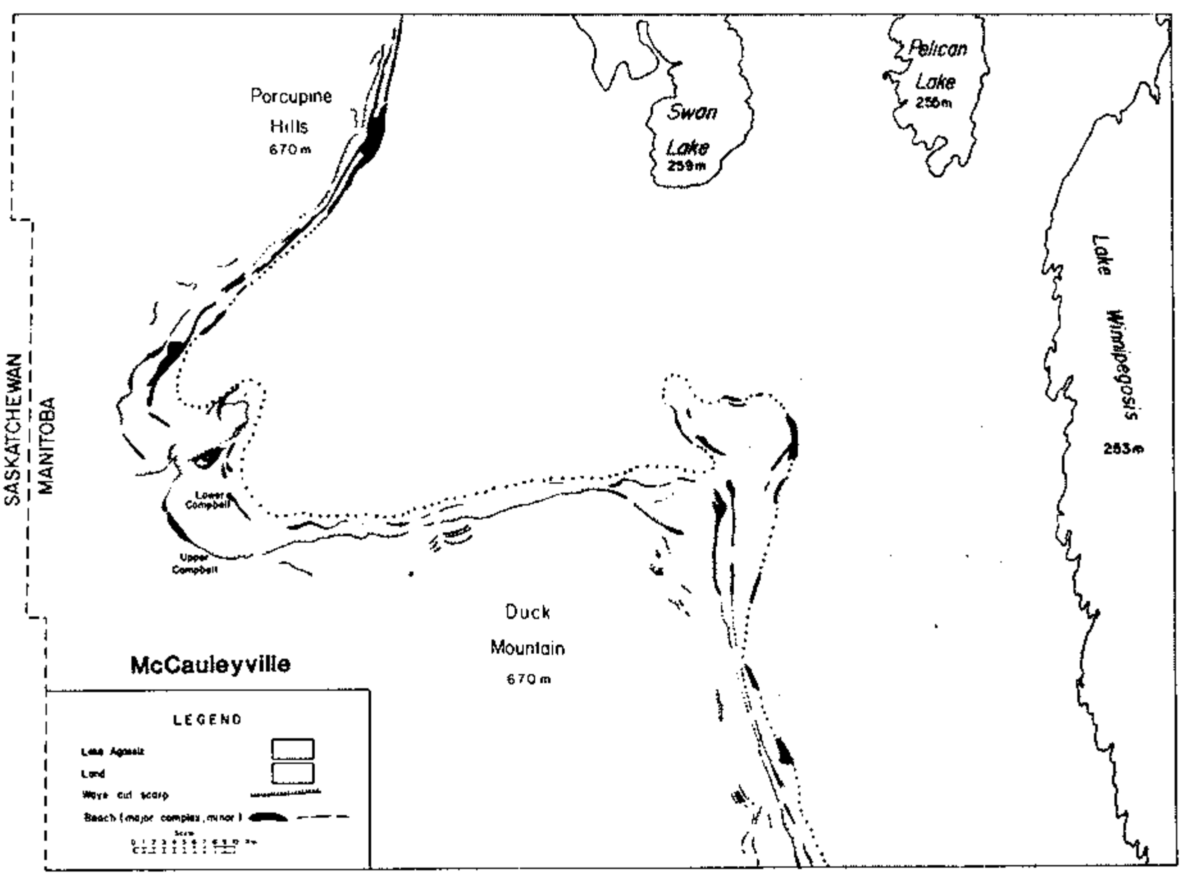


Figure 76: *Paleogeographic reconstruction for the Late Wisconsinan.*

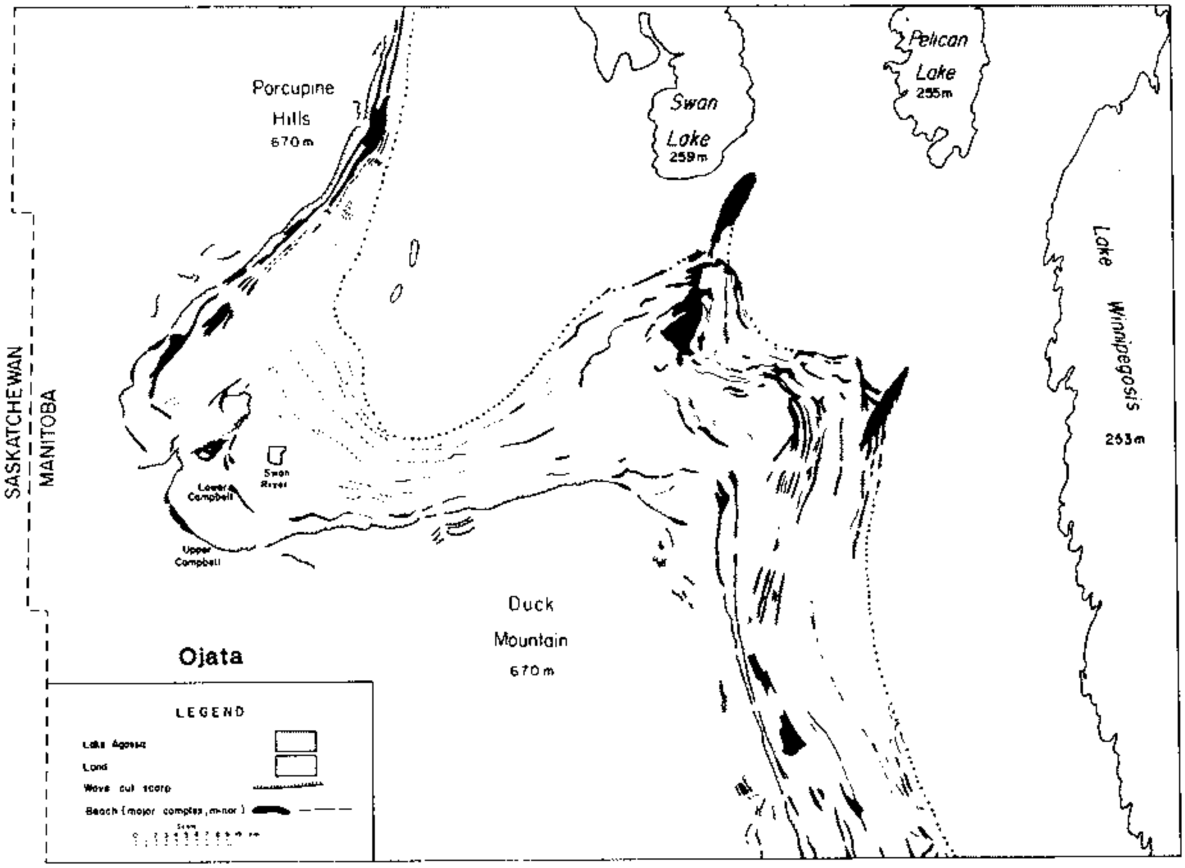
(A) Zelena Till deposited by southerly ice flow.
(B) *Stagnation of "Zelena ice" on uplands with active ice in the lowland.*
(C) Readvance of the Swan River sublobe to Arran Saskatchewan.
(D) Supraglacial lake on Duck Mountain draining south via Shell River spillway.
(E) Glacial Lake Swan draining east via North Duck spillway.
(F) Glacial Lake Swan draining north of Duck Mountain into glacial Lake Agassiz.



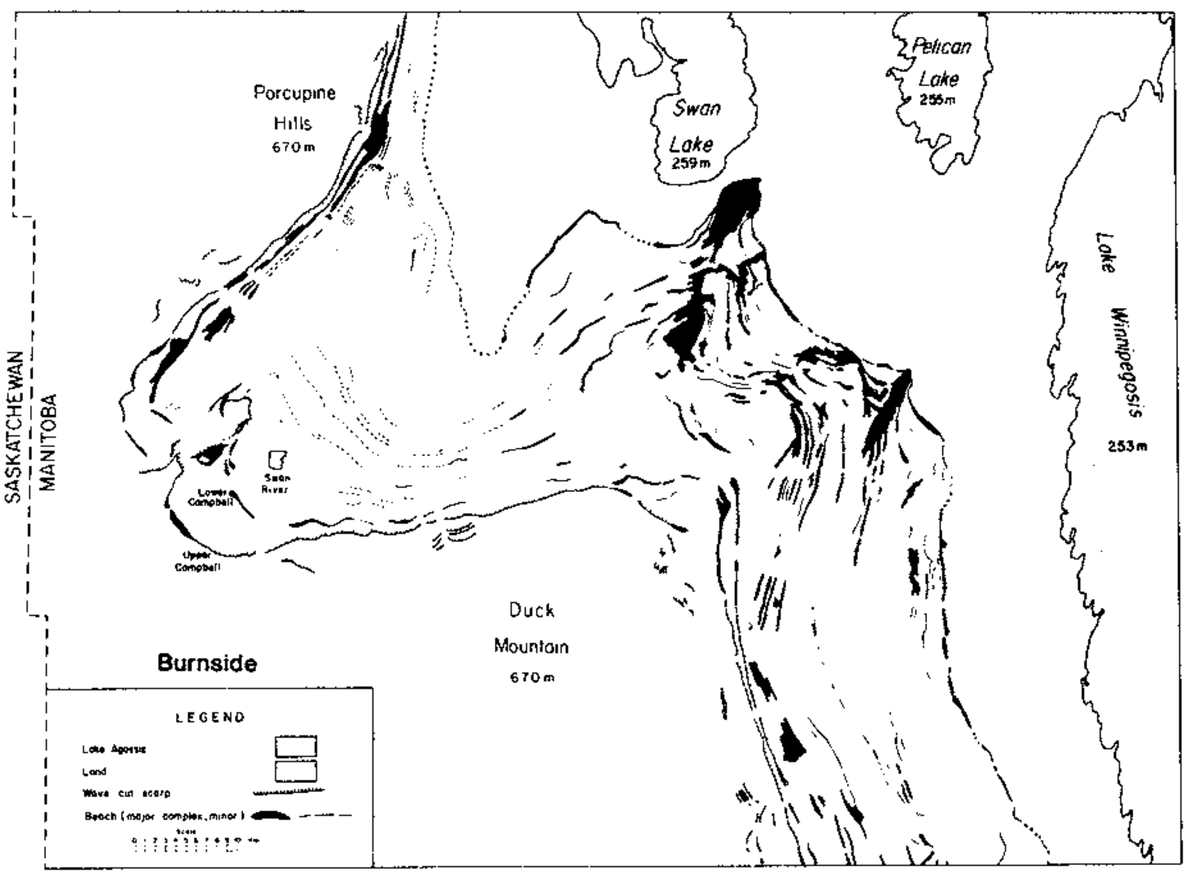
(A) Upper Campbell level (9900 years BP).



(B) Lower Campbell level (about 9500 years BP) and McCauleyville level.



(C) *Ojata level.*



(D) *Burnside level.*

Figure 77: *Paleogeographic reconstruction of glacial Lake Agassiz.*

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