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PLEISTOCENE GEOLOGY AND GEOMORPHOLOGY OF THE RIDING MOUNTAIN AND DUCK MOUNTAIN AREAS, MANITOBA-SASKATCHEWAN

R.W. Klassen

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Preface

The Riding Mountain and Duck Mountain map areas include much of the prime agricultural and recreational land of southwestern Manitoba and a part of southeastern Saskatchewan. This report deals with the surficial deposits and landforms in glaciated terrain typical of the Canadian prairies and presents information on the nature, distribution and origin of the unconsolidated materials forming the land surface. This information is intended as a basis for more specialized studies directed towards maximizing the economic and aesthetic potential of the land and has direct application to land use studies, agronomy, forestry, groundwater investigations and engineering construction.

D.J. McLaren
Director-General
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PLEISTOCENE GEOLOGY AND GEOMORPHOLOGY OF THE RIDING MOUNTAIN AND DUCK MOUNTAIN AREAS, MANITOBA-SASKATCHEWAN

Abstract

This report describes and interprets the Pleistocene stratigraphy, landscapes and glacial features of some 31 000 km^2 (12 000 mi^2) of glaciated terrain in southwestern Manitoba and southeastern Saskatchewan.

The greatest part of the thick drift of the Assiniboine River plain, Riding Mountain upland and Duck Mountain upland consists of tills. These tills range in age from pre-Wisconsin (Largs, Tee Lakes and Shell? formations) to early Wisconsin (Minnedosa Formation) and late Wisconsin (Zelena and Lennard formations). The tills of the Valley River, Westlake and Swan River plains are part of a thin drift blanket and includes mainly late Wisconsin tills (Zelena and Arran formations).

The landscape and glacial features include bedrock plains, till plains, corrugated moraines, hummocky moraines, outwash plains, lacustrine plains, end moraines, kame moraines, moraine plateaus, kames, eskers, meltwater channels, buried valleys and boulder pavements. Although most landscapes and glacial features formed during the late Wisconsin glaciation, stratigraphic evidence indicates that some predate it.

The economic and geotechnical aspects of the drift are discussed in qualitative terms related to foundation and construction materials, groundwater and agricultural practices.

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Résumé

Dans le présent rapport, sont décrits et interprétés la stratigraphie, les reliefs structuraux et glaciaires de 31 000 km^2 (12 000 mi^2) de terrains du Pléistocène, dans le sud-ouest du Manitoba et le sud-est de la Saskatchewan.

La majeure partie du drift épais qui couvre la plaine de la rivière Assiniboine, les hautes-terres du mont Riding et celles du mont Duck contiennent des tills. Ces tills peuvent être antérieurs au Wisconsin (formations de Largs, Tee Lakes et Shell?) ou dater du Wisconsin inférieur (formation de Minnedosa) et du Wisconsin supérieur (formations de Zelena et Lennard). Les tills des plaines de Valley River, Westlake et Swan forment partiellement une mince couverture de drift, où les tills sont principalement du Wisconsin supérieur (formations de Zelena et Arran).

Parmi ces divers reliefs structuraux et glaciaires, citons des plaines dont le matériau constitutif est la roche en place, des moraines ondulées et bosselées, des plaines alluviales proglaciaires, des plaines lacustres, des moraines frontales, des moraines de kame, des plateaux morainiques, des kames, des eskers, des chenaux proglaciaires, des vallées enfouies et des champs de blocs. Bien que la plupart de ces reliefs aient été édifiés pendant la glaciation du Wisconsin supérieur, certains indices stratigraphiques montrent qu'une partie d'entre eux existaient avant cette glaciation.

On étudie qualitativement les problèmes économiques et géotechniques créés par la présence du drift, c'est-à-dire du point de vue des fondations, des matériaux de construction, des eaux souterrains et des pratiques agricoles adoptées.

Introduction

General Setting

Glacial landscapes typical of much of the Canadian prairies occur in the Riding Mountain and Duck Mountain areas of southwestern Manitoba and southeastern Saskatchewan. The area studied covers about 31 000 km^2 (12 000 mi^2) between 50 and 52°N and 100 and 102°W, mostly within the Saskatchewan Plains region (Fig. 1) of the Interior Plains Province (Bostock, 1964, p. 21). A small part in the northeastern corner of the Duck Mountain map area is in the Manitoba Plains region (Fig. 1).

The area is within the humid microthermal climatic region and has a humid continental climate with warm summers (Canada Department of Mines, 1957). The yearly precipitation averages 43 cm (17 in.) and has ranged between 25 and 66 cm (10 and 26 in.). Precipitation is greatest in the eastern part of the area. Records spanning more than 70 years indicate that the wettest month is June with 5 to 8 cm (2 to 3 in.) and that the driest months are February and December with 2 cm (0.7 in.) precipitation a month.

Soils on the plains are mostly black earth types and on the uplands are grey wooded types (Canada Department of Mines, 1957). Regosolic types are developed on the eastern slopes of the uplands and on the plains to the east (Ehrlich et al., 1956, 1959). The boundaries of soil associations generally coincide with the boundaries of surficial geologic units, as the soil associations reflect parent materials.

The area lies in the zone of transition from boreal forest to prairie bordering the southern part. The low parts of the Saskatchewan Plains are in the aspen-oak and aspen grove sections (Rowe, 1972, p. 34–35) where trembling aspen and balsam poplar are the prevalent species, with bur oak along the rivers. The uplands are in the mixed wood section where natural stands of trembling aspen, balsam poplar, white spruce and balsam fir (Rowe, 1972, p. 36) cover most of the land surface. In the Manitoba Plains the vegetation includes mixed wood types along with an extensive cover of black spruce and tamarack between swamps and meadows.

Approach and scope

This report presents the results of field studies and of laboratory analyses of samples collected in the area during the summers of 1961 to 1970, while the writer was conducting Quaternary geology studies in the general region. Surface and subsurface information obtained during the summers of 1961 to 1965 in the Riding Mountain area formed the basis of an unpublished doctoral thesis (Klassen, 1966b). Additional information was obtained from a drilling and mapping project in the Duck Mountain area during the summers of 1966 to 1969.

Stratigraphic drilling by rotary rig was done during the summers of 1963 and of 1966 to 1969. Samples generally were taken at 1.5 to 3 m (5 to 10 ft) intervals, and most boreholes ended in bedrock. During 1963, 48 holes were drilled, and drilling chips formed the basis for the descriptive log at the drilling site. The silt fraction later was analyzed for carbonate content by the Chittick method (Dreimanis, 1962), generally using the somewhat modified procedure described by Christiansen (1968).[1] All holes were logged electrically to aid in determining unit contacts. During subsequent summers 18 holes were drilled in the Duck Mountain area; samples for carbonate and grain size analyses were obtained by using a sidewall coring device (Morrison, 1969). Some 850 till samples, including 170 surface ones, were analyzed for carbonate content. Grain size analyses were made mostly by the hydrometer method (Bouyoucos, 1951), on 150 sidewall cores and surface samples. The final logs are based on drilling chip and sidewall sample descriptions and electrical logs. Munsell chart colour designations were used.[2]

The results of much of the work done in the Riding Mountain and Duck Mountain areas have appeared in published and unpublished reports (Klassen, 1965, 1966a,b, 1969, 1971, 1972a,b, 1975; Klassen et al., 1967, 1970; Klassen and Elson, 1972). This report presents a synthesis of relevant aspects of the published reports and unpublished information to elucidate the main facets of the surficial geology of the area.

Previous studies

Some aspects of the glacial geology of the area are discussed in geological reports by Hind (1859), Bell (1876), Tyrrell (1893), Johnston (1934), and in water supply papers by MacKay et al. (1936) and Halstead (1951, 1953). More detailed reports by Christiansen (1960), Cherry (1966), and those by the writer listed above describe various aspects of the Quaternary geology.

The bedrock geology of this region was mapped by Wickenden (1945). Another regional map of the bedrock geology at a scale of 1 inch to 8 miles, with topography shown by a 100 foot contour interval, includes the Manitoba part of the map area (Klassen et al., 1970). A similar type of map at a scale of 1 inch to 4 miles (Cherry and Whitaker, 1969) covers the Saskatchewan part of the Duck Mountain area.

Acknowledgments

I very much appreciate the helpful advice and much time given by A. MacS. Stalker of the Geological Survey of Canada during preparation of this and related reports, and while in the field. The guidance of W.O. Kupsch, Professor of Geology, University of Saskatchewan, as advisor for the doctoral thesis on the Riding Mountain area is gratefully acknowledged. Worthwhile field assistance was given during the summers by W.P. Wilson, J.G. Senecal, R.K. Springer, D.H. Watkins, S. Odut, P. Conlon B. Mann and G.

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[1]The modified procedure gave more consistent calcite to dolomite ratios, but the total carbonate content remained about the same.

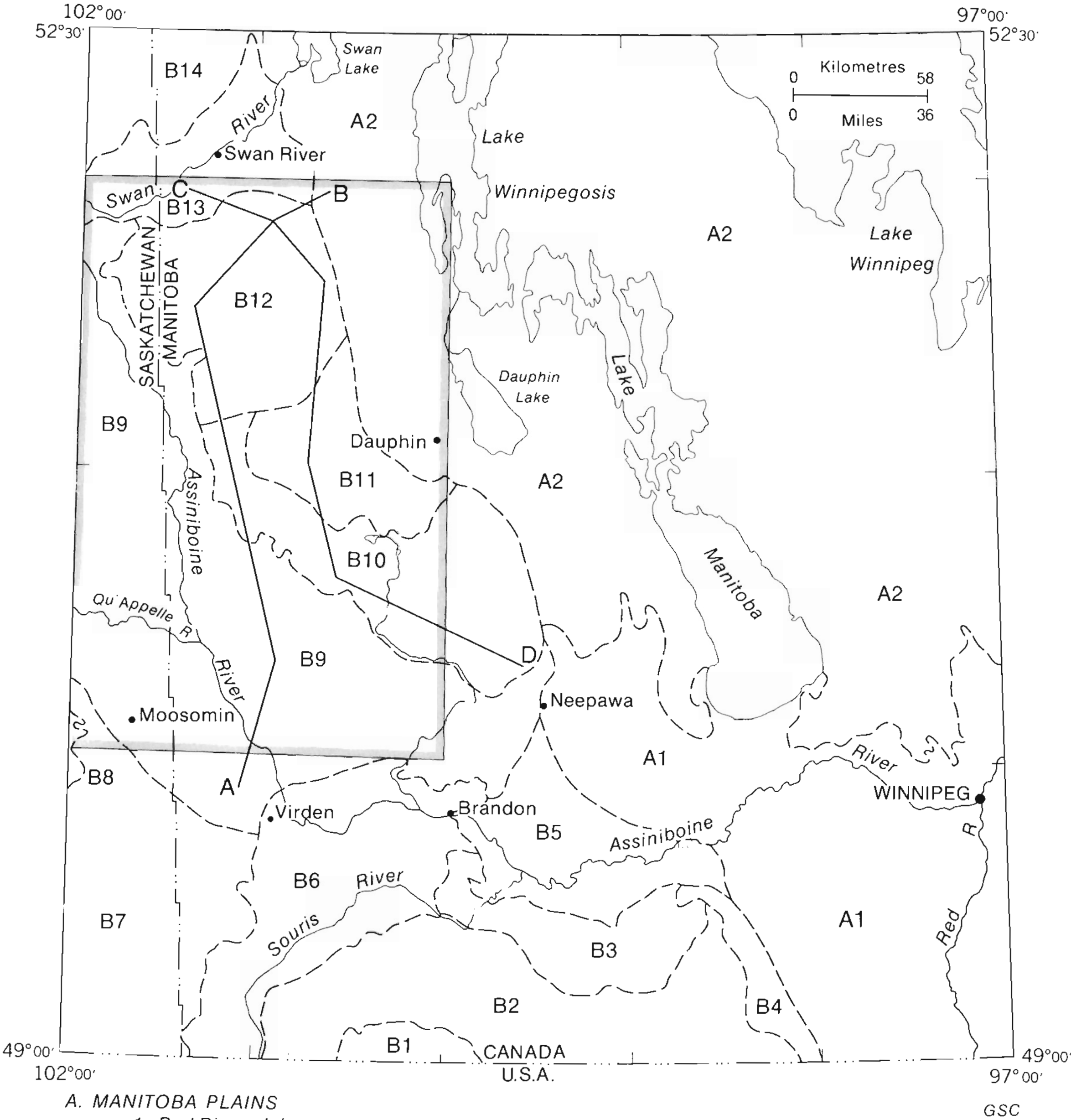
[2]Colours given are for moist samples unless stated otherwise.

Burwasser. Personnel of various federal and provincial government departments and oil and mining companies provided access to unpublished subsurface data. In particular, I thank E.A. Christiansen of the Saskatchewan Research Council, and B. Bannatyne and L. Gray of the Manitoba Department of Mines, Resources and Environmental Management.

Regional physiography and bedrock geology

Physiographic divisions

The Saskatchewan Plains are gently undulating to rolling prairie generally 460 to 610 m (1500 to 2000 ft) a.s.l., in places, interrupted by broad hilly uplands 550 to 820 m (1800 to 2700 ft) a.s.l. Divisions of the Saskatchewan



A. MANITOBA PLAINS
1. Red River plain
2. Interlake-Westlake plain

B. SASKATCHEWAN PLAINS
1. Turtle Mountain upland
2. Boissevain plain
3. Tiger Hills upland
4. Pembina Hills upland
5. Assiniboine delta
6. Souris basin
7. Souris River plain
8. Moose Mountain upland
9. Assiniboine River plain
10. Riding Mountain upland
11. Valley River plain
12. Duck Mountain upland
13. Swan River plain
14. Porcupine Hills upland

Figure 1. Index map and physiographic map of southwestern Manitoba and southeastern Saskatchewan. Lines AB and CD locate sections shown in Figure 2.

Plains in the map area are the Assiniboine River plain, Valley River plain, Swan River plain, Duck Mountain upland and Riding Mountain upland (Fig. 1). The steep, east facing slopes of the two uplands form part of the Manitoba escarpment, which here marks a drop of 240 to 300 m (800 to 1000 ft) from the uplands to the nearly flat Manitoba Plains. The part of the Manitoba Plains west of lakes Winnipegosis and Manitoba, including the flat terrain between about 430 and 270 m (1400 and 900 ft) a.s.l. in the extreme eastern part of the Duck Mountain area, commonly is called the Westlake plain. The northwestern corner of the map area is in the Swan River plain, and parts along the southwestern boundary of the map area are in the Souris River plain and Moose Mountain upland. More detailed descriptions of these physiographic divisions are given later.

The broad elements of the bedrock topography (Klassen et al., 1970) are reflected at the surface and to varying degrees coincide with the physiographic divisions. They probably do not differ much from the preglacial topography. Glacial erosion was greatest in the low areas and along the northeast facing slopes of the uplands. For example, the Assiniboine River plain along Assiniboine Valley, where bedrock commonly is exposed, was eroded more than the higher parts. Probably the most striking modification in the preglacial bedrock surface is the trench-like Assiniboine Valley, which in places is incised 60 to 90 m (200 to 300 ft) below the Assiniboine River plain.

Bedrock geology and topography

Most of the study area is within the Saskatchewan Plains, which are underlain almost everywhere by marine shale of the Upper Cretaceous Riding Mountain Formation. This formation includes a soft, clayey facies and a hard siliceous facies (Wickenden, 1945, p. 47–50; Christiansen, 1971; Cherry and Whitaker, 1969). On the Duck Mountain upland, the Riding Mountain Formation is separated from the till by thick beds, mostly of silt and clay; these beds may be of the Wynyard Formation of probable Tertiary age (Cherry and Whitaker, 1969). The shale of the Riding Mountain Formation and some limestones of Upper Cretaceous age, including the Ashville, Favel and Vermilion River formations, outcrop along the Manitoba escarpment, whereas sand, sandstone, limestone and shale of Jurassic and Lower Cretaceous age underlie most of the Manitoba Plains. Dolomite and limestone of Middle and Upper Devonian age underlie the northeastern part of the Manitoba Plains (Wickenden, 1945, p. 5–47; Klassen et al., 1970).

Pleistocene geology and geomorphology

General till stratigraphy

The drift is mostly till but in places, particularly on the uplands, it includes much stratified sediment. The till consists of approximately equal parts of sand, silt and clay, usually with less than 10 per cent coarse material. About half the clasts are Paleozoic carbonate rocks derived from the Manitoba Plains, and the remainder are igneous and metamorphic rocks from the Precambrian Shield and shale clasts from local Cretaceous bedrock. Drift thickness in the study area is highly variable both locally and regionally and ranges from about 300 m (1000 ft) on the

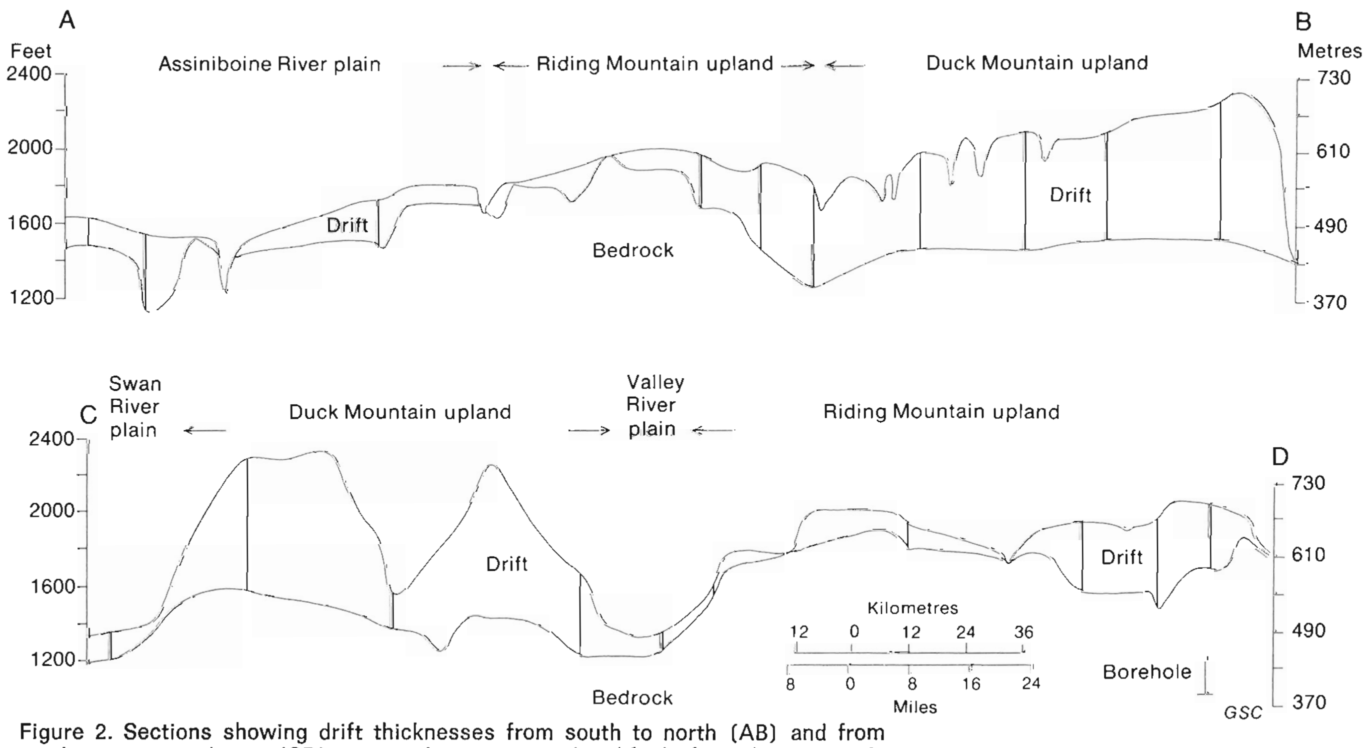
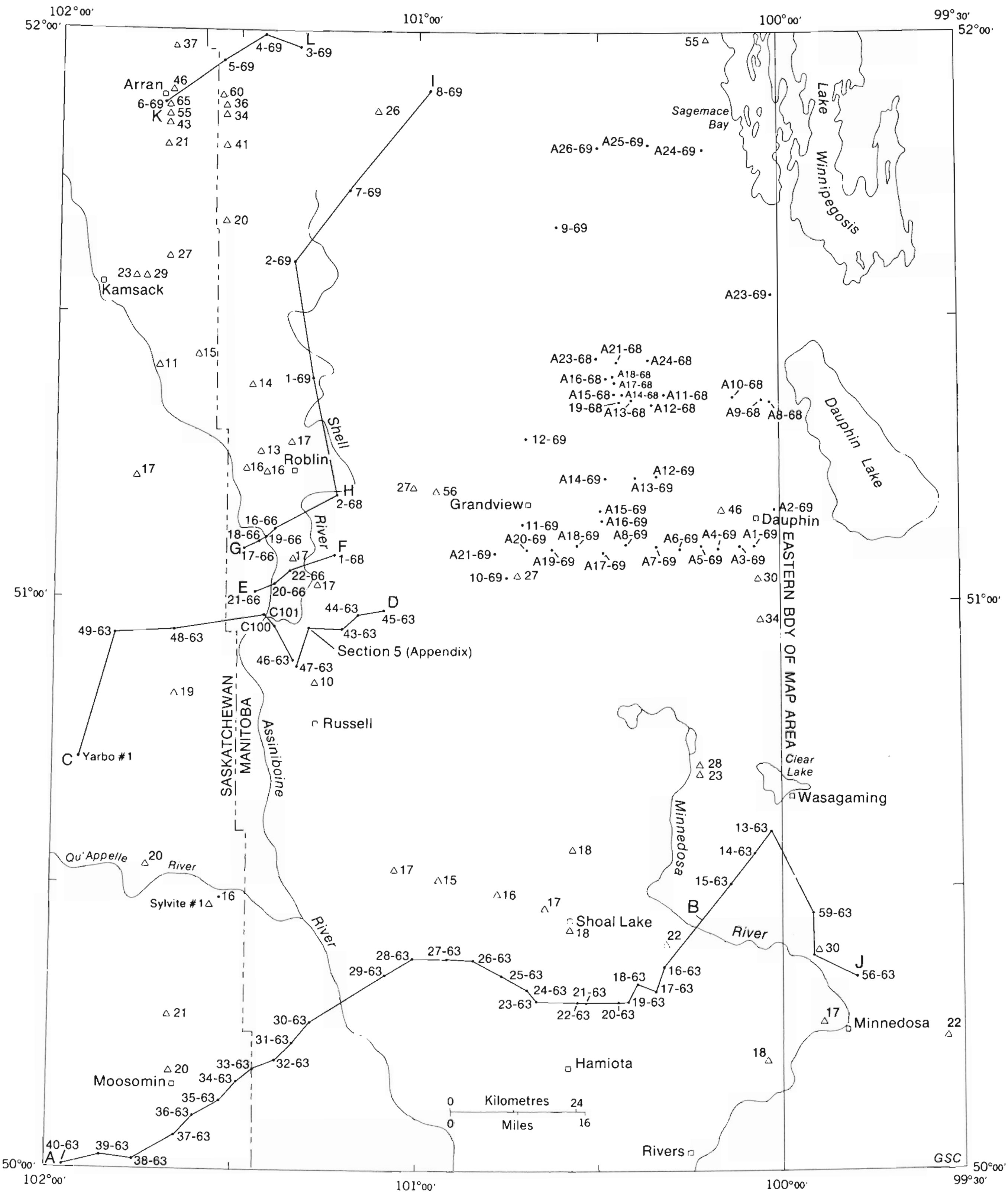


Figure 2. Sections showing drift thicknesses from south to north (AB) and from northwest to southeast (CD) across the map area (modified after Klassen et al., 1970). See Figure 1 for locations.

TIME UNITS	ROCK UNITS USED PREVIOUSLY: S.W. Manitoba (Klassen, 1969)	ROCK UNITS USED PREVIOUSLY: Duck Mountain upland (Klassen, 1971)	ROCK UNITS USED IN THIS REPORT: Duck Mountain upland		Assiniboine River plain		Riding Mountain upland		Valley River plain		Westlake plain		Swan River plain	
	Outcrop	Subsurface	Outcrop	Subsurface	Outcrop	Subsurface	Outcrop	Subsurface	Outcrop	Subsurface	Outcrop	Subsurface	Outcrop	Subsurface
WISCONSIN		Unit E							Arran F.	Arran F.	Arran F.	Arran F.	Arran F.	Arran F.
	Lennard Till		Zelena F.	Zelena F.	Lennard F.	Lennard F.	Zelena F.	Zelena F.	Zelena F.	Zelena F.	Zelena F.	Zelena F.		
	Unnamed middle deposits		Minnedosa Formation	Minnedosa Formation	Minnedosa Formation	Minnedosa Formation	Minnedosa Formation							
	Minnedosa Till													
	Roaring River Clay		Roaring River Clay		Roaring River Clay									
	Shell Till			Shell F.	Shell F.	Shell F.								
PRE-WISCONSIN	Unnamed lower deposits	Unit D		Tee Lakes F.		Tee Lakes F.								
		Unit C												
	Souris gravel and sand													
	Unnamed lower deposits	Unit B		Largs F.	Largs F.	Largs F.	Largs F.	Largs F.						
		Unit A												

GSC

Figure 3. Correlation of Pleistocene formations in the map area.



Test hole, Geological Survey of Canada ....21-63 •

Test hole, Canada Department of Agriculture ....C100 •

Auger hole, Geological Survey of Canada ....A1-69 •

Carbonate content of surface sample ....18△

Figure 4. Locations of sections, boreholes and sampling sites for carbonate content of surface tills.

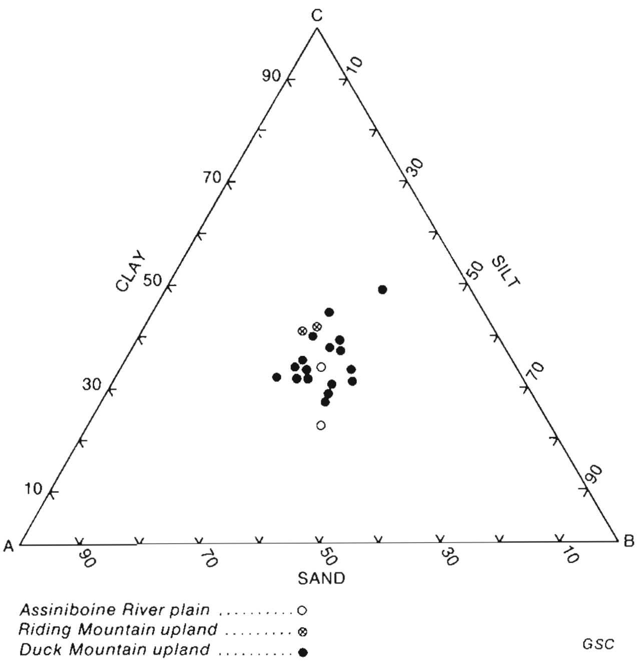


Figure 5. Grain size distribution of tills of the Largs Formation.

Duck Mountain upland to a patchy veneer over shale bedrock along part of Assiniboine Valley and on the north-facing slopes of the Riding Mountain upland. Over most of the plains and flanks of the uplands, thicknesses are between 15 and 60 m (50 and 200 ft), but on the uplands and over buried valleys thicknesses of the order of 120 m (400 ft) are common (Fig. 2).

The Pleistocene stratigraphy for southwestern Manitoba and adjoining southeastern Saskatchewan proposed by Klassen (1969, 1971, 1972a) is expanded in this report (Fig. 3) on the basis of further study and analyses of subsurface data (Fig. 4). In parts of the area units can be assigned to this framework with confidence; elsewhere correlations are less certain. Although a rock stratigraphic nomenclature is used, certain subsurface units may be assigned to a formation mainly on the basis of stratigraphic position as differences between formations are, in places, tenuous. Correlations of the till units seen in outcrop, however, are more reliable as they are based on physical properties such as jointing, weathered colour, stone fabric, carbonate content and stratigraphic position. The diagnostic properties of the formations are summarized in the following section.

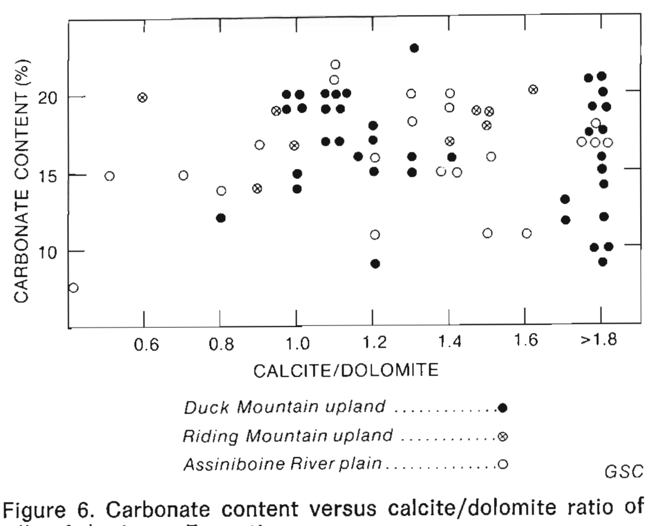


Figure 6. Carbonate content versus calcite/dolomite ratio of tills of the Largs Formation.

Largs Formation

The oldest till recognized is here formally named the Largs Formation after the railway siding Largs, Manitoba. Its type section is a roadcut about 1.5 km to the southeast in SW¼ section 9, township 15, range 18, W 1st meridian (50°15'N, 99°54'W), just east of the map area (Appendix, section 1).

This till is typically very dark grey (5 Y 3/1)[3], dark grey (5 Y 4/1), or very dark greyish brown (10 Y 3/2) where slightly oxidized in outcrop. It is a silty and clayey till (Fig. 5) with noticeably more shale stones than the other tills. The carbonate content is generally from 9 to 21 per cent (Fig. 6) or is significantly lower than that of tills of the younger Tee Lakes, Shell and Minnedosa formations. Calcite/dolomite ratios are generally greater than 1. Its thickness varies from 5 m (16 ft), where measured in outcrop, to 45 m (150 ft) in boreholes.

The Largs Formation outcrops along a broad bend of the Minnedosa Valley just east of the map area. It also was identified in outcrops and boreholes on the Assiniboine River plain, Riding Mountain upland and Duck Mountain upland. It occurs either between bedrock and younger drift or between stratified deposits and younger drift. On the Duck Mountain upland Klassen (1971, p. 256) previously designated it as Unit B, and on the Riding Mountain upland as the Shell Till. Later, studies showed, however, that on the Riding Mountain upland the carbonate content of this till was too low and the shale pebble content was too high to be designated as the Shell Till.

The stratigraphic position of this formation indicates that it is of pre-Wisconsin age and probably is early Pleistocene.

Tee Lakes Formation

The name Tee Lakes Formation is here given to multiple tills and intertill sediments between the Largs Formation and the Shell Formation. The type section is a borehole on the Duck Mountain upland in SW¼ section 11, township 32, range 27 (51°43'N, 101°12'W) near Tee Lakes (Appendix, section 17) after which it is named.

The tills are typically very dark grey (5 Y 3/1). The carbonate contents are mainly between 20 and 26 per cent, but the calcite/dolomite ratios vary widely (Fig. 7). Thicknesses are from 15 to 60 m (50 to 200 ft).

The Tee Lakes Formation is widespread on the Duck Mountain upland where it overlies the Largs Formation and underlies undivided drift. It also occurs beneath the northeastern part of the Assiniboine River plain inside a broad, buried valley where it overlies the Largs Formation

[3]Munsell chart colour designations.

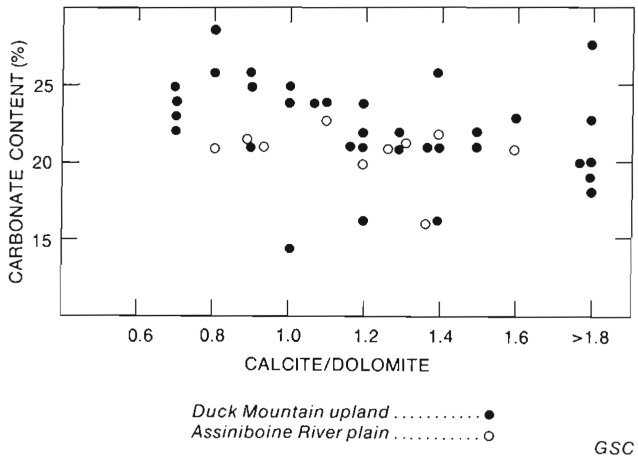


Figure 7. Carbonate content versus calcite/dolomite ratio of tills of the Tee Lakes Formation.

or unnamed sediments and underlies the Shell Formation or the undivided drift.

Because of its stratigraphic position, the Tee Lakes Formation is probably of pre-Wisconsin age.

Shell Formation

The Shell Till was named and described by Klassen (1969, p. 9–11). Additional subsurface information has necessitated a minor redefinition of this unit, which is here referred to as the Shell Formation. It generally consists of one till unit, but in places it includes several tills and also intertill sediments.

A diagnostic property of the tills in outcrops along the lower Shell Valley and in some boreholes is an upper zone of weathering that separates it from the overlying Minnedosa Formation. This zone is typically light olive brown (2.5 Y 5/6) or yellowish brown (10 YR 5/4) and grades into a dark grey (5 Y 4/1) or dark olive grey (5 Y 3/2) and even very dark grey (5 Y 3/1) some 3 to 6 m (10 to 20 ft) below the top. The carbonate content in and directly below the weathered zone is highly variable. At this type section (Appendix, section 3), which is entirely in the weathered zone, the carbonate content is 18 per cent and in a nearby borehole is 13 per cent (Appendix, section 18); in another nearby outcrop sampled near the contact with an underlying gravel bed, the carbonate content is 55 per cent (Appendix, section 9). The unweathered till generally has a carbonate content between 24 and 36 per cent (Fig. 8) or substantially higher than the 20 per cent indicated previously (Klassen, 1969, p. 10). The tills are somewhat sandier than those of other formations (Fig. 9). This formation is generally a thin unit, although locally it includes several tills and intertill sediments of more than 30 m (100 ft) total thickness.

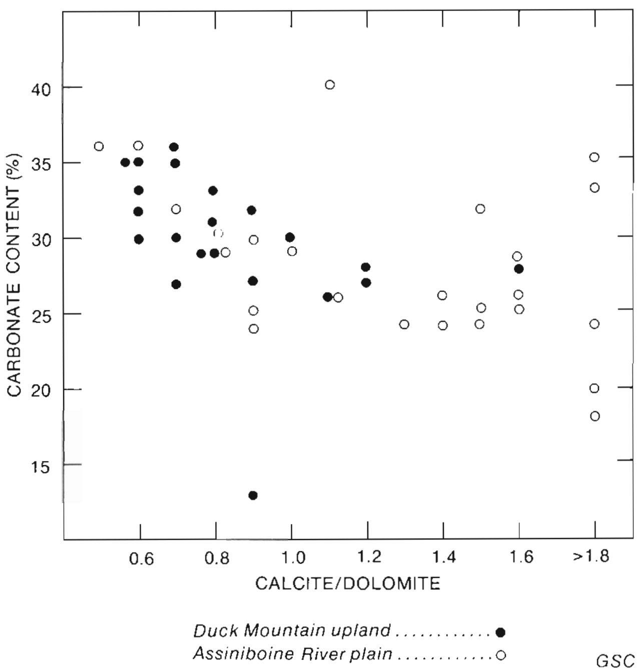


Figure 8. Carbonate content versus calcite/dolomite ratio of tills of the Shell Formation.

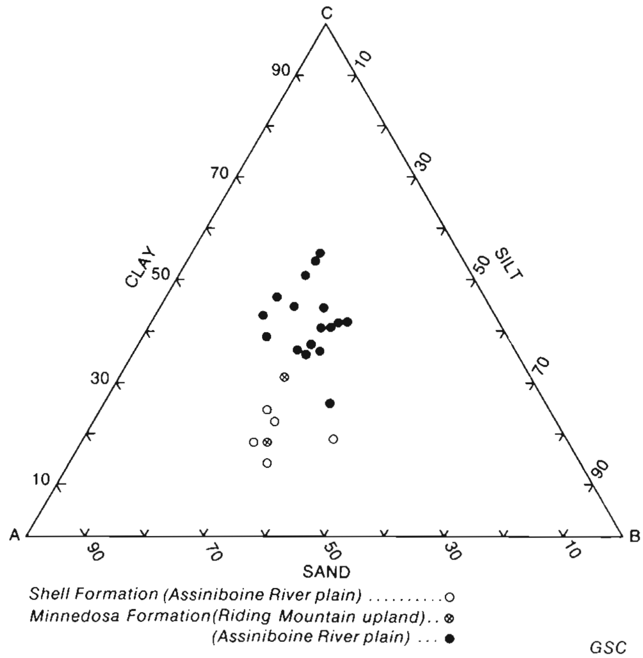


Figure 9. Grain size distribution of tills of the Shell and Minnedosa formations.

The Shell Formation occurs as a rather discontinuous unit. It outcrops along lower Shell Valley and was identified in a few boreholes in the northeastern part of the Assiniboine River plain and Duck Mountain upland. It is commonly underlain by the Tee Lakes Formation and overlain by the Minnedosa Formation.

As stated by Klassen (1969, p. 11; 1975, p. 5), the Shell Formation is of early Wisconsin or pre-Wisconsin age. At least two major glaciations and nonglacial intervals of interstadial or interglacial rank followed its deposition. Plant detritus from the oldest nonglacial interval is beyond the range of radiocarbon dating (Appendix, sections 11 and

19). Organic detritus from the younger nonglacial interval yielded finite ages of between 24 000 and 38 000 years (Appendix, section 21). Weathering of the upper zone of the Shell Formation apparently occurred during the oldest of these nonglacial intervals.

Minnedosa Formation

The Minnedosa Formation was named and described by Klassen (1969, p. 13–14). Its type section is an outcrop (Appendix, section 4) on the Riding Mountain upland. A till that previously was included in the unnamed middle deposits is here considered part of the Minnedosa Formation.

In outcrop the till commonly is recognized by an olive colour and distinct, closely spaced, joint lines. Where the till is unoxidized the characteristic colours are olive (5 Y 5/3) or olive grey (5 Y 4/2); and where it is oxidized, colours such as yellowish brown (10 YR 5/6), dark yellowish brown (10 YR 4/4), or dark greyish brown (10 YR 4/2) are common and identical to other oxidized tills. Subsurface samples are typically either olive grey (5 Y 4/2) or very dark grey (5 Y 3/1). The carbonate content is mostly between 18 and 24 per cent with the greatest number of samples near 20 per cent, but calcite/dolomite ratios are highly variable (Fig. 10). These tills are somewhat clayier than those of other formations (Fig. 9). Thicknesses are between 3 and 30 m (10 and 100 ft).

This formation is most widespread on the Assiniboine River plain, where it overlies bedrock, the Largs Formation or undivided drift, and forms the surface or is overlain by the Lennard Formation. It also outcrops on the Riding Mountain upland (Appendix, section 4), and on the Duck Mountain upland, but identification in the subsurface on Riding Mountain upland is uncertain, although it probably is included in the undivided drift.

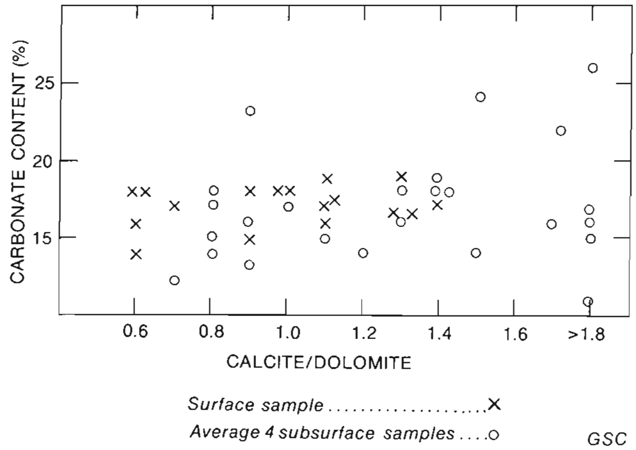


Figure 11. Carbonate content versus calcite/dolomite ratio of tills of the Lennard Formation on the Assiniboine River plain.

Orientations of elongate till stones evident in several outcrops indicate that glacier flow likely was to the southwest. An early Wisconsin age is considered most likely for this till.

Lennard Formation

The previously named Lennard Till (Klassen, 1969) is here referred to as the Lennard Formation. More detailed studies have revealed significant differences in the physical properties of the surface tills of the uplands and adjacent plains and have led to the designation of another formation on the uplands (Zelena Formation) and another on the plains east of the uplands (Arran Formation). As a result, the Lennard Formation is not as extensive as initially was indicated.

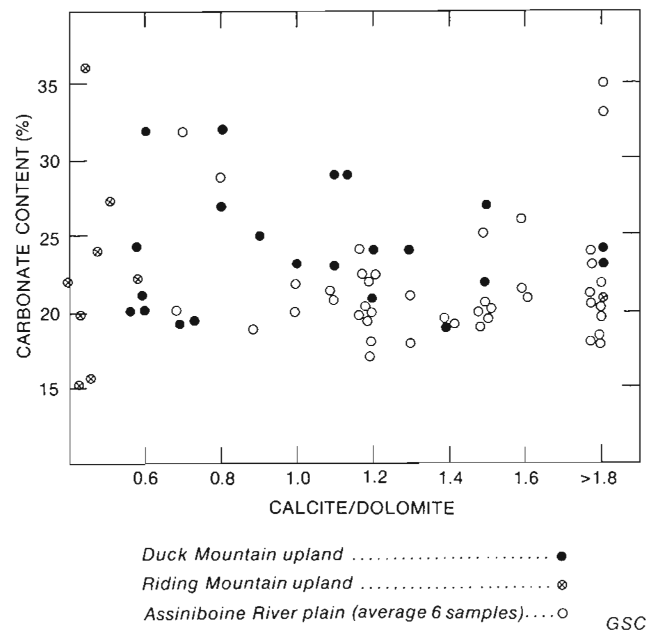


Figure 10. Carbonate content versus calcite/dolomite ratio of tills of the Minnedosa Formation.

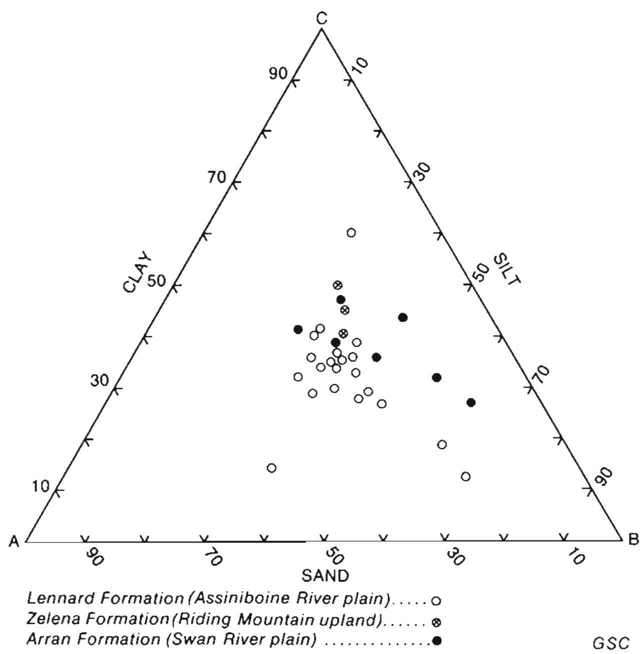


Figure 12. Grain size distribution of tills of the Lennard, Zelena and Arran formations.

Till of the Lennard Formation is commonly a dark greyish brown (2.5 Y 4/2) and is somewhat darker than the underlying, more strongly oxidized till of the Minnedosa Formation. Its carbonate content is typically between 14 and 19 per cent, but the calcite/dolomite ratios vary (Fig. 11). The till also is looser and siltier (Fig. 12) than the underlying till of the Minnedosa Formation, and its stone fabric has a preferred orientation to the southeast. West of Assiniboine River the till is generally thin or patchy, but it thickens to between 15 and 30 m (50 and 100 ft) or more east of the river.

The Lennard Formation occurs over most of the Assiniboine River plain but is very thin in places west of Assiniboine River valley, where the ridges of corrugated moraine are composed of till of the Minnedosa Formation. The contact between these formations is marked by a boulder pavement that is commonly seen along roadcuts and ditch bottoms.

The Lennard Formation was deposited during the late Wisconsin glaciation by a southeasterly flowing glacier.

Zelena Formation

The uppermost tills and intertill sediments on the Riding Mountain and Duck Mountain uplands are here named the Zelena Formation after the hamlet of Zelena, Manitoba near the type section (Appendix, section 21) on the east side of Shell Valley in NW¼ section 17, township 28, range 27 (51°24′N, 101°13′W).

Tills of the Zelena Formation are commonly yellowish brown (10 YR 5/4) or very dark greyish brown (2.5 Y 3/2) where oxidized and dark olive grey (5 Y 3/2) or very dark grey (5 Y 3/1) where unoxidized. Carbonate contents are mostly in the 26 to 36 per cent range, and calcite/dolomite ratios are typically greater than 1 (Fig. 13). On the uplands the till is commonly less indurated and siltier (Fig. 12) than the underlying till of the Minnedosa Formation. Beneath the Valley River plain it is stonier than the till of the overlying Arran Formation, a characteristic particularly noticeable during augering. The till is generally between 3 and 15 m (10 to 50 ft) thick, but locally it exceeds 30 m (100 ft).

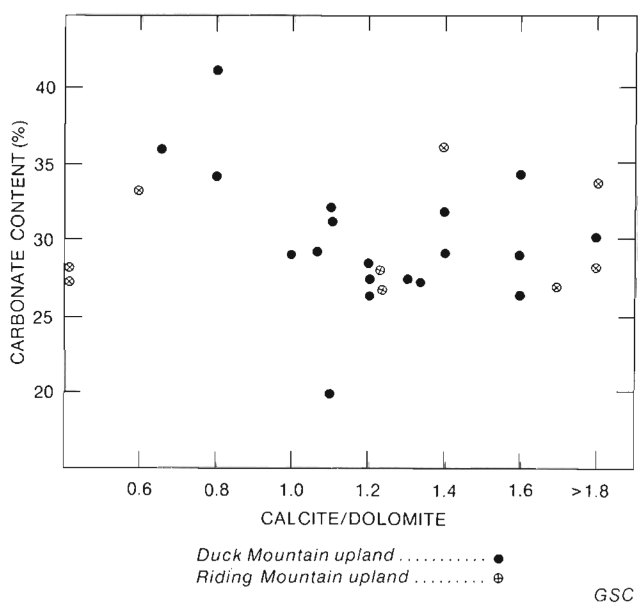


Figure 13. Carbonate content versus calcite/dolomite ratio of tills of the Zelena Formation.

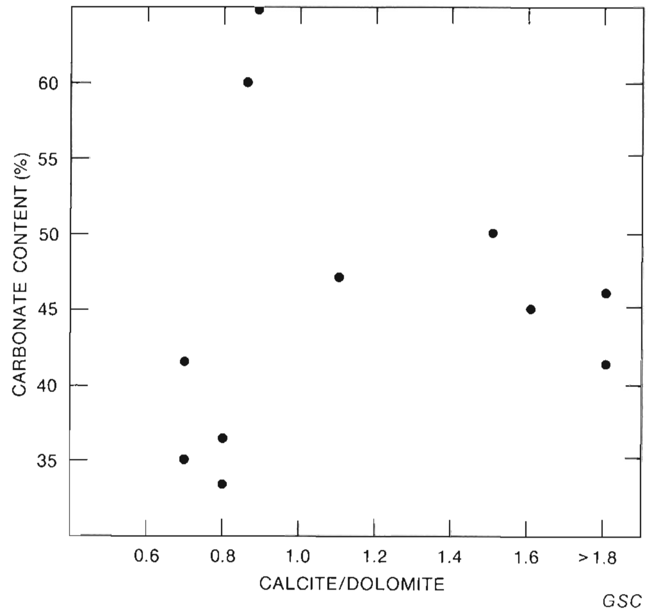


Figure 14. Carbonate content versus calcite/dolomite ratio of tills of the Arran Formation on the Swan River plain.

The Zelena Formation forms the surface drift on the Riding Mountain and Duck Mountain uplands where it overlies the Minnedosa Formation. It underlies the Arran Formation within the Valley River plain.

The Zelena Formation was deposited during the final stagnation of the late Wisconsin ice sheet on the Riding Mountain and Duck Mountain uplands. The ice over the nearby plains remained active somewhat longer.

Arran Formation

The youngest till and its overlying stratified sediments on the Valley River plain, Westlake plain and Swan River plain are here named the Arran Formation. The type section for the till is a roadcut along Highway 49, 1 km east of Arran, Saskatchewan in SE¼ section 6, township 34, range 30 (51°53′N, 101°42′W).

The till typically has a brown colour in outcrop (yellowish brown (10 YR 5/6), light olive brown (2.5 Y 5/4), olive brown (2.5 Y 4/4), brown (10 YR 5/3)) that probably is the result of a high carbonate content, which ranges between 34 and 65 per cent (Fig. 14). In the subsurface it is very dark greyish brown (10 YR 3/2). The till is similar in grain size to the tills of the Zelena and Lennard formations (Fig. 12). The till is normally between 2 and 5 m (5 and 15 ft) thick, but locally it may be thicker or else may occur as a patchy veneer.

The Arran Formation forms the surface of the Valley River, Westlake and Swan River plains. It overlies the Minnedosa or Zelena formations.

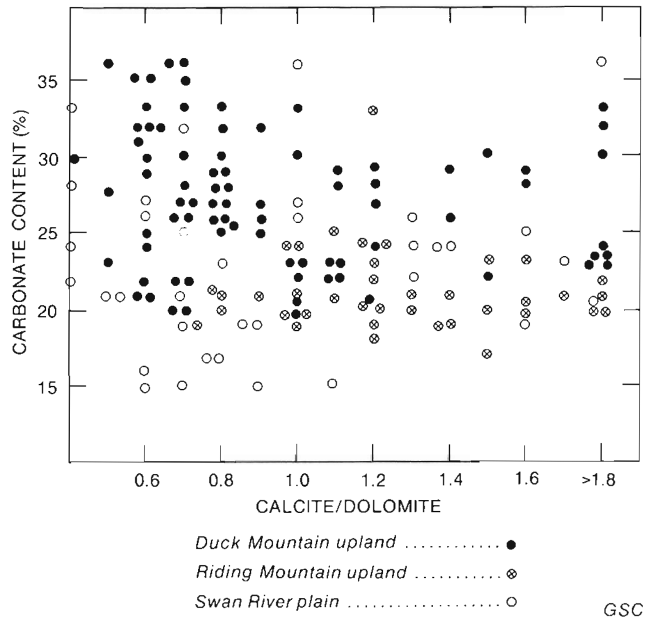


Figure 15. Carbonate content versus calcite/dolomite ratio of tills of the undivided drift.

The Arran Formation was deposited during the advance and retreat of the late Wisconsin glacier east of the Manitoba escarpment and its lobate portions that occupied the re-entrants between the Riding Mountain, Duck Mountain and Porcupine Hills uplands (Klassen, 1975, p. 47–55). It was the last drift deposited in the map area during the final ice retreat some 13 000 years ago (Klassen, 1975).

Undivided drift

In parts of the map area certain tills and intertill sediments penetrated in boreholes cannot be assigned to any of the described formations, either because of insufficient data or because of inconsistent physical properties. The units are designated as 'undivided drift'. Carbonate contents range from 15 to 36 per cent (Fig. 15), and total thicknesses are mostly from 30 to 60 m (100 to 200 ft), although they are thinner or up to 120 m (400 ft) thick locally. The units commonly overlie the Largs Formation or Tee Lakes Formation, but in places they directly overlie bedrock. This drift consists of till units of one or several formations, such as the Tee Lakes, Shell, Minnedosa and Zelena, that have not been identified locally.

Landscapes

The widespread use of aerial photographs for mapping the prairies of western Canada and the north-central United States during the past 20 years has resulted in the recognition of a variety of glacial landscapes and associated features within the broad categories of ground moraine and end moraine mapped by earlier investigators. This has led to the introduction of a host of new terms with morphologic and/or morphogenetic implications (Gravenor, 1955;

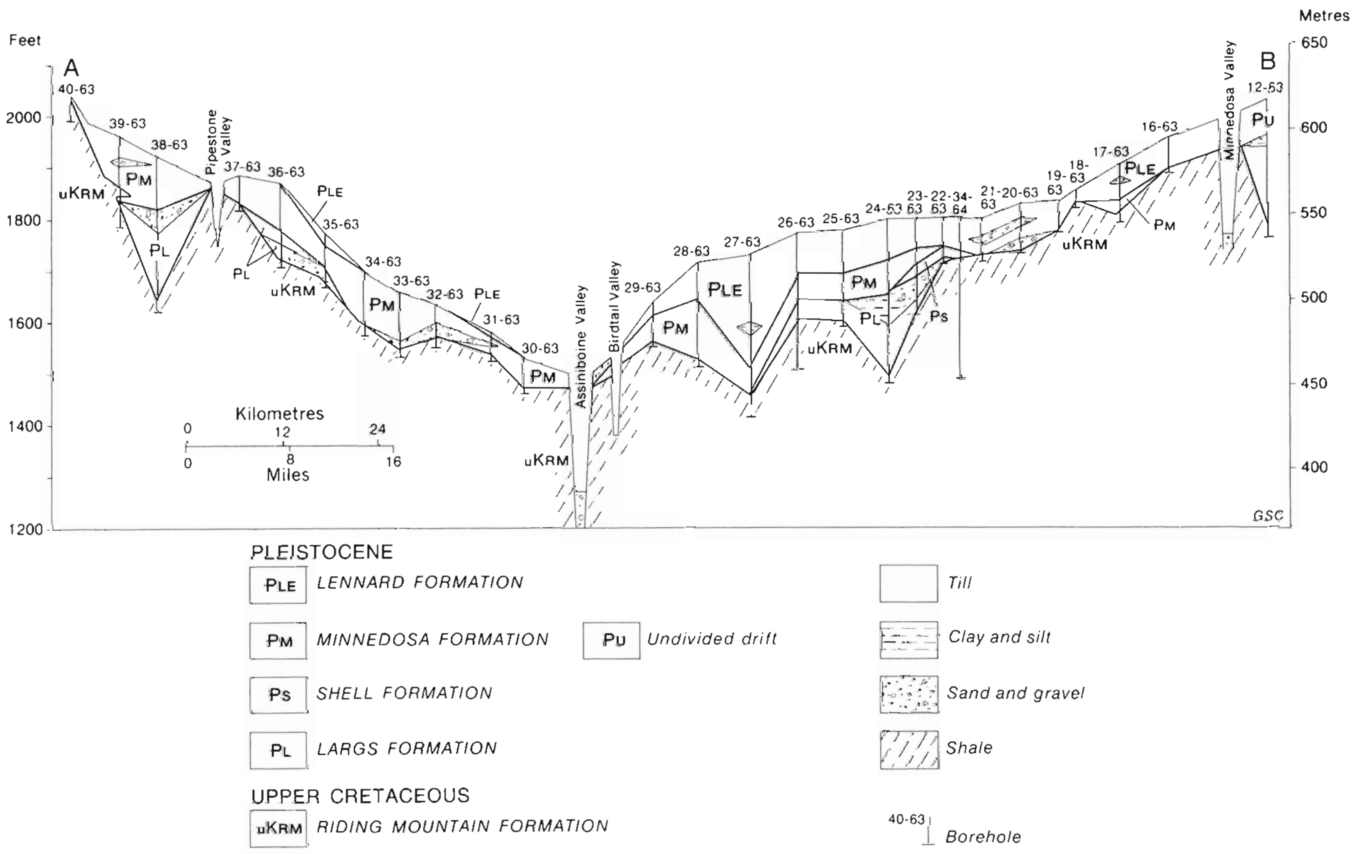


Figure 16. Section AB across the southern part of the Assiniboine River plain (see Fig. 4 for location).

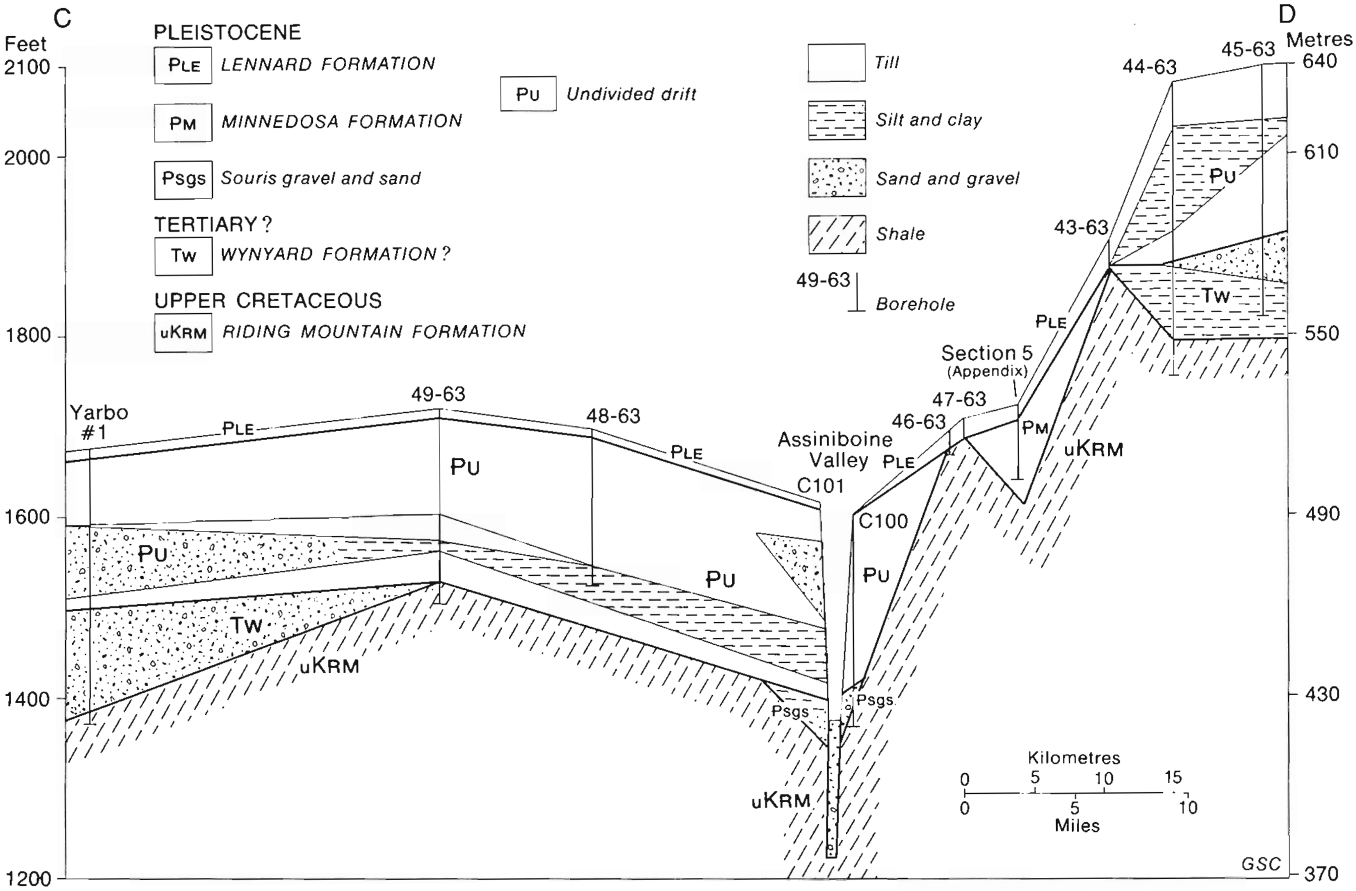


Figure 17. Section CD across the east-central part of the Assiniboine River plain (see Fig. 4 for location).

Gravenor and Kupsch, 1959; Stalker, 1960b; Clayton, 1962, p. 17–45; Parizek, 1969). Some of the terminology used was original, and some of it was adapted from European glaciological literature. This, to a certain extent, has resulted in usage described as "somewhat chaotic" (Prest, 1968, p. 1). The following discussion is aimed primarily towards clarifying the terminology used in this report and elucidating morphogenetic aspects of certain landscapes or features.

Bedrock plains

Bedrock plains are nearly flat or broadly rolling surfaces of bedrock or till veneered bedrock. The thin or patchy distribution of till, along with the presence of local drumlins and drumloids, indicates a subglacially modified surface.

The bedrock plains shown on the accompanying surficial geology maps were shown as ground moraine on earlier maps (Christiansen, 1960; Klassen, 1965).

Till plains

Till plains are flat to gently irregular surfaces formed of both lodgment and englacial till and are marked by randomly oriented ridges, knolls and intervening depressions. The relief is generally low, but clusters of ridges and knolls of intermediate relief occur locally.

The till plains were shown previously as either ground moraine (Christiansen, 1960) or irregular recessional moraine (Klassen, 1965), but these terms have genetic implications that are not everywhere valid within these plains.

Corrugated moraine

This moraine is characterized by aligned ridges and knolls of clayey till and intervening troughs. On aerial photographs and mosaics they form a distinct corrugated pattern with broadly lobate outlines. The pattern results from the subparallel trend of the main ridges and depressions, along with less prominent shorter ridges transverse to this trend.

Prest (1968, p. 3) proposed the term 'corrugated ground moraine', but it is modified here to 'corrugated moraine' to avoid the genetic implications of the term ground moraine. His contention that the ridges "probably owe their emplacement to subglacial pushing, thrusting, or squeezing in association with a fracture system or zone of weakness, in an ice-marginal zone, and were preserved because of subsequent stagnation of the local ice" is supported by field observations from the study area.

Hummocky moraine

Areas designated as hummocky moraine consist mostly of till ridges, knolls, and intervening elongate and irregular

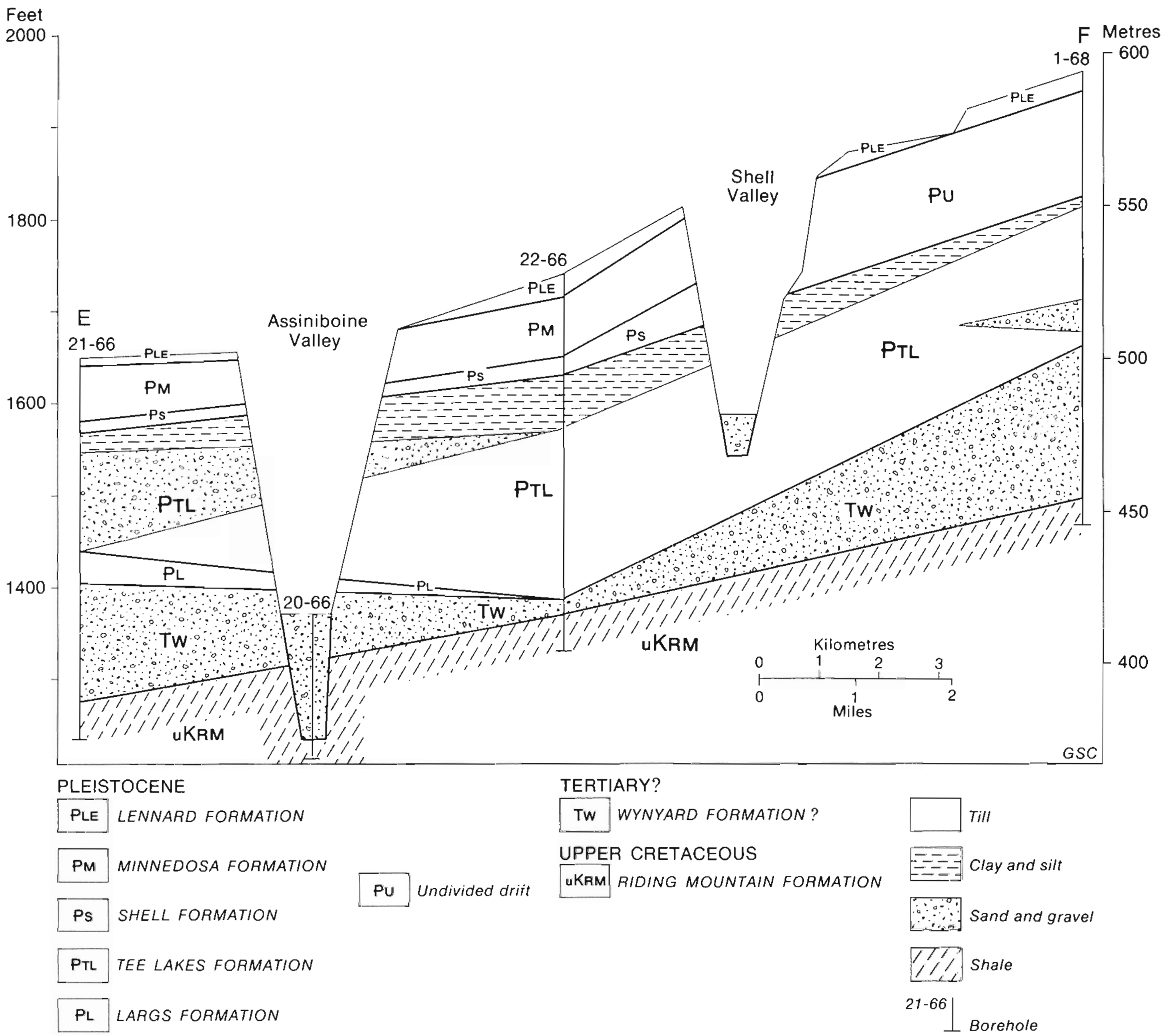


Figure 18. Section EF across the east-central part of the Assiniboine River plain (see Fig. 4 for location).

depressions with 5 to 30 m (15 to 100 ft) local relief. This moraine is in Prest's (1968, p. 10) category of 'high relief, hummocky moraine', and moraine plateau features (Stalker, 1960b) are an integral part of it.

Much has been written concerning the origin of the hummocky moraine so widespread on the uplands of western Canada and north-central United States (Gravenor and Kupsch, 1959, p. 56; Stalker, 1960a, p. 29–35, 1960b, 1973, p. 31–34; Clayton, 1962, p. 35–38). There is general agreement that hummocky moraine formed as a result of stagnant or near stagnant glacier ice on the uplands during the general downslope retreat of the continental glacier. Little is known concerning the glaciological mechanisms and processes involved, although recent studies of retreating arctic glaciers (Boulton, 1972, p. 370–373) suggest that slow melting of debris-rich ice was a factor in the formation of hummocky moraine.

Geology and geomorphology of physiographic divisions

Assiniboine River Plain

The Assiniboine River plain covers more than 14 000 km^2 (5400 mi^2) adjacent to much of Qu'Appelle and Assiniboine valleys in Manitoba and Saskatchewan. It lies at about 455 m (1550 ft) a.s.l. along Assiniboine Valley in the southwestern part of the map area and 575 m (1900 ft) a.s.l. near the Riding Mountain and Duck Mountain uplands to the northeast and the Souris River plain to the southwest (Fig. 1).

Drift thickness. The average thickness of the drift, based on

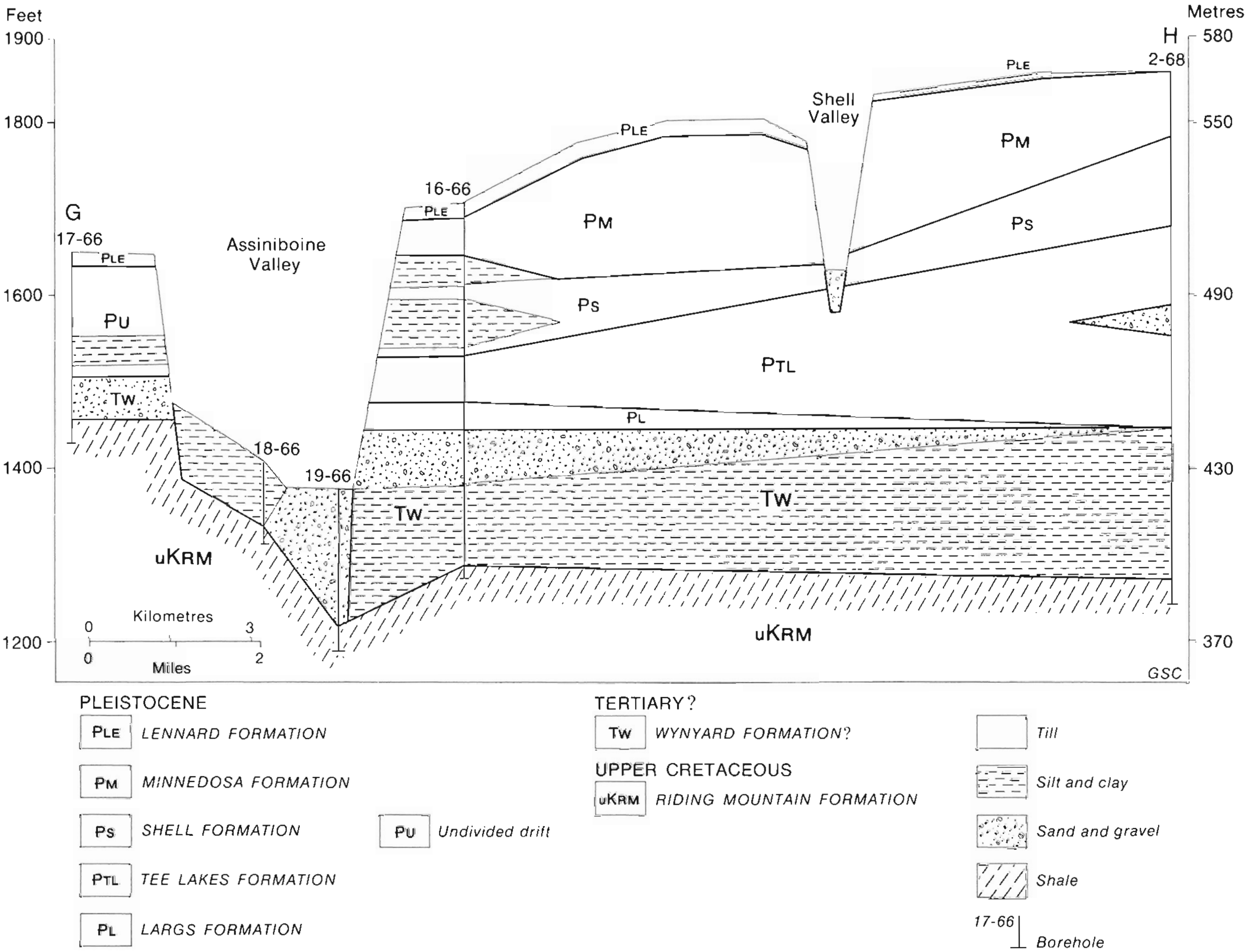


Figure 19. Section GH across the east-central part of the Assiniboine River plain (see Fig. 4 for location).

information from 55 boreholes in selected parts of the Assiniboine River plain, is 40 m (130 ft) (Figs. 16 to 19). Thicknesses range from a thin veneer between bedrock exposures along parts of Assiniboine and Qu'Appelle valleys to between 15 and 60 m (50 and 200 ft) elsewhere. Certain buried valleys contain 90 to 120 m (300 to 400 ft) of drift.

Till stratigraphy. Tills of the Largs, Tee Lakes, Shell, Minnedosa and Lennard formations underlie the Assiniboine River plain (Figs. 16 to 19). The Largs Formation appears to be restricted mostly to buried valleys where it is more than 30 m (100 ft) thick (Fig. 16). About 60 m (200 ft) of the Tee Lakes Formation was identified in the subsurface in the northern part of the plain (Figs. 18 and 19). The Shell Formation is widespread in the northern part of the plain (Figs. 18 and 19), but it is absent or discontinuous elsewhere (Fig. 16), whereas the Minnedosa Formation occurs over most of the plain and forms the bulk of the drift west of Assiniboine Valley. The surface till is of the Lennard Formation, although in places west of Assiniboine Valley in the southern part, it is thin and patchy.

Landscapes and glacial features. Bedrock plains. Bedrock plains occur in several belts and patches, totalling some 1000 km^2 (400 mi^2), along the Assiniboine and Qu'Appelle valleys in the southern part of the Assiniboine River plain. Along Qu'Appelle Valley and the lower part of Assiniboine Valley they are nearly flat or gently irregular (Figs. 20 and 21), but along the east side of Assiniboine Valley between its confluence with Qu'Appelle and Shell valleys, they have a broadly rolling swell and swale topography (Fig. 22). Some of the swells are drumlinized bedrock ridges 15 to 30 m (50 to 100 ft) high with crests 1 to 1.5 km apart. These features lie on a slope of about 8 m (25 ft) a mile towards Assiniboine Valley, and so their height is exaggerated when they are viewed upslope.

Ice flow features, including drumlins, drumloids and flutings, form both prominent hills and subdued features detected primarily on aerial photographs (Figs. 20 and 21).

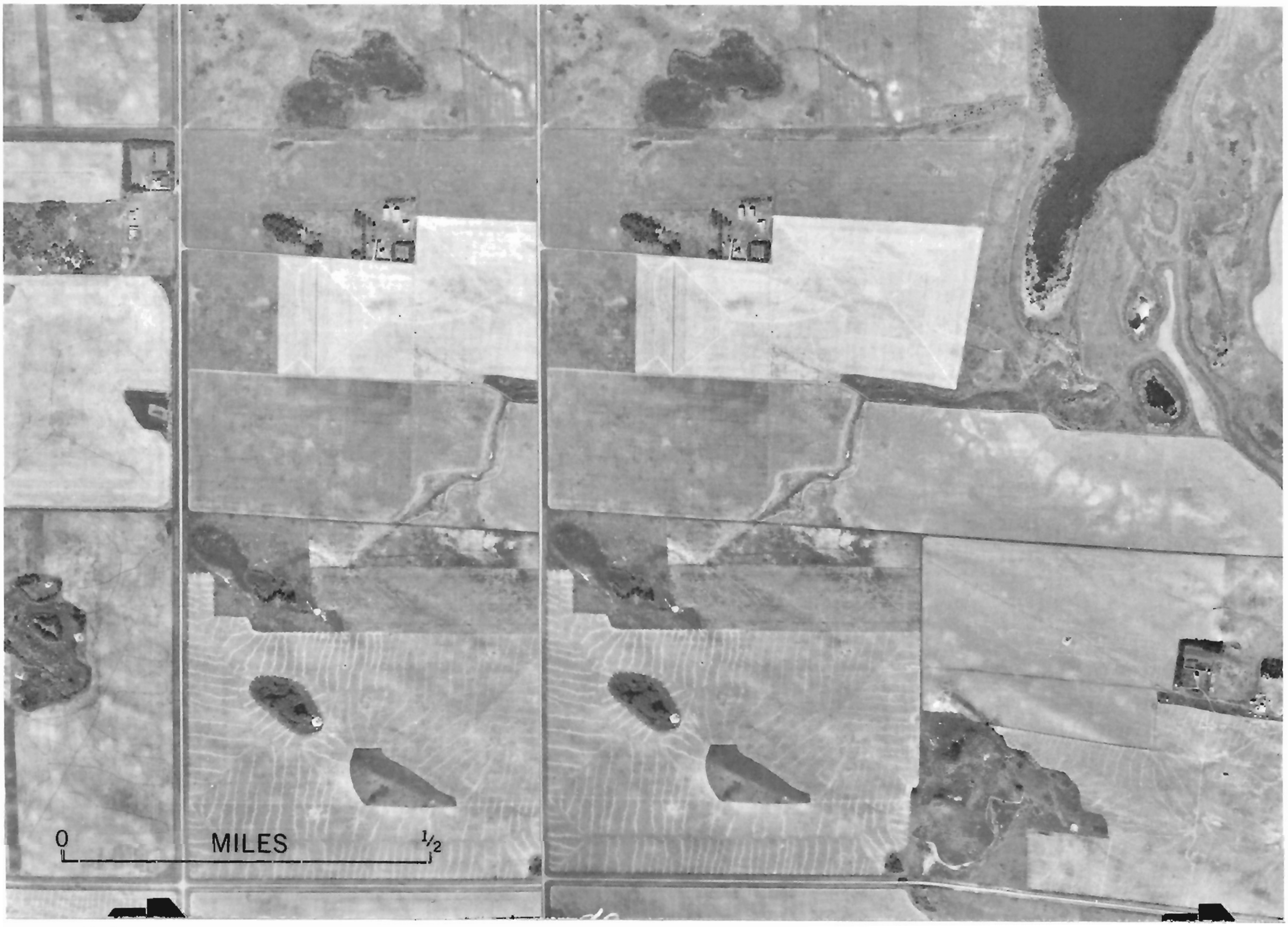


Figure 20. Stereopair aerial photographs showing drumlinized bedrock plain (sec. 20, tp. 12, rge. 24) east of Assiniboine Valley near the southern boundary of the map area (A11731-90,89).

The drumlins commonly have bedrock cores, but the subdued features are composed entirely of till. Flutings near Binscarth and Russell occur as aligned ridges about 150 m (500 ft) apart, 1.5 to 3 m (5 to 10 ft) high and 1.5 to 5 km (1 to 3 mi) long.

Till plains. Gently irregular till plains marked by ridges and knolls generally less than 3 m (10 ft) high cover some 6800 km² (2600 mi²) of the Assiniboine River plain. Southeast trending belts of hummocky topography that are 3 to 8 m (10 to 25 ft) higher than other parts of the plains occur here and there.

Till of the Lennard Formation forms the plains. Pockets of silt and sand commonly are seen within the till where it is exposed in dug-outs and roadcuts (Figs. 23 and 24).

Corrugated moraine. Corrugated moraine covers 5200 km² (2000 mi²) mostly west of Assiniboine River. Till ridges and knolls 3 to 8 m (10 to 25 ft) high and 60 to 210 m (200 to 700 ft) wide, with intervening elongate depressions, form a lobate corrugated pattern evident on aerial photographs and mosaics (Fig. 25). The ridges are generally 300 to 1200 m (1000 to 4000 ft) long, from 120 to 210 m (400

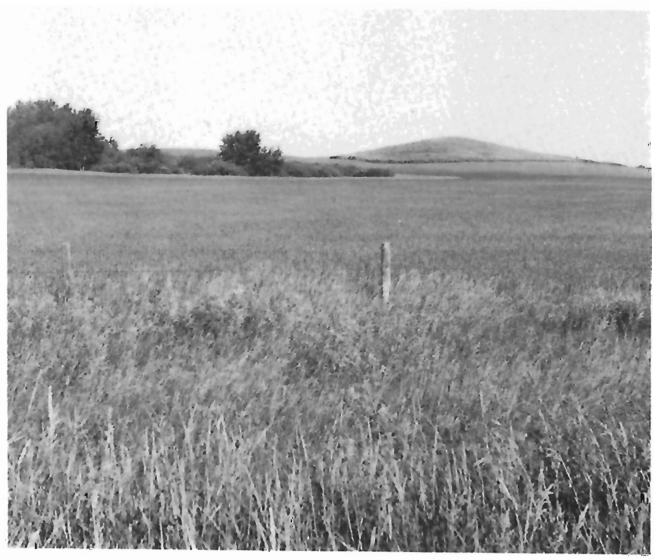


Figure 21. Ground view of bedrock plain shown in Figure 20. View is southeast from SW¼ sec. 20, tp. 12, rge. 24 towards the stoss slope of a drumlin (GSC 162877).

Figure 22. Broadly rolling bedrock plain east of Assiniboine Valley near Cracknell, Manitoba. View is south from NW¼ sec. 34, tp. 21, rge. 28 (GSC 162836).

to 700 ft) apart, and straight to slightly arcuate. They are aligned mainly transverse to the southerly direction of glacier flow across this part of the plain. The stones within the ridges commonly have a preferred orientation nearly parallel to the direction of ice flow (Table 1). Extensive areas of corrugated moraine west of Assiniboine Valley consist mostly of till of the Minnedosa Formation and some till of the Lennard Formation, whereas on higher ground east of the valley it consists entirely of the latter till.

A fluted pattern is evident between corrugated moraine ridges in the vicinity of township 20, range 31 and is most pronounced where the surface has been eroded by water.

Outwash plains. Outwash covers about 470 km² (180 mi²) near Assiniboine and Qu'Appelle valleys in the southern part of the Assiniboine River plain. The main body of outwash, found northwest of the confluence of Assiniboine and Qu'Appelle valleys, forms a smooth plain, except for some sand dunes. Christiansen (1960, p. 18) referred to it as the 'Welby sand plain'. It is generally 3 to 9 m (10 to 30 ft) thick and consists mainly of sand and fine gravel. About 8 m (25 ft) of outwash is exposed in a gravel pit (SW¼ sec. 13, tp. 17, rge. 29) along the north edge of Qu'Appelle Valley. It consists of a lower sand unit and an overlying gravelly unit separated by a boulder layer overlain by silt and sand.

Parabolic and longitudinal sand dunes (Thornbury, 1954, p. 310) cover some 50 km² (20 mi²) of the outwash. Generally, the dunes are minor features except near Assiniboine Valley where they form ridges 1.5 to 6 m (5 to 20 ft) high, 15 to 60 m (50 to 200 ft) wide, and from 300 m (1000 ft) to more than 1.5 km (1 mi) long. Most of the ridges are nearly straight to slightly arcuate and trend southeast, to some extent arranged en echelon. In places they converge and form hairpin or chevron outlines open to the northwest. A succession of small dunes, with blowouts at some of the apices, is superimposed along the length of some of the large ridges that form the predominant patterns. Vegetation has stabilized the northeastern slopes and interdune areas.

The dunes were built by the northwesterly winds that continue to be the prevailing winds today. It is possible that some dunes were built in late Wisconsin time by winds

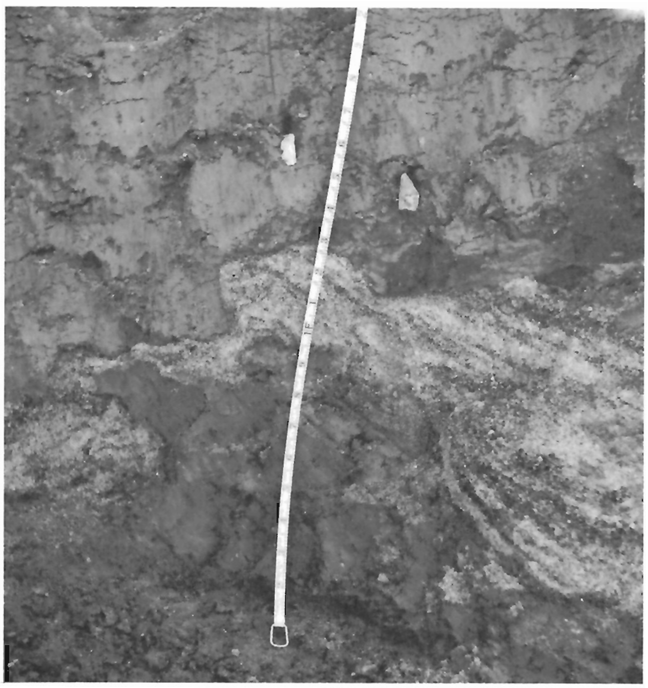


Figure 23. Sand lens enclosed in clayey till in SW¼ sec. 29, tp. 17, rge. 25. Lens was exposed 4 m below the surface (GSC 124552).

Fig. 24. Bedding within the lens shown in Figure 23 (GSC 124551).

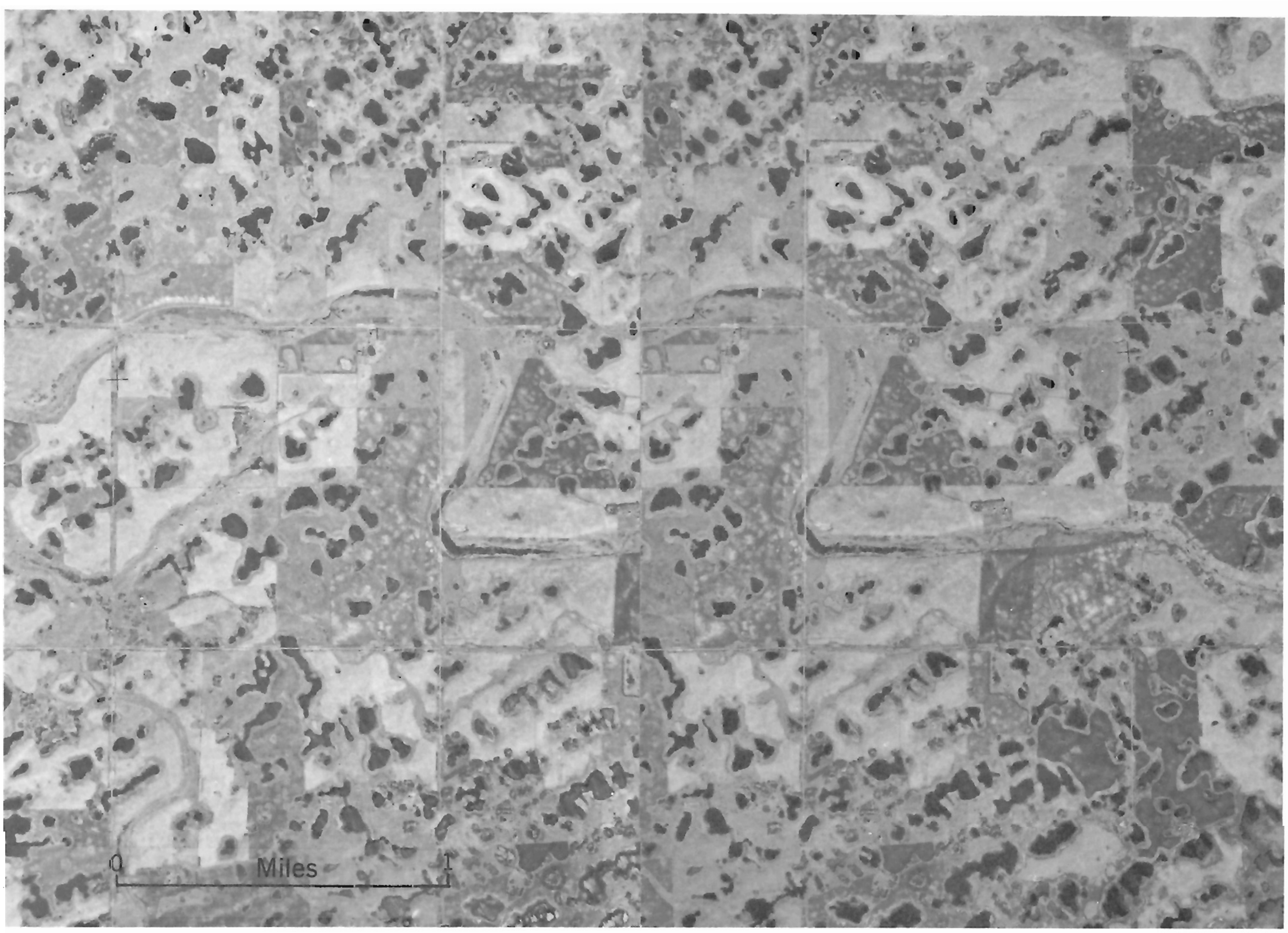


Figure 25. Stereopair aerial photographs showing corrugated moraine about 3 km south of Manson, Manitoba (sec. 18, tp. 13, rge. 28) (A15528-18, 19).

blowing from the glacier situated to the northwest, but the majority of dunes are postglacial in age as their forms show the controlling influence of recent vegetation.

The outwash along the east side of Assiniboine Valley between Snake and Minnewasta creeks is a deeply pitted surface with local relief of up to 12 m (40 ft). An ice-contact face forms part of its western margin, and eskers are found near the northwestern apex. The outwash south of Minnewasta Creek, as well as a narrow belt adjoining the pitted outwash, is fairly flat and in places it forms the floors of meltwater channels that are cut into it. The outwash is generally sandy although in places, and particularly in the pitted part, coarse gravel and boulders occur. Along Birdtail Valley, near its confluence with Assiniboine Valley, the outwash is more than 9 m (30 ft) thick, but it thins southward to about 5 m (15 ft) near Miniota and to less than 3 m (10 ft) south of the Arrow Hills. These outwash plains formed within a re-entrant in the Assiniboine lobe (Klassen, 1972a, p. 554) as the glacier retreated to the northwest. Later they were partly dissected by meltwater and by the initial flood that, early in the excavation of Assiniboine and Qu'Appelle valleys (Klassen, 1972a, p. 552), marked the breaking of those ice dams that held in glacial lakes Indian Head and Regina.

Near Shellmouth, outwash covers 26 km^2 (10 mi^2) between Assiniboine Valley and Thunder Creek (tp. 22, rge. 29). Along Assiniboine Valley small kames occur along the margin of a narrow, pitted belt of this outwash. Here the outwash is gravelly, but it is sandier towards the southeast where the surface is smooth or gently irregular. The thickness of the outwash equals its local relief, which is 3 to 8 m (10 to 25 ft). This outwash formed during the early stages of Shell Valley (Klassen, 1972a) along the southeasterly margin of the Assiniboine ice lobe.

Outwash gravel, sand and silt cover about 40 km^2 (15 mi^2) along the southern margin of the map area near the town of Rivers. In a large gravel pit east of Rivers (N½ sec. 24, tp. 12, rge. 21), where about 8 m (25 ft) of it is exposed, the lower 3 to 6 m (15 to 20 ft) is sand and gravel with well developed foreset bedding. The upper part is more bouldery and poorly bedded. These sediments were deposited as a delta in glacial Lake Souris (Klassen, 1975, p. 47).

Lacustrine plains. A nearly flat or gently irregular lake

Table 1. Stone orientations in corrugated moraine

Location Sec. Tp. Rge.	Ridge height	Site location below ridge crest	Stones measured	Mean azimuth	Ridge trend
	m (ft)			degrees	
SW22 13 29	2.4(8)	2.4(8)	59	176	65
SW22 13 29	2.4(8)	2.4(8)	65	136	65
SW22 13 29	2.4(8)	1.5(8)	63	117	65
SW22 13 29	2.4(8)	0.9(3)	59	40	65
SW23 12 29	2.4(8)	1.2(4)	50	145	75
NE9 12 28	4.5(15)	3.0(10)	53	133	80
SW10 13 29	2.4(8)	1.2(4)	50	135	60
SW24 13 29	3.0(10)	1.5(5)	51	78	63

plain, about 440 km^2 (170 mi^2) in extent, borders Assiniboine Valley north of Kamsack. It forms the eastern margin of an extensive glaciolacustrine complex that lies mostly west and northwest of the map area (Cherry, 1966, p. 57–77). The lake deposits consist mainly of massive silt and varved silt and clay (Fig. 26), from 1.5 to 9 m (5 to 30 ft) thick, overlying till or bedrock. The silt is thickest where the surface becomes irregular west of Assiniboine Valley. In places the silt (Fig. 27) is overlain by a veneer of Lennard Till or gravel. Beds of stony silt are locally present within the top silty unit. These beds are less than 30 cm (1 ft) thick and either are massive and till-like or are composed of thin, contorted laminae that impart a brecciated appearance to the beds.

The lake plain adjacent to Assiniboine Valley near Kamsack formed beneath the glacial Lake Assiniboine of Tyrrel (1893, p. 137E). Within the map area this lake was mostly proglacial, but farther to the northwest it apparently covered extensive areas of stagnant ice (Cherry, 1966, p. 57–77) that bordered the Assiniboine ice lobe (Klassen, 1972a, p. 556). Minor readvances of this lobe during deglaciation could have deposited the veneer of till found over some of the lake sediments.

A flat lacustrine plain about 16 km^2 (6 mi^2) in extent occurs east of Big Boggy Creek, in township 28, range 29. The deposits consist of thin massive clay that probably was deposited in a small, proglacial lake along the northeastern margin of the Assiniboine ice lobe.

Figure 26. Varved silt and clay overlying till exposed a road ditch about 14 km northwest of Kamsack, Saskatchewan (SW¼ sec. 27, tp. 31, rge. 22). Note scale with 1 foot units (GSC 165783).

Figure 27. Glaciolacustrine silt and clay overlain by thin, water eroded till of the Lennard Formation. View is east towards Kamsack from the edge of Assiniboine Valley (NE¼ sec. 32, tp. 29, rge. 32) (GSC 165778).

Figure 28. Esker across the boundary of lake deposits and a till plain 1.5 km south of Myra, Manitoba (NW¼ sec. 24, tp. 22, rge. 22) (GSC 124536).

In addition, a narrow belt of lacustrine sand, silt and clay deposited in glacial Lake Souris occurs west of Minnedosa Valley near the southern boundary of the map area. Near the boundary it is 23 to 30 m (75 to 100 ft) thick. It thins to the northeast, where it grades into deltaic outwash.

Eskers. Esker ridges occur here and there either singly or as complexes. Most are near or within outwash plains, although some distinct ones occur in or form continuations of meltwater channels. One discontinuous esker ridge, some 32 km (20 mi) long, up to 300 m (1000 ft) wide and 9 m (30 ft) high, trends southeastward from Minnewasta Creek (near sec. 29, tp. 16, rge. 25) to Oak River (near sec. 35, tp. 14, rge. 23). Highway cuts in this ridge expose typical ice-contact deposits of silt, sand, gravel and till. A large

Figure 29. Spy Hill, a prominent kame at the apex of the Welby sand plain. View is northwest from SW¼ sec. 6, tp. 19, rge. 30 (GSC 162833).

Figure 30. Drumlinized kame about 6 km east of Kamsack, Saskatchewan. Glacier flowed from left to right (southeast). View is northeast from NE¼ sec. 33, tp. 29, rge. 31 (GSC 162846).

meltwater channel occupied by Oak River extends from the southeast end of the ridge.

A network of braided eskers forms a belt about 1 km wide and 3 km long from the edge of Shell Valley (in NE¼ sec. 31, tp. 22, rge. 28), southward to a northwest-trending channel (in SW¼ sec. 30, tp. 22, rge. 28). The individual eskers are 3 to 6 m (10 to 20 ft) high and 30 m (100 ft) wide. They consist mainly of bedded silt and sand, with minor gravel. Similar though more subdued ridges occur at the apex of the outwash plain (tp. 16, rge. 27) south of

Figure 31. Gravel pit on the lee side of the drumlin shown in Figure 30. Bedded sand and gravel is overlain by a boulder pavement in till (GSC 165779).

Figure 32. Hummocky topography of Arrow Hills. View is southeast from NW¼ sec. 30, tp. 13, rge. 25 (GSC 124541).

Wattsview. A distinct esker ridge lies within a ravine tributary to Shell Valley near Dropmore (Klassen, 1975, p. 27). It is a sinuous gravel ridge 45 to 120 m (150 to 400 ft) wide, and 3 to 12 m (10 to 40 ft) above the ravine bottom. In places it is joined by smaller ridges extending from the valley wall. Where the ravine joins Shell Valley, the crest of the main ridge is about 5 m (15 ft) below the valley rim, and the ravine bottom hangs about 12 m (40 ft) above the floor of Shell Valley.

The esker ridges on the bedrock plain south of Binscarth lie on low ground between bedrock swales and are continuous with shallow channels cut across the swales. Near Rivers the eskers bordering the lake sediments form low but distinctive ridges 3 to 5 m (10 to 15 ft) high and 30 to 60 m (100 to 200 ft) wide (Fig. 28). They are continuous with meltwater channels to the north. Esker and eskerlike ridges that occur in the corrugated moraine areas are commonly transverse to the trend of the moraine ridges. Some of the eskerlike ridges are composed chiefly of till.

Eskers in the map area apparently formed in the usual manner in tunnels near the ice margin. The location of many in relation to meltwater channels and the location of others crossing swales between bedrock ridges indicate that the streams that built them elsewhere eroded channels. Stalker (1973, p. 60) refers to the latter as 'esker channels'.

Kames. Kames occur as isolated hills or in chains of hills and knolls beside or within meltwater channels. They are composed mostly of gravel, sand and wedges of till. Scattered boulders are also present but are more common near the surface.

A prominent kame (Spy Hill) was first noted and re-

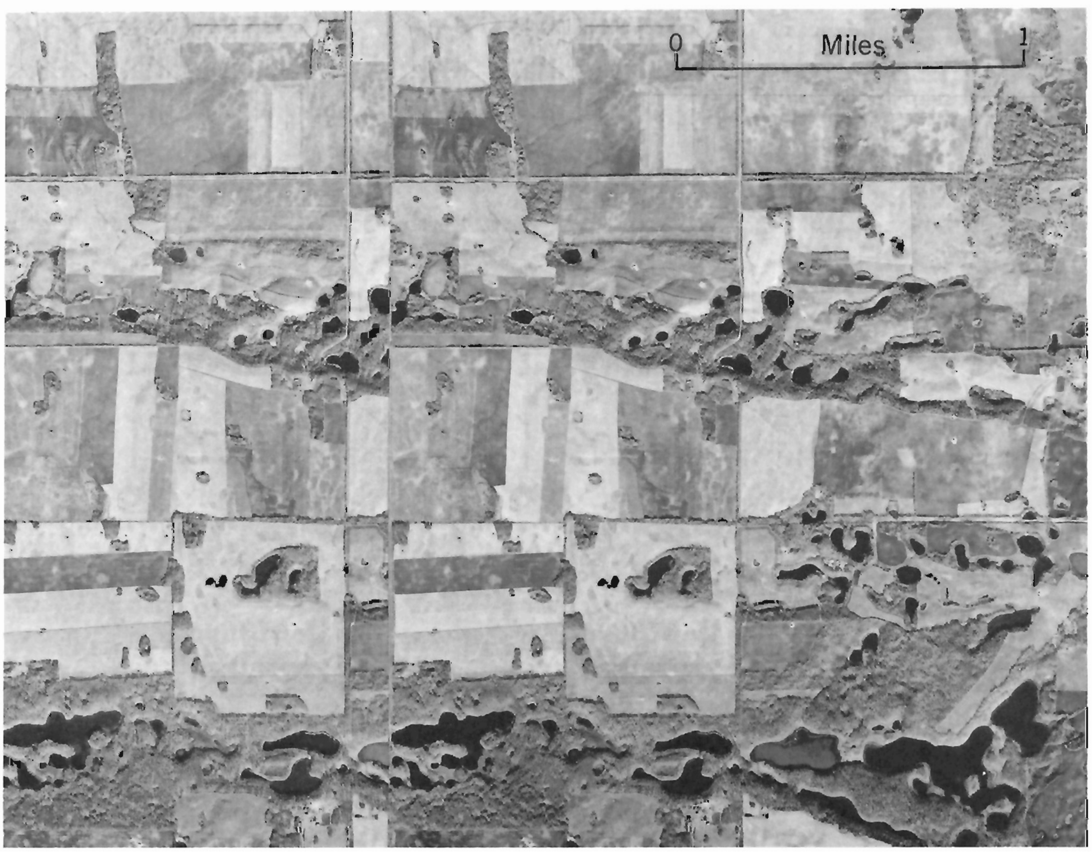


Figure 33. Stereopair aerial photographs showing partly buried valleys (across sec. 25 and 26, tp. 25, rge. 29) on the till plain southeast of Roblin, Manitoba (A15915-135,134).

ferred to by Hind (1859, p. 70) as a "gravelly eminence." It lies in the mouth of a broad meltwater channel (in SW¼ sec. 6, tp. 19, rge. 30), along the northeastern margin of the Welby sand plain. From a distance the kame appears roughly conical, but the surface is actually irregular with local relief of nearly 30 m (100 ft) (Fig. 29). Near Kamsack a drumlinized kame rises sharply above the adjacent till plain (Figs. 30 and 31).

A few distinctive kames along the east rim of Assiniboine Valley (sec. 26, tp. 18, rge. 29) form a belt about 760 m (2500 ft) long and 200 m (650 ft) wide. One of these is about 14 m (45 ft) high and has several short ridges, about 5 m (15 ft) high and 15 m (50 ft) wide, that form digitate extensions of this kame. A belt of kames up to 23 m (75 ft) high occurs along the southeast edge of Minnedosa Valley near Rivers. Large boulders are scattered over the kame surfaces, and pits expose bedded silt, sand and gravel, in places separated by wedges of till.

The kames were built along the ice front in re-entrants, in ice walled channels and in moulins. The isolated position and conical shape of Spy Hill suggest that it is a moulin kame. The drumlinized kame near Kamsack was deposited prior to the last readvance of the Assiniboine ice lobe.

Complexes of kames and eskers with patches of hummocky moraine, which are arranged so as to indicate the trend or position of a former ice margin, are mapped as kame moraines. The Arrow Hills, which lie in the southern part of the map area (tp. 13, rge. 25) between a bedrock plain to the southwest and a till plain to the northeast, are a moraine of this type. The Arrow Hills moraine trends southeast for about 20 km (12 mi) from section 25, township 13, range 26 near the hamlet of Arrow River to section 33, township 12, range 24. It is about 6 km (4 mi) wide

Figure 34. Gravel ridge (foreground) within a partly buried valley crossed by Highway 83. View is east from SE¼ sec. 17, tp. 24, rge. 28 (GSC 162837).

Figure 35. Gravel deposit overlain by Lennard Formation till and boulder pavement within buried valley shown in Figure 34 (GSC 162839).

near Arrow River and about 0.5 km wide near its southern end. Eskerlike ridges, kames and patches of outwash, all consisting of massive sand and fine shaly gravel, form the south side of the moraine. Eskerlike ridges, about 8 m (25 ft) high and 60 m (200 ft) wide, are particularly well developed in the widest part of the moraine where they are approximately normal to the southeast trend. Knolls (Fig. 32) consisting of till and shale blocks with minor gravel form the north side of the Arrow Hills moraine where its local relief in places exceeds 38 m (125 ft). A meltwater channel, about 0.5 km wide and floored with outwash, connects the southeastern end of this moraine to a similar kame-esker complex about 1.5 km south of the map area.

A belt of kames and kame-esker complexes parallels Pipestone Valley for some 21 km (13 mi) in the southeast corner of the map area. It continues southeastward beyond the map area for the same distance to terminate near the Manitoba-Saskatchewan boundary. It is up to 3 km (2 mi) wide and generally is less than 8 m (25 ft) high, except for a few isolated kames that are more than 23 m (75 ft) high.

The Arrow Hills kame complex was built, in part, in a narrow re-entrant in the ice of the Assiniboine lobe, whereas the one along Pipestone Valley was built near the southwestern margin (Klassen, 1975, p. 47).

Meltwater channels. Meltwater channels, generally 3 to 6 m (10 to 20 ft) deep, 60 to 300 m (200 to 1000 ft) wide, and with trenchlike or broadly U-shaped cross-sections are found mainly in till plains and corrugated moraine, although some occur on bedrock plains. Deposits of gravel, sand, silt and clay, up to 3 m (10 ft) thick, floor most of these channels. Bends in the channels are typically angular and are sharpest where they cross the moraine ridges (see Fig. 25). Many channels are in a sidehill position for distances of up to 32 km (20 mi). In places (e.g., tp. 14,

Figure 36. Boulder pavement between Minnedosa Till and Lennard Till west of Roblin, Manitoba. Surface of pavement marks the contact between the tills. View is northeast across Big Boggy Creek valley from SW¼ sec. 23, tp. 26, rge. 29 (GSC 150040).

rge. 29) consequent drainage channels branch from the sidehill channels to create a rectangular pattern. The modern Oak River follows one such sidehill meltwater channel as far as section 3, township 14, range 22, where it turns sharply out of the channel to continue downslope to the south.

Buried valleys. Buried valleys are fairly common but either are completely masked and traceable only by subsurface mapping of the bedrock topography (Klassen et al., 1970; Klassen and Wyder, 1970) or are only partly buried and readily traced on airphotos. The second type is common near Roblin in the northeastern part of the Assiniboine River plain, where shallow, east trending valleys up to 18 km (11 mi) long cross the gently irregular till plain between the south trending Assiniboine and Shell valleys (Fig. 33). These valleys, which are well displayed, are floored with hummocky moraine. Most are less than 1 km wide; where several valleys meet they may be twice as wide. On the ground, the valley rims are well marked by a 1.5 to 5 m (5 to 15 ft) drop and by a change to hummocky topography with relief from 5 to 30 m (15 to 100 ft), in sharp contrast to the nearby till plain.

The fill in the valleys consists of sand, gravel and till, with till overlying the gravel or else grading laterally into it. The uppermost deposit includes till, gravel and a boulder pavement of the Lennard Formation (Figs. 34 and 35), which along the valley edge is thinly draped over till or gravel of the Minnedosa Formation.

These features are similar to ones in central Alberta that Gravenor and Bayrock (1956) named "stream-trench systems" and suggested formed during final deglaciation. The stratigraphy of the features of the Roblin district, however, shows that they predate the last ice advance over the Assiniboine River plain.

Boulder pavements. Many road ditches in the bedrock plains and till plains expose a nearly horizontal boulder pavement (Fig. 36). In places the boulders are within till of the Lennard Formation, but generally they are within the underlying till, sand, gravel or shale. The boulders are up to 1.5 m (5 ft) in diameter. Their upper surfaces are faceted and strongly etched with sets of grooves and striae (Fig. 37). These typically trend southeast like nearby flutings and drumlins, and parallel the preferred orientation of stones within the till above the boulder pavement. Sets of more poorly developed grooves and striae, however, deviate as much as 50° from this southeasterly orientation.

The boulder pavement formed during deposition of the till of the Lennard Formation. This is shown by the similar orientation of grooves and striae on the boulder surfaces, the elongate pebbles within the till and the streamlined surface features. Whether the boulders were brought in by the last glacier or were exposed on the surface prior to the last glaciation is, in most cases, uncertain, but where the pavement is within the till of the Lennard Formation the former is obviously the case. The conditions under which the boulder pavement formed may well have been unique to the east-central Saskatchewan and southwestern Manitoba regions where they are most extensive. Elson (1955, p. 95) suggested that the boulders in a boulder pavement that he examined in southwestern Manitoba were deposited subglacially during ice stagnation and produced the pavement

Figure 37. Faceted surface of dolomite boulder in road ditch (NW¼ sec. 24, tp. 28, rge. 30) near Runneymede, Saskatchewan. The grooves and striae are typical of the upper surface of the regional boulder pavement. Note light meter for scale (GSC 165806).

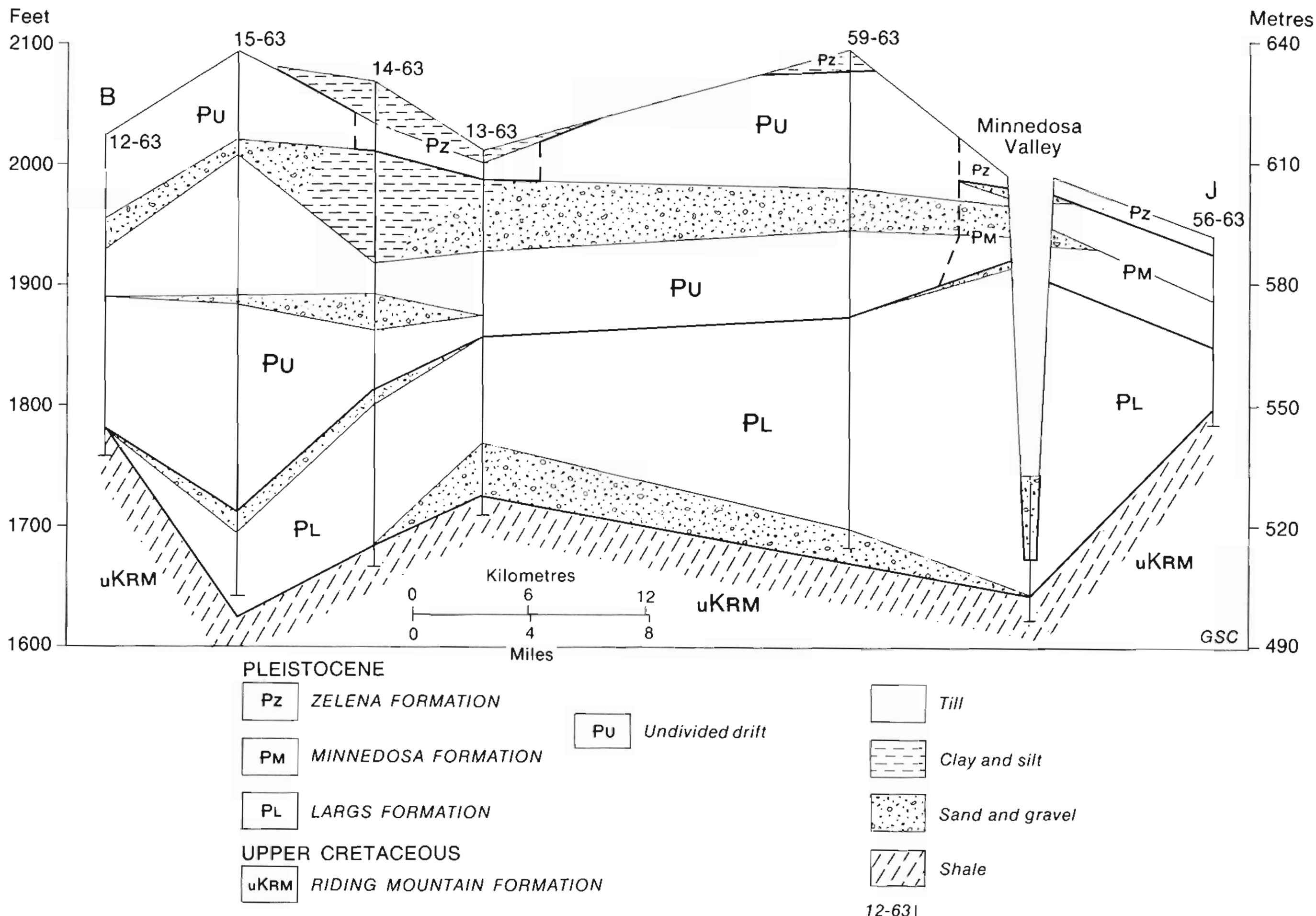


Figure 38. Section BJ across the southeastern part of the Riding Mountain upland (see Fig. 4 for location).

when the ice was rejuvenated. Meneley (1964, p. 101) proposed that a boulder pavement in the Melfort area of Saskatchewan was formed subglacially from boulders carried in the ice during an 'extending flow' type of glacier regimen.

Riding Mountain upland

The Riding Mountain upland covers 3400 km² (1300 mi²) of the Riding Mountain map area and 800 km² (300 mi²) of the Duck Mountain map area where it is much narrower (Fig. 1). This upland is separated from the Duck Mountain upland by a broad meltwater channel that is occupied, in part, by Short Creek. Its western and southwestern boundary, which is at about 550 m (1800 ft) a.s.l., lies along the transition from hummocky moraine on the upland to the gently irregular landscape of the Assiniboine River plain. On the northeast its boundary is an end moraine about 510 m (1700 ft) a.s.l., which forms a broad arc between the Valley River plain and the Riding Mountain upland. Much of its north facing slope above 450 m (1500 ft) a.s.l. is a bedrock escarpment that gives way to more gradual slopes towards the west. The boundary between the Riding Mountain upland and Valley River plain is arbitrarily drawn at 450 and 510 m (1500 and 1700 ft) a.s.l. A dense tree cover makes the upland less accessible than the adjacent plains with their cleared areas and surveyed roads.

Drift thickness. Information about drift thickness and bedrock topography on the Riding Mountain upland comes mainly from boreholes in the southeastern and the northwestern parts and outcrops in the southwestern and northeastern parts. Where the drift is thin, some control was obtained from outcrops along valley walls and along forestry road ditches. Under this upland the Cretaceous shale is considerably higher than in adjoining areas (Klassen et al., 1970). The thickest drift (120 to 180 m) (400 to 600 ft) is in the narrow northwestern part of the upland (Duck Mountain map area) and on the southeastern slopes of the upland. The only information about drift thickness over it is usually 15 to 60 m (50 to 200 ft) thick. The drift generally is thinnest on the northeastern slopes of the upland. The only information about drift thickness over most of the central part of the upland comes from two boreholes between Clear Lake and Minnedosa Valley

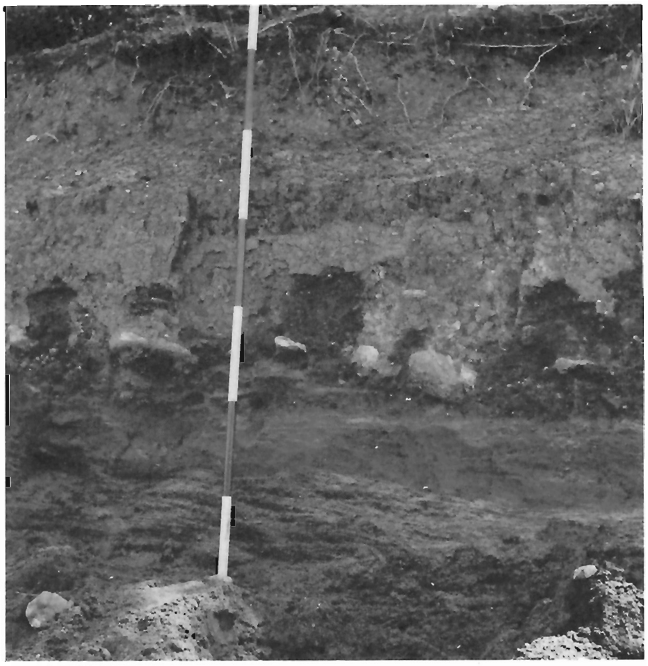


Figure 39. Clayey till overlying stratified silt and sand in hummocky moraine (NE¼ sec. 6, tp. 17, rge. 19) 1.5 km east of Ozerna, Manitoba. Scale is in 1 foot units (GSC 124554).

(Fig. 2), which show a thickness of 90 to 120 m (300 to 400 ft).

Till stratigraphy. The tills of the Riding Mountain upland are from the Largs, Minnedosa and Zelena formations (Fig. 38), but till of the Tee Lakes Formation may be included in a thick wedge of undivided drift. A thick till succession in the north part of the Riding Mountain upland near its boundary with the Duck Mountain upland is described with that of the latter upland to which it is more closely related.

Information from several boreholes in the southeastern part of the upland indicates that till of the Largs Formation occurs within a wide buried valley, where it is more than 60 m (200 ft) thick (Fig. 38). Its presence elsewhere on the upland probably is restricted to this or to another buried valley. The Minnedosa Formation, although recognized in outcrops along Minnedosa Valley (Appendix, section 4), has not been identified in the subsurface. Much of the drift overlying the Largs Formation is designated as undivided drift (Fig. 38). It has the typical carbonate content, mostly between 19 and 24 per cent (Fig. 15), of tills of the Tee Lakes and Minnedosa formations. However, the absence of the Shell Formation till with high carbonate contents, which is used to separate these formations on the Assiniboine River plain and the Duck Mountain upland, makes their identification uncertain. The considerable thickness of up to 120 m (400 ft) of the undivided drift indicates that tills of the Tee Lakes, Minnedosa and Zelena formations may all be included. The Zelena Formation forms the upland surface.

Landscapes and glacial features. Till plains. Till plains include an area of about 800 km^2 (300 mi^2) on the northeastern and eastern slopes of the Riding Mountain upland adjacent to the Valley River plain. The northeastern slopes within Riding Mountain National Park are mostly heavily wooded, and so the areas of till plain were delimited largely by airphoto interpretation. In places, no doubt, bedrock plains are present, but ground control was not adequate to separate them from the till plains. Where till plains are cultivated, they are a gently rolling surface of the Zelena Formation with 1.5 to 3 m (5 to 10 ft) local relief.

Hummocky moraine. Hummocky moraine covers about 1700 km^2 (650 mi^2) of the Riding Mountain upland mostly above 580 m (1900 ft) altitude. It consists of ridges, hummocks and intervening depressions, resulting in from 5 m (15 ft) to more than 15 m (50 ft) of local relief. The depressions are commonly elongate and irregular in plan. They include kettle holes as well as discontinuous meltwater channels. Lakes commonly occupy the depressions, the largest being Clear Lake, which is some 13 km (8 mi) long, 5 km (3 mi) wide and more than 30 m (100 ft) deep.

Till of the Zelena Formation probably forms most of the hummocky moraine (Figs. 39 and 40), yet in places along the northwestern margin of the upland the topography reflects the older till of the Minnedosa Formation (Fig. 41). The hummocky moraine also includes hummocks and ridges of stratified sediments.

Outwash and lacustrine complexes. Outwash and lake deposits, mostly within, beside or gradational into areas of hummocky moraine, cover 260 km^2 (100 mi^2) of the eastern part of the Riding Mountain upland. Much of their surface resembles that of the hummocky moraine. A belt of these deposits, consisting of hummocky silt, sand and gravel, stretches for about 32 km (20 mi) from the southwestern shore of Proven Lake to Heron Creek. Its margin along

Figure 40. Displacement of stratified sediments and till along a minor fault in the exposure shown in Figure 39 (GSC 124555).

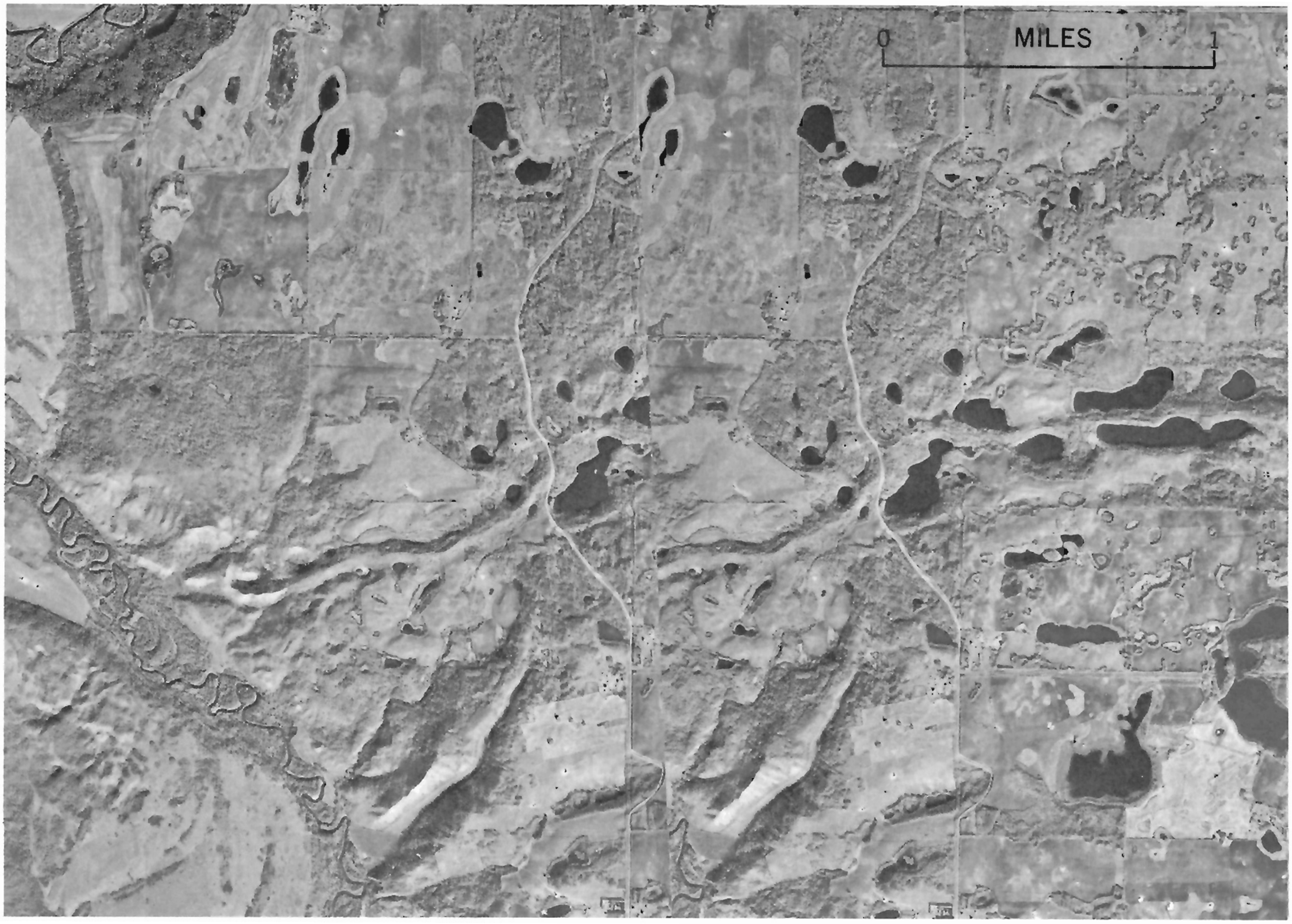


Figure 41. Stereopair aerial photographs showing eskerlike ridges composed of till of the Minnedosa Formation within a buried valley in hummocky moraine (sec. 12, tp. 24, rge. 27). Valley is along the northwestern margin of the Riding Mountain upland bordering Shell Valley (A15915-35,36).

Proven Lake is a steep, ice-contact face. Roadcuts through the hummocks show mostly silt, more than 8 m (25 ft) thick. Usually the silt is bedded, but in places it is massive. Towards the northwest sand and gravel are associated with the silt, and large surface boulders, which are rare in the southeast part, are common, particularly where till hummocks occur. Hummocks in the gradational zone to hummocky moraine may be composed entirely of till, silt or of both. For example, a roadcut in SW¼ section 7, township 18, range 19 shows clayey till overlain by thinly bedded silt and clay 1.5 m (5 ft) thick, capped by 1 to 3 m (4 to 10 ft) of sand and gravel. Near a large depression in SW¼ section 6, township 19, range 19, where more than 4 m (12 ft) of laminated silt is exposed, lenses of clayey till, stringers of unctuous clay and scattered boulders also are found in the silt. The largest till lens was 0.5 m (2 ft) thick and 12 m (40 ft) long (Fig. 42) and formed a sharp contact with the silt, except where small faults occurred or where stringers of till extended into the silt. The area of outwash between Minnedosa River (NW¼ tp. 19, rge. 21) and Heron Creek is roughly triangular. Coarse, bouldery gravel high in shale clasts occurs near its northwestern apex, whereas extensive patches of silt, sand and shaly gravel are present in the wide part to the southeast. The surface is typically hummocky with 3 to 9 m (10 to 30 ft) of local relief, although the surface near Seech (sec. 35, tp. 19, rge. 22) is locally almost flat. In NE¼ section 19, township 19, range 21, an 18 m (60 ft) deep well was entirely in coarse gravel. A roadcut 5 km (3 mi) to the east exposed 6 m (20 ft) of finely cross-bedded silt over silty to clayey till. Faults, with up to 38 cm (15 in) displacement, truncate the bedding (Fig. 43). About 10 km (6 mi) west of Clear Lake, in SE¼ section 33, township 19, range 20, the transition zone from hummocky silt to hummocky moraine shows about 4 m (12 ft) of silt and silty till overlain by up to 1 m of loose stony till. The lower part of the silt is massive with few boulders, whereas the upper 2 m (7 ft) is fissile with thin stringers of clayey till and clay, inclusions of laminated silt, and scattered stones. The outwash and lake deposits near Whitewater and Audy lakes and other inaccessible parts of the upland were mapped mainly from aerial photographs.

Outwash gravel, sand and silt deposited on stagnant ice

Figure 42. Lens of clayey till (dark band) enclosed in stratified silt along the northeastern side of Payne Lake. Note the irregular contact at the end of the lens and the sharp offset along the lower contact (SW¼ sec. 6, tp. 19, rge. 19) (GSC 124545).

or in holes in the ice, and lacustrine silt deposited in part in a superglacial lake, probably formed the hummocky deposits between Heron Creek and Proven Lake. The lake level apparently fluctuated considerably, resulting in a close association of coarse and fine sediments. Lenses of till-like material, found locally in the silt, may be flowtill (Hartshorn, 1958, p. 477–481). Ice rafted till or subaqueous mudflows (Clayton, 1962, p. 39) also could have produced some of the till-like sediment.

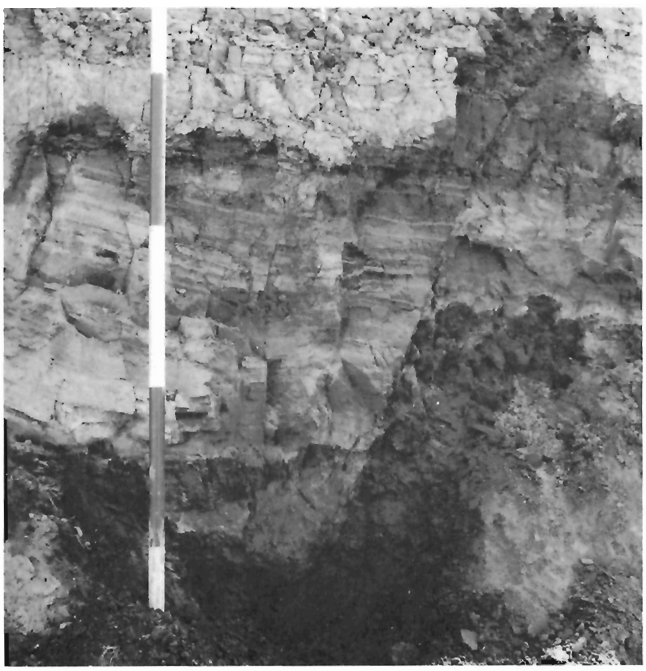


Figure 43. Minor fault in hummocky silt along the western edge of Minnedosa Valley near Horod, Manitoba (NE¼ sec. 22, tp. 19, rge. 21) (GSC 124546).

End moraine. A belt of till ridges and hummocks 3 to 8 m (10 to 25 ft) high and their intervening depressions trend southward for about 13 km (8 mi) from the southern part of township 25, range 25 near Timberton to Petlura. There the belt swings southeastward and terminates in the northwestern part of Riding Mountain National Park about 32 km (20 mi) from Petlura. This is an end moraine, which is here formally named the Petlura Moraine after the hamlet of Petlura, which is about 1.5 km west of the moraine in the SW¼ section 18, township 24, range 25.

A complex of knolls and ridges of silt, sand and gravel, about 1 km wide and 10 km (6 mi) long, constitutes the most prominent part of this moraine. Its distal side rises abruptly some 15 to 30 m (50 to 100 ft) above the till plain to the west (Fig. 44) but grades into hummocky moraine to the east.

The Petlura Moraine is one of the few distinct end moraines in southwestern Manitoba. It was formed along the western and southwestern margin of the Valley River sublobe (Klassen, 1972a, p. 553–557) and marks the transition from the surface till of the Valley River plain (Arran Formation) to the surface till of the Riding Mountain and Duck Mountain uplands (Zelena Formation).

Eskers and kames. Isolated eskers and kames are, no doubt, fairly common on the Riding Mountain upland, but as they resemble many of the till ridges and knolls in the moraine they are generally recognized only where cuts or excavations expose their internal composition. Thus, roadcuts in an esker 60 m (200 ft) wide, 5 m (15 ft) high and 1000 m (3400 ft) long, bordering a depression in NE¼ section 23, township 17, range 20, show 3 to 5 m (10 to 15 ft) of sand and silt. In places clayey till 1 to 5 m (2 to 15 ft) thick overlies the sand and silt, or thin stringers of till occur within it, and small vertical faults cross the contact of the overlying till and stratified deposits. A kame along the hummocky moraine margin west of Clear Lake (SW¼ sec. 12, tp. 20, rge. 20) forms a ridge about 60 m (200 ft)

Figure 44. West facing, distal part of Petlura Moraine and till plain in the foreground. View is southeast from SE¼ sec. 5, tp. 25, rge. 25 (GSC 150030).

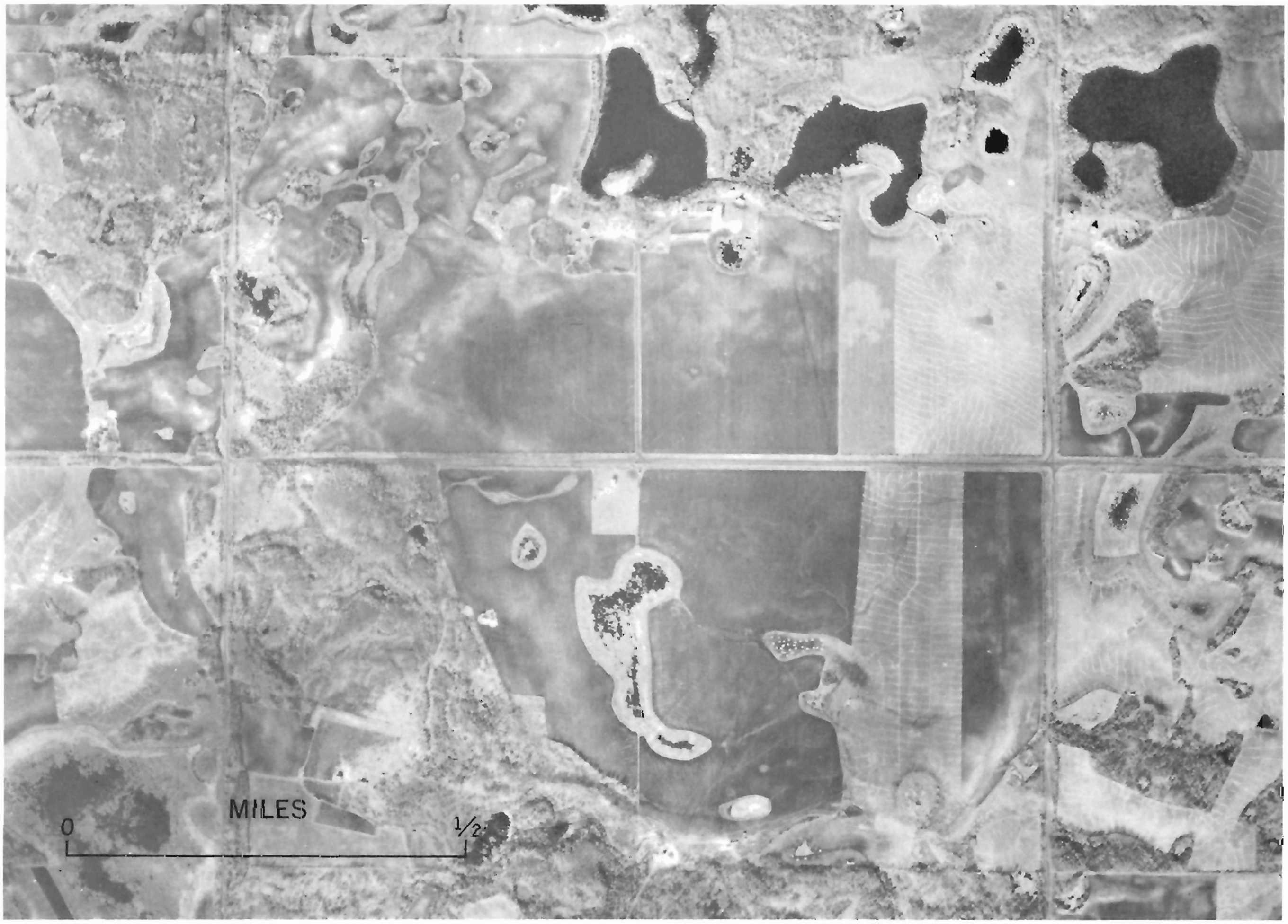


Figure 45. Aerial photograph of moraine plateau in hummocky moraine about 1.5 km east of Gundy Lake (sec. 11, tp. 20, rge. 24). The crest of the rim ridge is marked by the light tone around the periphery (A13070-175).

wide, 9 m (30 ft) high and 270 m (900 ft) long that terminates in a hummocky, bulbous portion about 300 m (1000 ft) across. Large boulders are common on the surface of the ridge, but internally it is composed of sand and gravel. The attitude of the beds indicates southeastward stream flow. A gravel pit in NE¼ section 9, township 20, range 23 served to identify a kame along the margin of some hummocky silt. This feature was similar in form to the adjacent silt and till hummocks but consisted of 18 m (60 ft) of bedded silt, sand and gravel with a few inclusions of till and boulders. In places hard silty till, up to 1.5 m (5 ft) thick, overlay it.

The kames and eskers associated with the hummocky moraine apparently formed in openings within and under stagnant ice and along the margins of stagnant ice blocks. Well rounded boulders within some kames on the Riding Mountain upland show that those kames formed in moulins, although others such as the one in the SW¼ section 12, township 20, range 20 formed partly in front of an ice mass.

Kame-esker complexes. Several prominent kame-esker complexes trend roughly southeast across the hummocky moraine. One can be traced for 27 km (17 mi) between upper Birdtail Valley (sec. 3, tp. 23, rge. 25) and upper Heron Valley (sec. 7, tp. 21, rge. 23). In the northwest it is about 6 km (4 mi) wide and grades laterally into the adjoining hummocky moraine. The southeastern portion is more distinct, about 1.5 km wide, and is formed of numerous eskerlike ridges about 180 m (600 ft) apart that parallel the trend of the complex. Boulders occur on the surface of the ridges but are rare in the internal shaly gravel and sand. The local relief in places approaches 30 m (100 ft), but the average is about 12 m (40 ft).

Kames, eskers and patches of outwash composed of shaly gravel and sand with minor silt form another complex with relief up to 30 m (100 ft) between Minnedosa Valley (tp. 19, rge. 20) and Clear Lake. One segment of this complex, about 13 km (8 mi) long, trends west to form a belt 0.5 to 2.5 km wide, which continues as pitted outwash along the south edge of Clear Lake; the other part, about 8 km (5 mi) long, trends south. Small eskerlike ridges, similar to those of the Birdtail Valley complex, form the outer margin of the widest part which otherwise has a fairly smooth surface. Hummocky moraine composed of till and silt borders the complex, and at one locality (NW¼ sec. 21, tp. 19, rge. 20) on the north side of the complex, till overlies shaly gravel. The south trending part of the complex is nearly at right angles to the longer part. A northeast trending channel floored by fine gravel and sand divides the complex into two parts. The outwash southwest of Clear Lake is separated from the main rise by a till plain less than 1.5 km wide.

The two kame-esker complexes apparently were built on and within stagnant ice by meltwater flowing mainly to the southeast. They resemble features in North Dakota referred to by Winters (1963, p. 44) as "ice-walled gravel trains" for which he postulated a similar origin.

Moraine plateaus. Moraine plateaus are common between upper Heron Creek and Birdtail Creek (tp. 20, rge. 23 and 24). They are positive features, 0.5 to 2.5 km across, roughly circular to irregular in plan, with gently irregular surfaces (Fig. 45), and are covered by clay and silt commonly more than 5 m (15 ft) thick.

A low rim ridge marks the periphery of some well developed plateaus. One oval-shaped plateau found in NW¼ section 30, township 19, range 23, which was about 1 km (0.5 mi) long, has a distinct rim ridge 45 to 180 m (150 to 600 ft) wide (Fig. 46). This ridge rises 8 m (25 ft) above the adjacent depressions and 1.5 to 5 m (5 to 15 ft) above the centre of the plateau and has a 25° outer slope and a 10° inner one.

Two moraine plateaus are associated with a partly filled channel, about 13 km (8 mi) long, that extends from Arrow Lake (sec. 34, tp. 19, rge. 24) and Heron Creek (sec. 26, tp. 20, rge. 23). Another plateau (sec. 16, tp. 20, rge. 23), about 1.5 km long and 1 km wide, forms part of the channel wall. Hummocky silt, covering more than 2.5 km^2 along the margin of the plateau away from the channel, is above, or is even with, the plateau surface. Massive or bedded unctuous clay, more than 5 m (15 ft) thick, forms the flat surface of the plateau. Pelecypod and ostracod shells occur within the clays exposed in a roadcut along the edge of the plateau.

A distinct plateau (SE¼ sec. 28, tp. 20, rge. 23) lies within the channel. It is circular, 760 m (2500 ft) in diameter and 12 m (40 ft) high. The plateau has a gently irregular surface underlain by clay and has a gravelly rim ridge less than 1.5 m (5 ft) high and 46 m (150 ft) wide. A roadcut across the edge of the plateau exposes stratified sand overlain by 2.5 m (8 ft) of silty till.

The moraine plateaus in the Riding Mountain area are similar to those in central Alberta described by Stalker (1960a, p. 31–35) and those in southern Saskatchewan described by Parizek (1969, p. 57–71). These landforms developed in part in lakes associated with stagnant ice. The presence of freshwater fossils within the stratified sediments of the moraine plateaus, as well as the thickness of these sediments, indicates that the lakes existed for a considerable time. Stalker and Parizek give detailed accounts of the possible ways these features could have formed.

Meltwater channels and buried valleys. The main streams on the upland, including Birdtail Creek, Heron Creek and Minnedosa River, occupy valleys that formed as meltwater channels. The channel occupied by Heron Creek is partly buried where it crosses the southern part of township 20, range 22 and is joined by several smaller buried valleys. The distinct, smaller meltwater channels that are common on the till plains are not present on hummocky moraine.

The close association of certain meltwater channels, buried valleys and kame-esker complexes on the upland suggest that they formed contemporaneously during melting of stagnant ice. On the other hand they resemble the buried valleys of the Assiniboine plain that formed prior to the last glaciation. Most likely the buried segments are largely within valleys that predate the last glaciation of the upland. Subglacial drainage probably was concentrated along these older drainage lines and re-excavated segments of them and infilled others.

Valley River plain

The Valley River plain is a roughly triangular area of gently rolling or nearly flat till and lake plain covering 1000 km^2 (400 mi^2) between Riding Mountain upland and Duck Mountain upland. Near the uplands it is at about 500 m (1700 ft) a.s.l. and gradually falls off to 400 m (1300 ft) a.s.l. near an abandoned beach complex that marks its boundary with the Westlake plain to the east.

Drift thickness. Subsurface information is limited to a few widely separated boreholes through drift, some shallow auger holes (Fig. 4) and bedrock outcrops along the principal streams. The drift is generally thin, and bedrock outcrops are common on the southern part of the plain, on the rise to the Riding Mountain upland and along the eastern margin where it drops, steplike, towards the Westlake plain. In those areas thicknesses are generally less than 15 m (50 ft) but locally reach 30 m (100 ft). In the centre and northwest where the plain rises towards the Duck Mountain upland thicknesses are generally 30 to 45 m (100 to 150 ft), but in buried valleys they are greater (Klassen et al., 1970).

Figure 46. Rim ridge of till along the edge of a moraine plateau about 10 km east of Rossburn, Manitoba in NW¼ sec. 30, tp. 19, rge. 23 (GSC 124550).

Till stratigraphy. Tills of the Zelena and Arran formations occur on the plain as well as undivided drift of possibly the Tee Lakes or Minnedosa formations.

The Zelena Formation generally is present where the till succession is more than 8 m (25 ft) thick. It commonly overlies shale bedrock and underlies till of the Arran Formation. Some auger holes located along an east-west line in the south-central part of the plain (Fig. 4) reached till of the Zelena Formation beneath 3 to 8 m (10 to 25 ft) of Arran Formation till, which includes the surface till on the Valley River plain. In the southwestern part of the plain where the drift is thin a boulder pavement with west trending striae marks the contact between the tills of these formations.

Landscapes and glacial features. Till plains. About 800 km^2 (300 mi^2) of the Valley River plain is nearly flat to gently rolling till plain with local relief of generally less than 1.5 m (5 ft). About 450 km^2 (175 mi^2) of this is mapped as water eroded till plains. These were inundated by short-lived glacial lakes that left the plain slightly eroded or veneered with silty clay typically less than 0.3 m thick. Most of the unmodified till plain is above 450 m (1500 ft) a.s.l.; however, some lies in the extreme northeastern part of the plain between the highest beaches of the Westlake plain at 400 m (1300 ft) a.s.l. and the Grifton Moraine of the Duck Mountain upland.

Lacustrine plains. These areas vary considerably in size and have a patchy distribution. They are generally underlain by silt and clay, 1.5 to 5 m (5 to 15 ft) thick, which subdue minor irregularities of the underlying till plain sufficiently to give a nearly flat surface. Numerous local patches within the till plains are not mapped as they are similar to the till plain landscape. For this reason, the boundaries of the lacustrine and till plains are mostly approximate ones.

Meltwater channels. Short Creek and the upper part of Valley River occupy former channels that carried meltwater from stagnant ice on the uplands. A buried valley south of Meharry, Manitoba, which parallels part of the Valley River channel, may be part of the ancestral valley that elsewhere was re-excavated by Valley River.

Boulder pavement. A boulder pavement occurs locally in the western part of the plain. It records the westerly flow of the Valley River sublobe of the northeastern ice that formed the Petlura Moraine (Klassen, 1975, p. 50).

Westlake plain

The Westlake plain, about 2600 km^2 (1000 mi^2) in extent, is nearly flat or gently irregular and in most places reflects the topography of the underlying Mesozoic sandstones and shales. Paleozoic carbonates underlie thin drift along a narrow strip in the northeastern part. The plain slopes gradually eastward from about 400 m (1350 ft) a.s.l. along the boundary with the Valley River plain and Duck Mountain upland to about 270 m (900 ft) a.s.l. along the eastern margin of the map area. This plain was inundated by glacial Lake Agassiz, which reworked much of the till veneer and in places deposited silt and clay over it. Flights of distinct

Figure 47. Bouldery surface of till plain marks former shore about 11 m above Lake Winnipegosis. View is to the east from SE1/4 sec. 5, tp. 33, rge. 19 (GSC 162858).

abandoned beaches trend south along the western boundary of the plain, and more subdued ones mark much of the cultivated southern part. Peatlands and mixed forest mask small features in the northern half, but in places widely separated beaches and broadly fluted surfaces can be seen on aerial photographs.

Drift thickness. The drift of the Westlake plain is generally less than 5 m (15 ft) thick in most of the poorly drained northern portion and in a belt along the southwestern margin that includes the highest (Norcross) beach complex. Thicknesses of 15 to 30 m (50 to 100 ft) occur beneath most of the southern portion, and in buried valleys up to 76 m (250 ft) of drift has accumulated (Klassen et al., 1970).

Till stratigraphy. Stratigraphic information on tills was obtained from roadcuts and from shallow auger holes and thus was limited. Tills of the Zelena and Arran formations, in places separated by fine stratified sediments, were found in 30 auger holes (Fig. 4) drilled to depths of 8 to 18 m (25 to 60 ft). Where the drift is thin, however, only Arran Formation till occurs and directly overlies bedrock, which is commonly exposed between the discontinuous patches of drift.

Till of the Zelena Formation forms the surface of a bench that marks the initial rise from the main basin of Lake Agassiz to the Riding Mountain upland in the southeast part of the plain. Elsewhere, it either underlies the surface tills of the Arran Formation or is absent. The Arran Formation till is typically about 5 m (15 ft) thick.

Landscapes and glacial features. Till plains. Some 1950 km^2 (750 mi^2) of the Westlake plain is a nearly flat till plain that to varying degrees has been modified by lakewater

Figure 48. Lower Campbell beach about 6.5 km north of Ashville, Manitoba is the low rise at the left that trends towards the horizon. View is north from SW¼ sec. 15, tp. 26, rge. 21 (GSC 162862).

erosion and deposition. The effects of wave erosion are shown by bouldery surfaces (Fig. 47) and gravelly veneers over till that are most pronounced along former shores. Several strongly eroded belts are found from 335 to 365 m (1100 to 1200 ft) a.s.l. between or continuous with poorly developed strandlines west and southwest of Dauphin. Abandoned beach complexes occur as belts of parallel ridges, 1.5 to 3 m (5 to 10 ft) high, trending generally south across the till plain; much of the northern part is veneered with patches of silt and sand generally less than 0.5 m thick. Road ditches in the complexes commonly expose bedrock.

Lacustrine plains and abandoned beach complexes. An extensive lake plain is present in the eastern part of the Westlake plain, and smaller ones are found elsewhere on the plain. Altogether, lacustrine sediments, mostly silt and clay some 1.5 to 5 m (5 to 15 ft) thick, cover an area of about 650 km² (250 mi²) of its southern part. Lacustrine plains occur below the main beach complexes and apparently most of these sediments were derived from the deglaciated region to the west by stream erosion rather than from meltwater off the continental glacier to the northeast. This source is indicated by the location of the thickest sediments east of where the valleys of west flowing rivers, such as the Valley, Wilson and Vermilion, enter the former lake basin and by the absence of similar sediments to the north.

The highest abandoned beaches form a complex of ridges between 400 and 410 m (1300 and 1350 ft) a.s.l. in the north near Pine River and between 375 to 400 m (1235 and 1300 ft) a.s.l. farther south near Mink Creek. From here they continue southeastward until they merge with the initial rise to the Riding Mountain upland. These beaches are the northern continuation of the beaches between 359 and 368 m (1185 and 1215 ft) a.s.l., near Neepawa that Upham (1890, p. 92E) identified as Norcross beaches.

The Norcross beach complex is commonly 1.5 to 2.5 km (1 to 1.5 mi) wide, and its ridges are 1.5 to 3 m (5 to 10 ft) high along the foot of the east facing escarpment of the Duck Mountain upland; but the ridges are less developed on the gentler slopes farther south where the complex is up to 5 km (3 mi) wide. Auger holes and gravel pits indicate that the complex is mostly sand and fine gravel generally 1.5 to 3 m (5 to 10 ft) thick beneath the ridge crests and a veneer of sand, silt and clay over till or bedrock between the ridges.

Two prominent fairly continuous beach ridges occur below the level of the Norcross beach complex. Johnston (1946, p. 2) identified them as the Upper and Lower Campbell beaches. They are about 1.5 km apart and between 350 and 356 m (1150 and 1175 ft) a.s.l. in the north near Pine River and between 333 and 342 m (1100 and 1130 ft) a.s.l. in the south near Ashville. The upper beach is commonly 3 to 5 m (10 to 15 ft) high and the lower one 1.5 to 3 m (5 to 10 ft) (Fig. 48). Both are composed of sand and fine gravel of a thickness comparable to their local height. Sorting is commonly poorest in the lower beach (Fig. 49).

Numerous abandoned beaches occur below the Campbell beach, but they lack the continuity of the older beaches. Some, no doubt, are the northern equivalents of the abandoned beaches in the basin of Lake Agassiz to the south. For example, Johnston (1946, p. 7) traced the Gladstone and Burnside beaches north to the Westlake plain.

Duck Mountain upland

Duck Mountain upland, which is mostly hummocky moraine, extends for 5200 km² (2000 mi²) across the central part of the Duck Mountain map area. The eastern boundary

Figure 49. Regressing shore succession reflected by well sorted beds of sand and fine gravel in a post-Campbell beach (SW¼ sec. 30, tp. 24, rge. 19) about 6.5 km southwest of Dauphin (GSC 150034).

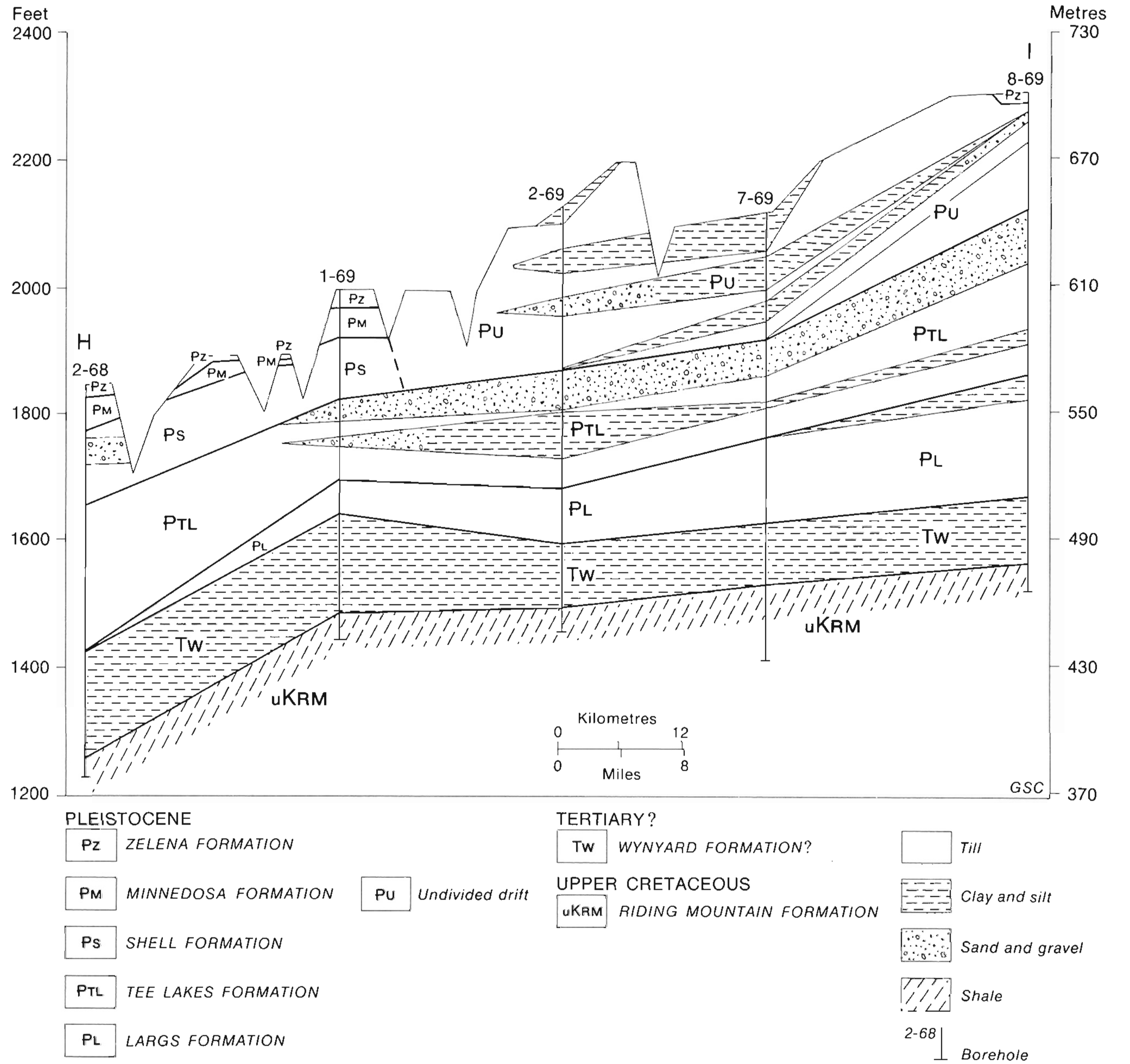


Figure 50. Section HI across the northwestern part of the Duck Mountain upland (see Fig. 4 for location).

with the Westlake plain is a steep drop, from about 670 to 425 m (2200 to 1400 ft) a.s.l. over a distance of 7 to 10 km (4 to 6 mi) that forms part of the Manitoba escarpment in this region. Baldy Mountain at 831 m (2727 ft) a.s.l., near the edge of the main escarpment in the southeastern part of the upland, is the highest elevation in Manitoba. Part of the northwesterly slope near the Swan River plain is also an abrupt drop, falling from 605 to 425 m (2000 to 1400 ft) a.s.l. in about 6 km (4 mi). Elsewhere the slopes are more gradual, and the boundaries with the Assiniboine plain, Riding Mountain upland and Valley River plain lie between 460 and 580 m (1500 and 1900 ft) a.s.l.

Close stands of spruce, aspen, poplar and birch trees cover all but the most poorly drained and the cultivated parts of the upland.

Drift thickness. Boreholes drilled at five sites within the Manitoba part of the upland (Fig. 50; Klassen et al., 1970) and one in the Saskatchewan part (Cherry and Whitaker, 1969) indicate that drift thickness is between 150 and 230 m (500 and 750 ft). Bedrock elevations obtained from other widely separated boreholes on the upland (Fig. 4) and from outcrops along streams adjacent to the upland indicate that the bedrock is mostly between 460 and 490 m (1500 and 1600 ft) a.s.l. and that the highest parts of the upland are underlain by more than 300 m (1000 ft) of

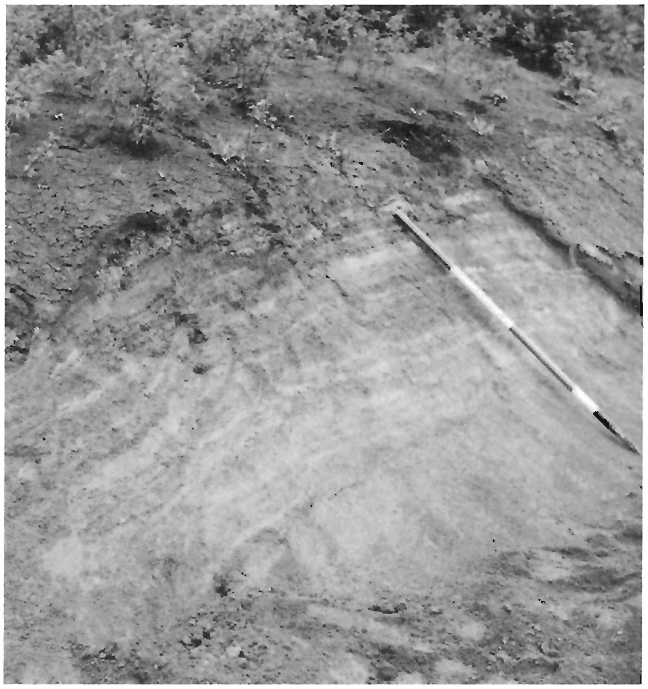


Figure 51. Varved silt and clay in a roadcut in the side of a hummock in hummocky lacustrine deposits in tp. 30, rge. 28 (see Fig. 52). Note scale of 1 foot units (GSC 165796).

drift. The Duck Mountain upland thus appears to be built largely of drift and, unlike the Riding Mountain upland, does not reflect the broad topographic elements of the underlying bedrock.

Till stratigraphy The great thickness of drift on the Duck Mountain upland includes many till units and intertill sediments. Subsurface information came mostly from five boreholes (Fig. 50), each showing six to ten till units. Klassen (1971, p. 256) proposed a stratigraphic framework for the Duck Mountain upland based on the borehole data and on analyses of carbonate content and grain size of 93 sidewall core samples. Earlier Klassen described two tills with associated sediments that were exposed along Roaring River (Appendix, section 19) in the northwest part of the upland (Klassen et al., 1967, p. 434) as well as three tills and associated sediments exposed along Shell River (Appendix, section 21) in the southwest part of the upland (Klassen, 1969, p. 10).

Tills of the Largs, Tee Lakes, Shell, Minnedosa and Zelena formations make up the nonstratified drift on this upland. The Largs and Tee Lakes formations were identified only in the subsurface (Fig. 50), but their uniformity and considerable thicknesses in most boreholes indicate that they occur beneath most of this upland. Tills of the Shell Formation were not exposed on the upland but were identified in two boreholes in the southwestern part (Fig. 50); its presence elsewhere on the upland is uncertain. Minnedosa Formation till outcrops along the valleys of Shell and Roaring rivers (Appendix, sections 18 and 20) and was identified in two boreholes in the southwestern part (Fig. 50). The surface till on the upland is of the Zelena Formation. It is exposed in numerous roadcuts and valley walls. Samples were taken mostly from exposures in the western part of the upland although subsurface samples were obtained at one site in the northeast part (Appendix, section 16). The thickness of the formation near the boundary of the upland is typically 1.5 to 9 m (5 to 30 ft), but in the central part (Fig. 50) more than 60 m (200 ft) of undivided drift overlying the Tee Lakes Formation may belong to the Zelena Formation. Although considerable information was obtained from three boreholes (Appendix, sections 16, 17 and 22), there is much uncertainty as to whether or not the bulk of the tills are from the Shell or Zelena formations. Several till units have carbonate contents comparable to tills of either the Shell or Zelena formations and calcite/dolomite ratios typical of Shell Formation tills (Fig. 15), yet their stratigraphic position suggests that they are of the Zelena Formation.

Landscapes and glacial features. Till plains. About 780 km^2 (300 mi^2) of the east facing and northwest facing slopes of the Duck Mountain upland is till plain. On the steeper parts the surface is strongly dissected by streams that have cut a network of gullies and valleys in the thick drift. A narrow belt of shallow bedrock found at the foot of the east facing slopes is included in the till plain. The more gradual slopes of the southeastern part of the upland are a gently rolling till plain with 1.5 to 5 m (5 to 15 ft) of local relief.

Hummocky moraine. Hummocky moraine covers an area of about 4100 km^2 (1600 mi^2) of the upland and, together with the hummocky moraine of the Riding Mountain upland, it forms a broad arc convex to the southwest. The greater thickness of drift underlying the Duck Mountain upland relative to the Riding Mountain upland is not reflected in the hummocky moraine.

Outwash and lacustrine complexes. These landscapes resemble those of the Riding Mountain upland and cover

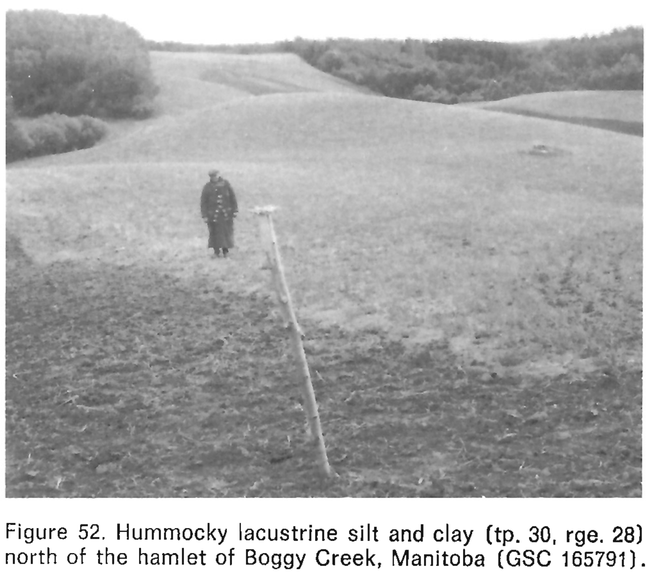


Figure 52. Hummocky lacustrine silt and clay (tp. 30, rge. 28) north of the hamlet of Boggy Creek, Manitoba (GSC 165791).

Figure 53. Little Boggy Creek valley deeply incised along the southwestern margin of Duck Mountain upland. View is northwest from SE¼ sec. 18, tp. 29, rge. 30. Light toned hummocks in the centre of the valley are silt and sand (GSC 165784).

about 360 km^2 (140 mi^2) of the western part of the upland. In places they were identified on the ground, but generally they were delineated on the basis of airphoto interpretation and so may be more or less extensive than shown on the map.

The lacustrine and outwash deposits, where accessible in the field, were separated primarily on the basis of composition. The lacustrine sediments consist mainly of thinly bedded or varved silt and clay (Fig. 51), whereas the outwash deposits consist mainly of bedded silt, sand and gravel. The surface of both types of deposits commonly resembles hummocky moraine (Fig. 52), although the narrower belts of outwash may be marked by poorly developed ridges parallel to the trend of the main body of outwash.

End moraine. Till knolls, ridges and depressions form a belt from 1 to 2.5 km (0.5 to 1.5 mi) wide and up to 8 m (25 ft) high that extends nearly continuously for about 56 km (35 mi) from section 26, township 26, range 24 near Grifton, northeast to section 2, township 32, range 23 south of Pine River. This morainic belt is here formally named the Grifton Moraine after the hamlet of Grifton, which is situated along the northwest margin of the most prominent, southwestern segment of the moraine.

The Grifton Moraine probably correlates with the Petlura Moraine of the Valley River plain. It formed along the margin of the "Valley River sublobe" of Klassen (1972a, p. 553–557) that lay between the Duck and Riding Mountain uplands.

Eskers, kames and moraine plateaus. The heavy tree cover over essentially all the Duck Mountain upland and the few access roads make the identification of glacial features such as eskers, kames and moraine plateaus difficult and uncertain. In a few of the cultivated fields along the southwestern margin of the upland a number of moraine plateaus were identified.

Meltwater channels and buried valleys. Some prominent meltwater channels and buried valleys cross parts of this upland. Shell River occupies the longest meltwater channel; it trends south across the western part of the upland. The glaciofluvial features that occur within this prominent valley, as well as other aspects, have been described by Klassen (1975, p. 25–28).

Several meltwater channels tributary to Shell Valley have unusually broad valleys where they descend from the upland to the plains. Little Boggy Creek occupies one such valley, more than 3 km (2 mi) wide and some 120 m (400 ft) deep (Fig. 53), along the southwestern margin of the upland. The presence of ice contact deposits within this valley indicates that it predates the last glacier advance. On the other hand, a valley of similar size occupied by Roaring River on the northwestern margin of the upland has a more pronounced V-shape and shows extensive slumping along its sides. These characteristics, along with an absence of ice contact deposits, suggest that this valley formed in late glacial time.

Some of the larger lakes on the upland occupy former glacial drainage systems that are readily traced on airphotos by the trend of open and partly buried channels. One of these systems, trending mainly southeast across the southwestern part of the upland, is occupied by Roy Lake and the Angling lakes. Another, trending southwest across the central part of the upland, is occupied by Whitemud and Singush lakes.

Swan River plain

The Swan River plain in the northwestern part of the map area includes about 670 km^2 (260 mi^2) of low relief glacial landscapes. Surface elevations range from about 520 m (1700 ft) a.s.l. along the southern boundary with the Duck Mountain upland to elevations of 490 to 460 m (1600 to 1500 ft) a.s.l. in the west. The surface drops gradually to 400 m (1300 ft) a.s.l. in the northeastern part.

Drift thickness. Outcrops along Swan River and borehole information at five sites on the plain indicate an average drift thickness of 26 m (85 ft), with a range from 6 to 35 m (20 to 115 ft). Near the Duck Mountain upland and across the Harvey Lake Moraine thicknesses are about 60 m (200 ft). Evidence of bedrock displacement over drift was noted in two boreholes (Appendix, sections 23 and 25).

Till stratigraphy. The till stratigraphy is based on information from four boreholes along a southwest line across the Swan River plain (Fig. 54) and some outcrops along road ditches. Multiple till exposures were seen in a few roadcuts in the southwest. In the central part of the plain, till is locally absent, and thick stratified surface sediments directly overlie bedrock.

Tills of the Shell, Minnedosa and Zelena formations may be included in the undivided drift that underlies the uppermost Arran Formation. These older tills were not identified largely because of the considerable differences in the nature of the till units from one borehole to another and the apparent 'stacking' of older units, including

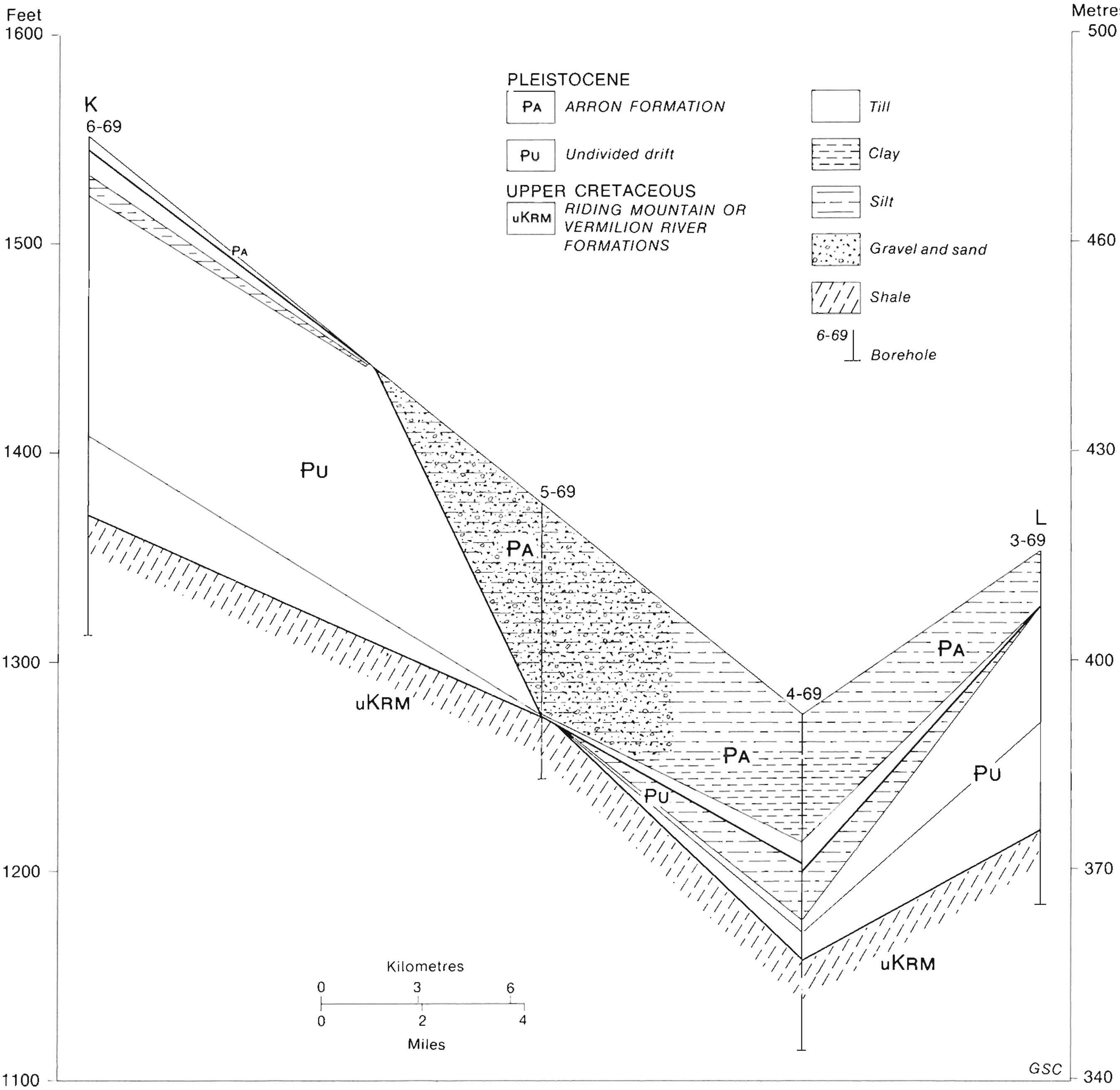


Figure 54. Section KL across the southwestern margin of the Swan River plain (see Fig. 4 for location).

bedrock, over younger units (Appendix, sections 23 and 25). Till of the Arran Formation forms the surface beyond the outwash and lacustrine plains. It occurs beneath the lacustrine sediments along the northeast boundary but is absent beneath the sediments around the outer part of the lacustrine plain where it probably was removed by water erosion.

Landscapes and glacial features. Till plains. Nearly flat or gently irregular till (Fig. 55) of the Arran Formation forms about 260 km² (100 mi²) of the Swan River plain. The surface is almost everywhere slightly eroded by proglacial lakes and streams.

Outwash and lacustrine plains. Outwash and lake deposits, generally with a gently irregular surface, cover about 340 km² (130 mi²) of the Swan River plain. In places the sandy outwash grades into the more widespread lake silt without any change in the landscape, or it is pitted and consists of bouldery gravel and sand. The bulk of the outwash deposits, with the exception of those underlying till, are of the Arran Formation.

Figure 55. Till plain near Arran, Saskatchewan. View is northeast from SW¼ sec. 4, tp. 35, rge. 30 towards Thunderhill, a prominent drumlinized hill of glacially displaced bedrock and drift (see Moran, 1971, p. 132) (GSC 162854).

Figure 57. A closed depression within a gully in lake silt. View is northeast from NE¼ sec. 4, tp. 35, rge. 29, about 8 km north of Benito, Manitoba (GSC 165808).

Several patches of outwash are incised by Swan Valley to the north and northeast of Pelly. The deposits are, in part, pitted and consist of bouldery gravel and sand, or else the surface is gently rolling and the deposits are finer. Exposures in gravel pits show thicknesses of more than 5 m (15 ft) of outwash deposited by east flowing streams (Fig. 56).

Lacustrine silt and sand give a nearly flat or gently rolling surface to about 260 km^2 (100 mi^2) of the northeastern part of the Swan River plain. Parts of Swan Valley and some smaller valleys across the delta and the main basin have tributary gullies that are much wider at their heads than where they join the main valley. Closed depressions within the gullies (Fig. 57) suggest 'piping' occurred here.

The outwash was deposited by streams flowing eastward from the Assiniboine lobe (Klassen, 1972a, p. 555). The straight part of Swan Valley (Fig. 58) terminates at the western apex of a gently rolling sand plain between Swan Valley and Benito. It consists of deltaic sediments lying between pitted outwash to the west and quiet water lake sediments to the east. The lacustrine sediments are about 30 m (100 ft) thick near the apex of the delta and about 20 m (70 ft) thick along the central axis of the basin to the northeast.

End moraine. An end moraine ridge, 1 to 3 km (0.5 to 2 mi) wide and 8 to 15 m (25 to 50 ft) high, trends

Figure 56. Gravel pit in outwash 4 km north of Arran, Saskatchewan. Foreset beds dip northeast (GSC 165811).

Figure 58. Swan River valley viewed northward from NW¼ sec. 4, tp. 34, rge. 32 about 5 km north of Pelly, Saskatchewan. Outwash bench on opposite side is the lowest of several that rise steplike beyond it to form the horizon (GSC 162851-A).

Figure 59. Abandoned valley that formed as a north-south spillway during final deglaciation; it now links the modern Swan and Assiniboine valleys. View is to the east from NE¼ sec. 12, tp. 34, rge. 1, W 2nd mer., 5.6 km northeast of Norquay, Saskatchewan (GSC 165812).

east for about 26 km (16 mi) between Lac La Course and Sarah Lake. It is here formally named the Harvey Lake Moraine after Harvey Lake, which is on the distal side of a prominent part of the moraine near its eastern terminus. This moraine marks the transition from till of the Arran Formation on the Swan River plain to till of the Zelena Formation on the Duck Mountain upland, and to Lennard Formation till on the Assiniboine River plain.

Another end moraine segment of similar width and height forms a distinct ridge in the extreme northwest corner of the map area. It is here formally named the Belleau Brook Moraine after the stream that crosses the moraine. This moraine separates nearly flat or gently rolling lake plain on the east side from hummocky lake deposits to the west. The Harvey Lake and Belleau Brook moraines were built during the last westward advance of ice of the Swan River sublobe across the Swan River plain.

Meltwater channels and buried valleys. Spillways, meltwater channels and partly buried valleys occur within the Swan River plain. The largest spillway, Swan Valley, is generally about 1.5 km wide and from 15 to 60 m (50 to 200 ft) deep (Fig. 58) and is a straight, low gradient (1 m/mi) trench in the outwash and till plains. In contrast, where it crosses the lacustrine plain farther east it is 0.5 to 1.5 km wide, 15 to 30 m (50 to 100 ft) deep, has a gradient of 5.5 m/mi (18 ft/mi), follows a meandering coarse, and has numerous tributary gullies. The trench probably formed as a spillway link from glacial lakes farther north when Lake Agassiz last inundated the northeast part of the Swan River plain. The segment across the lacustrine plain formed after Lake Agassiz receded from this area. Northeast of Pelly, Saskatchewan, the former spillway link between the earliest stage of Swan Valley and Assiniboine Valley (Klassen, 1972a, p. 558) now forms a broad, abandoned valley (Fig. 59). Its bottom lies at 450 m (1475 ft) a.s.l. or some 30 m (100 ft) above the bottom of the modern Swan Valley. This shows that Swan Valley north of Pelly was part of the Assiniboine drainage when either the Swan River sublobe or a glacial lake impounded by it directed the drainage southward. Most of Swan Valley apparently was excavated while Lake Agassiz covered the northeastern part of the Swan River plain and proglacial Lake Melfort (Klassen, 1972a, p. 557) spilled into Swan Valley via a number of now abandoned valleys.

Economic and geotechnical aspects of surficial materials

The following section is primarily a qualitative discussion of the main types of materials, shown on the accompanying surficial geology maps, as they relate to foundation and construction materials, groundwater exploration and agriculture.

Foundation and construction materials

Costs of construction and maintenance of roads, bridges, dams and buildings can be minimized if consideration is given to the general nature and distribution of surficial materials before and during site investigations. Valley walls are the commonest sites where the nature and stratigraphy of the materials affect the stability of the slopes. In much of the prairie region potentially unstable sites are present where valleys are cut mostly in fine stratified drift and/or shale (Christiansen, 1960, p. 22–25; Scott and Brooker, 1968; Klassen, 1975, p. 8–13, 33–77; Sauer, 1975). The most stable sites are found where the valley walls are of massive till or of coarse stratified deposits. Old stabilized slump blocks are common where the valleys are cut mostly in shale. These may be reactivated by excavating along their toes. Slopes crossing interbedded till and fine stratified drift, although not as likely to be disturbed by mass movement as those in shale, are unstable under certain groundwater conditions; for example, slumping in till during construction of the Shellmouth Dam[4] apparently began within a 1.5 m (5 ft) intertill clay bed (A.H. Pollock, pers. comm., 1975). Till of the Minnedosa Formation is more susceptible to minor earth flows than the other tills (Klassen, 1969, Fig. 6), probably because of its highly jointed nature and its locally fine grain size. Similarly, undercutting of road beds and foundations due to gullying and accompanying mass movement is greatest on slopes cut in clays, silts and shales, and is minimal on slopes in till and/or gravel. Excavation problems due to high boulder concentrations found on certain terraces (Klassen, 1975, p. 27) and in boulder pavements can be minimized if they are considered during the initial planning stages (Sauer, 1974, p. 396–370).

There are many factors to be taken into account for minimizing the costs of road and railway construction and

[4]The Shellmouth Dam was built during the 1960's in Assiniboine Valley just below the confluence with Shell Valley as a flood control and water conservation measure. It is mostly an earth-fill structure about 21 m (70 ft) high and 1280 m (4200 ft) long that holds a reservoir with a storage capacity of 430 000 acre feet.

maintenance. For example, roads require much more cut and fill in hummocky moraine than in smoother and flatter areas, but construction materials such as till, sand and gravel are more available on the former. In places, both factors can be used to advantage by locating a road along abandoned channel bottoms in the hummocky moraine. As another example, roads built through extensive areas of hummocky silts found in the uplands are excavated more cheaply than those in hummocky till but have greater maintenance costs. Where roads are built across the contacts of stratified sediments overlying till or bedrock along valley walls, the springs common to these zones likely will cause maintenance problems. Zones of fairly continuous seepage can be recognized by lines of dense vegetation, minor earth flows and by the occurrence of local deposits of calcareous tufa.

A striking example of the use of natural features for highway and railroad beds is found in the Westlake plain. There, Provincial Highway 10 follows the upper or lower Campbell beach for about 97 km (60 mi) north of Ashville, and the Canadian Pacific Railway follows the lower Campbell beach for about 56 km (35 mi) north of Ethelbert.

The distribution of construction quality gravel and sand within the stratified deposits is rather variable, but the potential of certain types of deposits can be predicted. Eskers, kames and kame moraines have a greater variety of materials and grain sizes than do outwash plains, outwash terraces, alluvial terraces, abandoned beaches and river flats. Coarse and fine sediments are found closely associated in the former deposits with pockets of coarse gravel and boulders commonly grading into sand, silt, clay or till. Yet certain conical kames of the moulin type, found here and there in the hummocky moraine, consist entirely of rounded boulders and so are useless for many purposes. One gravel constituent that causes problems, particularly for concrete, is the siliceous shale clast. The amount of shale present (Table 2) depends mainly on distance from the bedrock source, because the shale clasts break down and disintegrate rapidly during water transport. It also varies with the depth to bedrock; sand and gravel commonly will have many shale clasts where the drift is thin and bedrock outcrops are common or where blocks of shale occur in the drift. This is exemplified by the terrace and kame moraine deposits within and near upper Birdtail Valley on the Riding Mountain upland and in some of the outwash bordering Clear Lake.

Groundwater

Studies by the Geological Survey of Canada of groundwater conditions in numerous townships in the map area were published, beginning in the mid-1930's as groundwater resource papers. Johnston (1934) also reported on the general nature of groundwater supply in the map area. These early surveys included considerable water-well inventory, and the reports and surficial maps based on these

Table 2. Stone counts in gravels

General type of deposit and physiographic division	Location			Rock types			
	Sec.	Tp.	Rge.	Carbonate	Igneous (shield)	Quartzite and chert	Shale and other
				%			
Ice contact in hummocky moraine, Duck Mountain upland	NW16	30	28	50	48	0	2
	SW16	34	25	69	28	1	2
	SE26	30	30	52	34	12	2
Ice contact in hummocky moraine, Riding Mountain upland	NE4	17	19	57	40	1	2
Outwash, Assiniboine River plain	36	13	27	49	30	5	16
	NW32	29	31	52	37	10	1
Outwash, Riding Mountain upland	NE19	21	21	83	15	1	1
	NE12	21	21	42	20	1	37
Outwash, Swan River plain	NE10	34	30	71	25	1	4
	NW31	34	30	65	30	1	4
	NW22	34	32	52	40	7	1
Valley terrace, Duck Mountain upland	NW11	30	29	48	43	6	3
Valley terrace, Riding Mountain upland	NE12	21	25	42	16	1	41
	SE30	17	21	48	30	2	20
Valley terrace, Assiniboine River plain	SW31	13	21	46	54	1	1
	NE 9	28	29	57	35	8	0
	NW34	28	31	40	32	28	1
Outwash delta, Assiniboine River plain	24	12	21	56	27	2	15

data outlined the general stratigraphic and lithologic conditions conducive to the occurrence of recoverable supplies of water, mostly for farm use. The common types of aquifer are in surface sands and gravels, scattered pockets of sand and gravel, beds between till and bedrock, and the highly fractured siliceous shale bedrock beneath the drift or near the surface. A high content of dissolved minerals causes the water from certain deep wells to be only of marginal use. Special purpose hydrologic studies, such as one of the Oak River drainage basin in the southeastern part of the Riding Mountain area (Lissey, 1965), and others on local supply have been conducted by the Geological Survey of Canada and the Manitoba Water Control and Conservation Board.

The maps and cross-sections accompanying this report (Figs. 16, 17, 18, 19, 38, 50 and 54) can be useful guides for groundwater exploration and hydrologic studies in that they show the location and distribution of proven and potential surface and subsurface aquifers. Undiscovered large sources may be present within some of the thick stratified sediments penetrated by numerous boreholes, particularly within certain large buried valleys (Klassen et al., 1970). These valleys commonly include thick and extensive beds of sand and gravel underlain by impervious shale, clay or till. Where they are overlain by impervious drift, artesian conditions can occur. One example is a testhole drilled by the Geological Survey of Canada in 1966 near Rivers, Manitoba (SE¼ sec. 25, tp. 12, rge. 22) where artesian conditions resulted in a hydrostatic head sufficient to propel 2400 L/min (530 gal/min) about 3 m (10 ft) high. The aquifer was at a depth of 30 m (100 ft) in sand and gravel under till in a buried valley trending southeastward from the Riding Mountain upland (Klassen et al., 1970). A hydrostatic head also was present in a sand and gravel aquifer between till and bedrock at the eastern abutment of the Shellmouth Dam. The high quartzite and chert content (40 per cent) of this gravel indicates it is alluvium within an ancestral buried valley (Klassen, 1969, p. 2–9).

Sand and gravel lenses within the highly jointed till of the Minnedosa Formation will have greater recharge potential than similar lenses in the nonjointed, impermeable tills, for the joints significantly increase the permeability of the till.

Agricultural practices

The distribution of surficial deposits has an important effect on agriculture. Grain farming is common on the lacustrine plains, till plains and parts of corrugated moraine. Generally, uncultivated areas are extensive over tracts of hummocky moraine, outwash plains and strongly eroded till plains. Heavy concentrations of surface boulders can render the strongly eroded till plains unsuitable for cultivation. The presence of natural grass and clusters of trees have led to the extensive use of outwash and strongly eroded till plains as community pastures, particularly those areas of outwash where water for stock is available at 3 to 6 m (10 to 20 ft) depth. Most hummocky moraine is in federal or provincial parks. It is too rough to be cultivated, although locally the moraine plateaus within it are easily cultivated and are productive because of their nearly flat, clayey and stonefree surfaces. Cultivation of the hummocky silt is not only an extremely marginal operation but also is a questionable practice, for the thin, grey wooded topsoil on the steeper slopes is readily removed by water and wind erosion. Upon breaking of the sod, heavy rains result in gullying and deposition of silt fans over productive soils in lower areas. If these areas are farmed, the removal of the tree cover should be a highly selective operation, and the steeper slopes of hummocks should remain untouched. Not only will the trees deter soil erosion, but they also will provide a windbreak and conditions more favourable to soil moisture capture and retention. Damage in areas already cleared could be minimized by seeding perennial grasses.

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Appendix

Description of stratigraphic sections

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Section 1						
This is the type section for the Largs Till measured in 1970. It is in a roadcut on the east side of Highway 10 on the north side of Minnedosa Valley, near the Canadian Pacific Railway crossing in the SW ¼ section 9, township 15, range 18, W 1st meridian. The name is taken from the railway siding of Largs about 1.5 km northwest and 5 km east of the eastern boundary of the Riding Mountain map area.						
Lennard	5	Till: oxidized olive grey (5Y 4/2); loose; sand 27%, silt 32% and clay 41%;[1] carbonate 17% and ca/dol (calcite/dolomite) 1.4 (1 sample)	1.2	(4)	1.2	(4)
Lennard	4	Till: oxidized, olive brown (2.5Y 4/4); compact; sand 38%, silt 29%, clay 33%; carbonate 19% and ca/dol 1.4 (1 sample)	1.2	(4)	2.4	(8)
Lennard	3	Till: oxidized olive brown (2.5Y 4/4); compact and jointed with limonite staining along joints: sand 37%, silt 30%, clay 33%; carbonate 17% and ca/dol 1.0 (average 2 samples)	7.0	(23)	9.5	(31)
Minnedosa	2	Till: unoxidized olive grey (5Y 4/2); compact and jointed with manganese and limonite staining; sand 36%; silt 30%, clay 34%; carbonate 21% and ca/dol 0.8 (average 2 samples)	4.9	(16)	14.3	(47)
Largs	1	Till: unoxidized very dark greyish brown (2.5Y 3/2); compact; sand 28%, silt 35%, clay 37%; carbonate 12% and ca/dol 0.5 (average 2 samples); higher in shale pebbles than younger units; white flecks on surface impart a distinctive appearance; very compact with some jointing stained with limonite and manganese	>3.0	(10)	17.3	(57)
Section 2						
This was a temporary exposure of the Largs Till measured in 1967. It was in a damsite excavation at the foot of a low terrace on the west side of Assiniboine Valley (SW ¼ sec. 11, tp. 23, rge. 29) near Shellmouth, Manitoba.						
Lennard	3	Gravel and sand: gravel is mostly fine with a few scattered boulders; underlies a terrace at 434 m (1425 ft) a.s.l.	10.7	(35)	10.7	(35)
Largs	2	Till: unoxidized very dark grey (5Y 3/1); clayey and slightly stony; elongate pebbles trend west	4.9	(16)	15.5	(51)
Riding Mountain	1	Shale: very dark grey (5Y 3/1); soft and greasy texture	>1.5	(5)	17.1	(56)
Section 3						
This is the type section for the Shell Till measured in 1967. It is in an excavation on the north side of the road about 152 m (500 ft) west of Shell Valley (NE ¼ LSD[2]7, sec. 21, tp. 25, rge. 28) and 5.6 km south of Roblin, Manitoba.						
	3	Colluvium: dark yellowish brown (10YR 4/4) or brown (10YR 4/3), loose, sandy silt, moderately stony	0.9	(3)	0.9	(3)
Minnedosa	2	Till: oxidized dark greyish brown (2.5Y 4/2) or light yellowish brown (2.5Y 6/4), compact and hard, manganese and limonite staining along joints	5.5	(18)	6.4	(21)
Shell	1	Till: oxidized light olive brown (2.5Y 5/6) or light yellowish brown (2.5Y 6/4); weathered; hard; silty with some small sand lenses; compact; carbonate 18% and ca/dol 2.8 (1 sample); this is an exposure of the upper weathered zone of this till; in the subsurface it has a carbonate content of 25 to 30%	>3.4	(11)	9.8	(32)

[1]Analyzed by hydrometer method, i.e., gravel fraction not measured.
[2]Legal Survey Division.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)

Section 4

This is the type section for the Minnedosa Till measured in 1962 and 1964 (Fig. 60). It is located on Highway 10 on the west side of a gully in the north wall of Minnedosa Valley (NW 1/4 LSD 16, sec. 20, tp. 16, rge. 18) on the Riding Mountain upland about 6 km east of the eastern boundary of the map area.

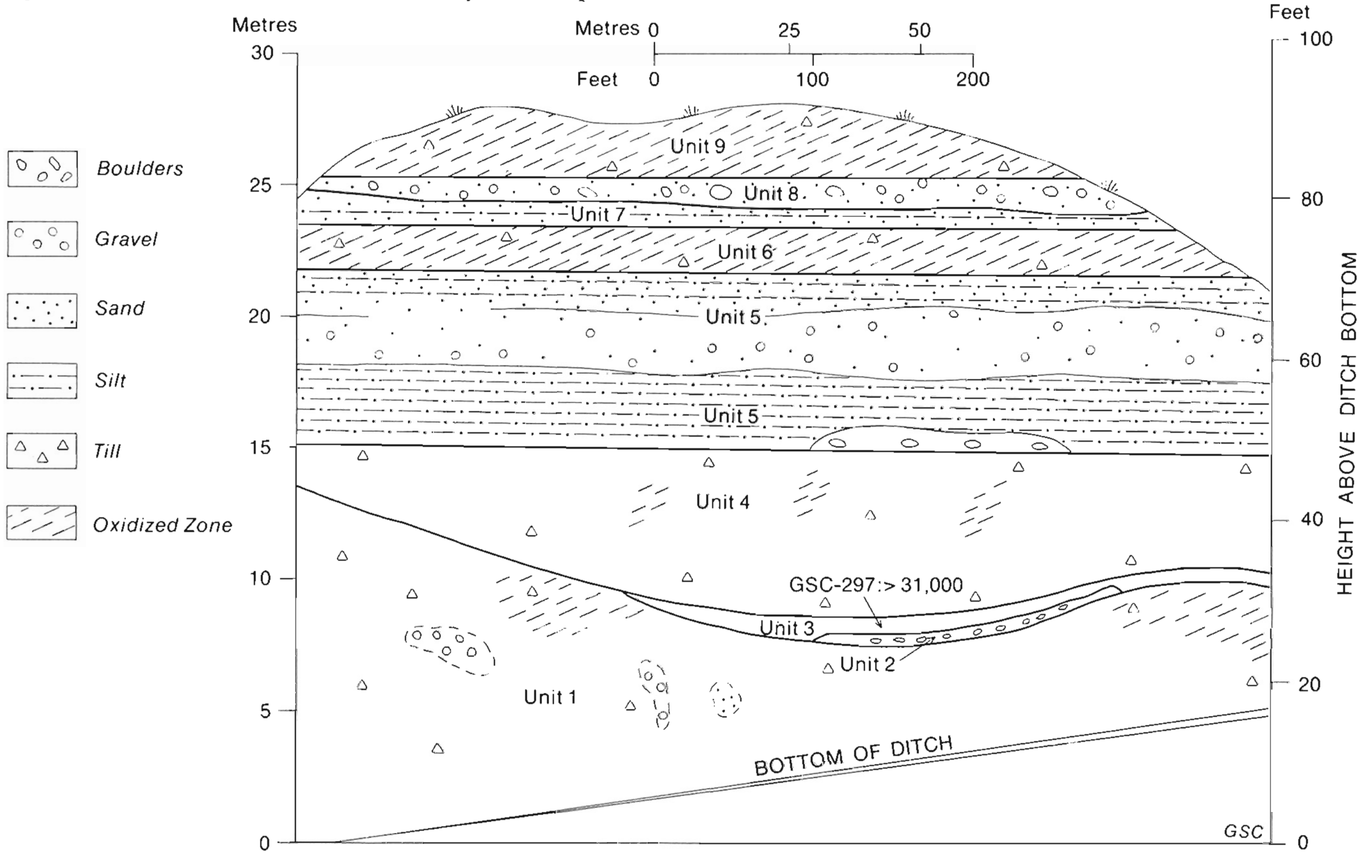

Figure 60. Type section for the Minnedosa Formation. Exposure is a roadcut along Minnedosa Valley.

Formation	Unit no.	Description	m	(ft)	m	(ft)
Zelena	9	Till: oxidized yellowish brown (10YR 5/3); loose or compact; gravel 9%, sand 34%, silt and clay 57%;[3] carbonate 33% and ca/dol 0.6 (average 3 samples); carbonate clasts 60%; elongate pebbles trend southwest	2.4	(8)	2.4	(8)
Minnedosa	8	Sand and gravel: weakly bedded, poorly sorted; boulders in gravel	0.9	(3)	3.6	(11)
Minnedosa	7	Silt and sand: thinly bedded	0.9	(3)	4.3	(14)
Minnedosa	6	Till: oxidized pale olive (5Y 6/4); compact; gravel 17%, sand 32%, silt and clay 61% (average 3 samples; carbonate 26% and ca/dol 0.3 (average 4 samples); carbonate clasts 33% of total; elongate pebbles trend southwest	2.1	(7)	6.4	(21)
Minnedosa	5	Silt, sand and fine gravel; thinly bedded; contains many local shale clasts	6.1	(20)	12.5	(41)
Minnedosa	4	Till: unoxidized olive (5Y 5/3); compact and jointed with manganese and limonite stains; gravel 6%, sand 22%, silt and clay 72%; carbonate 20% and ca/dol 0.4 (average 4 samples); carbonate clasts 42% of total; elongate pebbles trend south-southeast	6.1	(20)	18.6	(61)
Largs ?	3	Silt: massive: fissile; fossiliferous, plant detritus radiocarbon date as >31 300 years (GSC-297; Dyck et al., 1966, p. 12) and rodent bones (Klassen et al., 1967, p. 437–438)	1.5	(5)	20.1	(66)

[3]Total sieve analysis.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Largs	2	Gravel: highly stained with limonite; some carbonate pebbles weathered to a powder; scattered boulders	0.3	(1)	20.4	(67)
Largs	1	Till: very dark grey (5Y 3/1); compact; gravel 15%, sand 28%, silt and clay 57%; carbonate 15% and ca/dol 0.9 (average 2 samples); carbonate clasts 18% and shale clasts 72% of total; elongate pebbles trend south-southwest	>4.9	(16)	25.3	(83)

Section 5

This section was measured in 1961 (Fig. 61) and is in a roadcut above the east ditch of Highway 83 on the south side of Shell Valley (SE ¼ sec. 3, tp. 23, rge. 28) about 3 km west and 0.8 km north of Inglis, Manitoba.

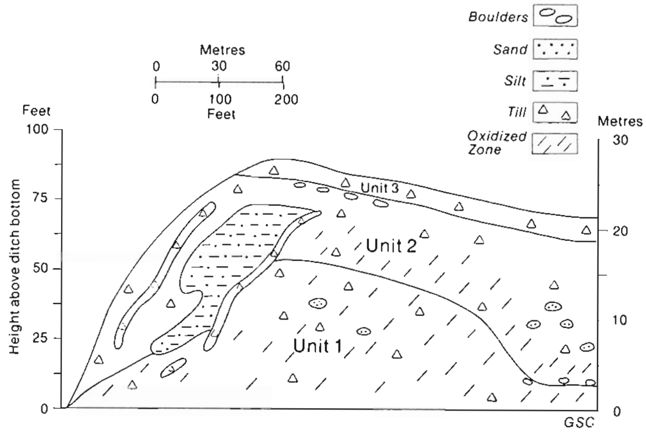

Figure 61. Section in a roadcut along Shell Valley near Inglis, Manitoba.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	3	Till: oxidized yellowish brown (10YR 5/4); loose or compact; silty	1.5	(5)	1.5	(5)
Minnedosa	2	Till: oxidized yellowish brown (10YR 5/4) or unoxidized very dark grey (5Y 3/1); compact; silty; weakly jointed; contains stringers of distinctive pink (7.5YR 7/4) till that extends partly into unit 1; contains numerous lenses of silt; elongate pebbles trend weakly southwest; boulder pavement between units 2 and 3 has faceted surfaces with striae and grooves oriented southeast	4.6	(15)	6.1	(20)
Minnedosa	1	Till: unoxidized olive (5Y 5/3) or very dark grey (5Y 3/1); silty with fewer stones than younger tills; jointed; elongate pebbles trend southwest; contact with unit 2 generally is not well defined across the section but in places is marked by an oxidized zone, a line of boulders, or stringers of pink till and silt	>15.2	(50)	21.3	(70)

Section 6

This section is from a borehole (17-66) located in a road ditch in the NW ¼ LSD 13, sec. 21, tp. 24, rge 29 about 3 km west and 8 km north of Dropmore, Manitoba.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	7	Till: oxidized olive grey (5Y 4/2)	2.4	(8)	2.4	(8)
Undivided	6	Till: unoxidized very dark grey (5Y 3/1); sand 46%, silt 37%, clay 17%; carbonate 21% and ca/dol 1.4 (average 9 samples), the range of carbonate values among samples is from 18% near the bottom of the unit to 27% near the top	26.8	(88)	29.2	(96)
Undivided	5	Silt: unoxidized dark grey (5Y 4/1)	10.4	(34)	36.6	(130)
Undivided	4	Till: unoxidized dark olive grey (5Y 3/2); sand 37%, silt 40%, clay 23%; carbonate 21% and ca/dol 1.3 (average 2 samples)	3.7	(12)	43.3	(142)
Undivided	3	Clay: unoxidized dark olive grey (5Y 3/2) or very dark grey (5Y 3/1)	14.6	(48)	57.9	(190)
Undivided	2	Gravel: higher in quartzite than other gravels	0.9	(3)	58.8	(193)
Riding Mountain	1	Shale: very dark grey (5Y 3/1); hard, waxy	>8.2	(27)	67.0	(220)

Section 7

This section is from a borehole (22-66) that was located in a road ditch in the NE ¼ LSD 16, sec. 5, tp. 24, rge 28 about 19 km south of Roblin, Manitoba.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	9	Till: oxidized olive brown (2.5Y 4/4); sand 60%; silt 15%, clay 25%; carbonate 12% and ca/dol 0.7 (1 sample)	6.1	(20)	6.1	(20)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Minnedosa	8	Till: unoxidized very dark grey (5Y 3/1); sand 46%, silt 35%, clay 19% (average 3 samples); carbonate 20% and ca/dol 1.0 (average 2 samples)	12.8	(42)	18.9	(62)
Minnedosa	7	Silt: unoxidized dark grey (5Y 4/1)	1.2	(4)	20.1	(66)
Minnedosa	6	Till: unoxidized dark olive grey (5Y 3/2) or olive grey (5Y 4/2); sand 42%, silt 34%, clay 24%; carbonate 21% and ca/dol 1.0 (average 2 samples)	8.8	(29)	28.9	(95)
Shell	5	Till: unoxidized very dark grey (5Y 3/1); sand 49%, silt 31%, clay 20%; carbonate 26% and ca/dol 0.8 (average 2 samples)	6.4	(21)	35.3	(116)
Tee Lakes	4	Clay: unoxidized very dark grey (5Y 3/1) or dark grey (5Y 4/2); laminated in part	15.2	(50)	50.5	(166)
Tee Lakes	3	Till: unoxidized very dark grey; sand 52%, silt 34%, clay 24%; carbonate content 21% and ca/dol 1.3 (average 6 samples)	56.1	(184)	106.6	(350)
Wynyard ?	2	Gravel and sand	5.5	(18)	112.1	(368)
Riding Mountain	1	Shale: very dark grey (5Y 3/1); waxy; noncalcareous	>11.3	(37)	123.4	(405)

Section 8

This section was exposed in 1968 during digging of the No. 1 shaft for Sylvite of Canada Ltd. (LSD 13, sec. 22, tp 17, rge. 30) about 4 km north of Ste-Marthe-Rocanville, Saskatchewan. Units were described and samples for carbonate analyses were collected by C.E. Wright and L.L. Price of the Geological Survey of Canada.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	5	Gravel: bouldery	5.8	(19)	5.8	(19)
Lennard	4	Till: oxidized and unoxidized light grey; loose; carbonate 16% and ca/dol 0.9 (average 3 samples)	4.6	(15)	10.4	(34)
Minnedosa	3	Till: unoxidized light grey; sandy; compact; carbonate 20% and ca/dol 0.7 (average 12 samples)	9.1	(30)	19.5	(64)
Minnedosa	2	Till; unoxidized light grey; silty; compact; carbonate 19% and ca/dol 1.2 (average 11 samples)	10.7	(35)	30.2	(99)
Riding Mountain	1	Shale: light or medium grey; blocky	11.9	(39)	42.1	(138)

Section 9

The type section for the Lennard Till was measured in 1967. It is from a roadcut above the north ditch, where it crosses the east edge of Shell Valley (SE ¼ LSD 1, sec. 27, tp. 23, rge. 28) 1.5 km north and 3 km west of Lennard, Manitoba.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	4	Till: slightly oxidized dark greyish brown (2.5Y 4/2); loose; gravel 5%, sand 32%, silt and clay 63%; carbonate 18% and ca/dol 1.4 (1 sample); elongate pebbles trend southeast	1.5	(5)	1.5	(5)
Minnedosa	3	Till: oxidized dark yellowish brown (10YR 5/4) or light yellowish brown (2.5Y 6/4); compact; jointed; gravel 7%, sand 35%, silt and clay 58%, carbonate 32% and ca/dol 0.8 (1 sample); elongate pebbles have a weak trend south-southwest; upper zone includes a boulder pavement with striae and grooves of similar orientation to that of the pebbles in unit 4	1.8	(6)	3.3	(11)
Shell	2	Till: oxidized yellowish brown (10YR 5/4) or very pale brown (10YR 7/3); compact and hard; gravel 10%, sand 27%, silt and clay 63%; carbonate 55% (1 sample); elongate pebbles trend west	0.9	(3)	4.2	(14)
Tee Lakes ?	1	Gravel and sand: fine gravel; carbonate pebbles are highly iron stained; cross-bedding indicates deposition by southwest flowing stream	>0.9	(3)	5.2	(17)

Section 10

This section, measured in 1963 and sampled in 1970, is in a roadcut above the north ditch of Highway 4 where it crosses the east side of Birdtail Valley (NE ¼ sec. 35, tp. 17, rge. 26) about 2.5 km northwest of Solsgirth, Manitoba.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	4	Till: oxidized yellowish brown (10YR 4/4); compact; silty; carbonate 15% and ca/dol 0.8 (average 2 samples)	6.1	(20)	6.1	(20)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Minnedosa	3	Till: unoxidized very dark grey (10YR 3/1) or very dark greyish brown (2.5Y 3/2); compact and hard; silty; carbonate 18% and ca/dol 1.4 (average 2 samples); units 3 and 4 are separated by degree of oxidation with no distinct contact between them	9.1	(30)	15.2	(50)
Minnedosa	2	Silt: finely laminated to massive; zones of carbonate cemented sand and gravel 2.5 to 5 cm thick occur at the contact with unit 1	9.1	(30)	24.3	(80)
Minnedosa	1	Till: oxidized light olive brown (2.5Y 5/4); silty; carbonate 20% and ca/dol 1.5; iron staining along joints	3.0	(10)	27.3	(90)

Section 11

This section, measured in 1966 and 1967 is in a roadcut along the south ditch slightly above the bottom of the east side of Big Boggy Valley (SW ¼ LSD 16, sec. 27, tp. 27, rge. 29) about 3 km northeast of Makaroff, Manitoba (Fig. 62).

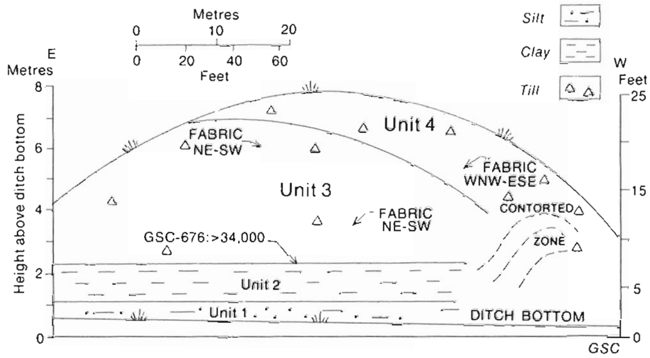

Figure 62. Section in a roadcut within Big Boggy Creek Valley.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Minnedosa	4	Till: oxidized olive brown (2.5YR 4/4); loose; gravel 11%, sand 30%, silt and clay 59%; carbonate 19% and ca/dol 1.4 (1 sample); elongate pebbles trend west-southwest	2.7	(9)	2.7	(9)
Minnedosa	3	Till: oxidized olive grey (5Y 4/2); compact; jointed; sand 28%, silt and clay 72%; carbonate 18% and ca/dol 1.2 (average 2 samples); elongate pebbles trend southwest	3.7	(12)	6.4	(21)
Minnedosa	2	Clay and silt: varved, beds less than 2.5 cm thick; an upper iron stained zone about 2.5 cm thick includes organic detritus radiocarbon dated as greater than 34 000 years (GSC-676, Lowdon and Blake, 1968, p. 218)	0.9	(3)	7.3	(24)
Minnedosa	1	Silt: massive; pebbly; jointed	>0.9	(3)	8.2	(27)

Section 12

This section was measured in 1969 and 1970. It is in a cut along the north ditch of an east-west road across the east edge of Big Boggy Valley (NE ¼ LSD 3, sec. 7, tp. 29, rge. 30) about 1.5 km north of Runnymede, Saskatchewan.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Lennard	4	Till: oxidized grey; loose; sand 15%, silt 51%, clay 34% (1 sample)	0.6	(2)	0.6	(2)
Minnedosa	3	Till: oxidized yellowish brown or grey; compact highly fractured and jointed with limonite and manganese stains along joints; sand 28%, silt 33%, clay 39%; carbonate 18% and ca/dol 1.4 (average 2 samples); contact with unit 4 is not as distinct as elsewhere but can be traced along a weakly developed boulder line	1.5	(5)	2.1	(7)
Minnedosa	2	Clay: varved with light and dark clayey bands 1 to 6 mm thick; some beds are strongly iron stained; upper 2.5 to 5 cm is leached and includes a carbonaceous band 6 to 12 mm thick that yielded a radiocarbon date of 30 000±490 years (GSC-1342; Lowdon and Blake, 1973, p. 23); finite dates of about the same age range were obtained above the till of the Minnedosa Formation at another site (see section 21), suggesting that GSC-1342 is too young	0.9	(3)	3.0	(10)
Minnedosa	1	Silt: oxidized, massive; scattered pebbles impart till-like appearance	1.2	(4)	4.3	(14)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Section 13						
This section is from a borehole (11-69) located in the road ditch (NW ¼ LSD 14, sec. 1, tp. 25, rge. 24) about 3 km south of Grandview, Manitoba.						
Arran	7	Till and Clay: till was not identified in the borehole, but nearby ditches expose some 1.2 m of till over clay; the clay is oxidized greyish brown (10YR 5/2); sand 12%, silt 29% (1 sample); scattered pebbles and coarse sand grains impart a till-like aspect to this unit	3.1	(10)	3.1	(10)
Zelena	6	Clay: oxidized dark greyish brown (2.5Y 4/2) or very dark greyish brown (2.5Y 3/2); sand 11%, silt 32%, clay 57%; carbonate 54% and ca/dol 0.3 (average 2 samples); scattered pebbles and coarse sand grains impart a till-like aspect to this unit	9.1	(30)	12.2	(40)
Zelena	5	Clay: oxidized very dark greyish brown (2.5Y 3/2); sand 7%, silt 17%, clay 76%; similar to above unit except that coarse fraction is absent; carbonate 46% and ca/dol 0.6 (1 sample)	2.1	(7)	14.3	(47)
Zelena	4	Till (Zelena): unoxidized very dark grey (5Y 3/1); fairly hard; sand 33%, silt 31%, clay 36%; carbonate 33% and ca/dol 0.5 (average 2 samples)	2.1	(7)	16.4	(54)
Minnedosa ?	3	Clay: unoxidized dark grey (5Y 4/1); massive; sandy in lower zone	3.7	(12)	20.1	(66)
Minnedosa ?	2	Till: unoxidized very dark grey (5Y 3/1); sand 36%, silt 29%, clay 35%; carbonate 26% and ca/dol 0.7 (average 2 samples)	12.8	(42)	32.9	(108)
Vermilion River	1	Shale: very dark grey (5Y 3/1); fissile; noncalcareous	>7.3	(24)	40.2	(132)
Section 14						
This section is in a roadcut on the west side of Highway 10 about 305 m north of the junction with Highway 5 (SE¼ sec. 14, tp. 25, rge. 21). The cut is across the north edge of a valley tributary to the valley of Wilson Creek.						
Arran	3	Till: oxidized dark greyish brown (10YR 4/2); upper zone is marked by greyish mottles and streaks of calcium carbonate; fairly loose	1.2	(4)	1.2	(4)
Zelena ?	2	Till: oxidized yellowship brown (10YR 5/4); fairly hard; jointed, with strong oxidation along joints	2.7	(9)	3.9	(13)
Ashville	1	Shale: very dark grey (2.5Y N/3); fissile and jointed; sulphur along joints	>1.8	(6)	5.7	(19)
Section 15						
This section is from a roadcut on the west side of Highway 10 (NE ¼ sec. 33, tp. 23, rge. 19) about 11 km south of Dauphin, Manitoba. The cut is across the edge of a terrace (Norcross – 390 m a.s.l.) that marks the initial rise of the Westlake plain to the Riding Mountain upland.						
Zelena	1	Till: oxidized yellowish brown (10YR 5/4) or dark yellowish brown (10YR 4/4); crumbly and breaks with a hackly fracture; upper 1.2 m zone has a mottled appearance and contains pockets of grey (5Y 5/1) clay; carbonate 30% and ca/dol 1.0 (1 sample); boulder pavement at the surface consists mostly of igneous rocks with strongly weathered, faceted surfaces lacking visible grooves or striae; patches of stony clay less than 0.3 m thick occur on the surface	4.6	(15)	4.6	(15)
Section 16						
This section is from a borehole (8-69) on a side road off provincial road 366 (LSD 2, sec. 8, tp. 34, rge. 25) about 8 km northwest of Wellman Lake on the Duck Mountain upland.						
Zelena	26	Till: oxidized light olive brown (2.5Y 5/4) or dark greyish brown (2.5Y 4/2); sandy; carbonate 28% and ca/dol 1.8	5.5	(18)	5.5	(18)
Zelena ?	25	Till: unoxidized very dark grey (5Y 3/1); sandy; fairly stony	4.6	(15)	10.0	(33)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Minnedosa ?	24	Gravel	4.3	(14)	14.3	(47)
Minnedosa ?	23	Till: oxidized olive grey (5Y 4/2); sand 43%, silt 32%, clay 25%; carbonate 22% and ca/dol 0.7 (1 sample)	1.5	(5)	15.9	(52)
Minnedosa ?	22	Till: unoxidized dark grey (5Y 4/1); sand 43%, silt 32%, clay 25%; carbonate 22% and ca/dol 0.8 (1 sample)	3.4	(11)	19.2	(63)
Minnedosa ?	21	Clay: dark grey (5Y 4/1); calcareous	1.2	(4)	20.4	(67)
Minnedosa ?	20	Till: oxidized olive (5Y 5/3); sand 45%, silt 28%, clay 27% (average 2 samples); carbonate 25% and ca/dol 1.4 (average 4 samples)	2.1	(7)	22.6	(74)
Shell ?	19	Till: oxidized very dark greyish brown (2.5Y 3/2) or dark olive grey (5Y 3/2); sand 45%, silt 28%, clay 27% (average 2 samples); carbonate 30% and ca/dol 1.4 (average 4 samples)	6.7	(22)	29.3	(96)
Undivided	18	Till: unoxidized very dark grey (5Y 3/1); sand 38%, silt 24%, clay 38% (1 sample); carbonate 20% and ca/dol 2.1 (average 9 samples)	7.9	(26)	37.2	(122)
Undivided	17	Clay: very dark grey (5Y 3/1); calcareous	1.8	(6)	39.0	(128)
Undivided	16	Till: unoxidized, very dark grey (5Y 3/1); sand 36%, silt 33%, clay 31%; carbonate 17% and ca/dol 0.7 (average 2 samples)	5.8	(19)	44.8	(147)
Undivided	15	Clay: very dark grey (5Y 3/1); slightly calcareous	1.5	(5)	46.3	(152)
Undivided	14	Till: unoxidized very dark grey (5Y 3/1); sand 35%, silt 36%, clay 29%; carbonate 14% and ca/dol 1.0 (average 2 samples)	3.4	(11)	49.7	(163)
Undivided	13	Clay: dark grey (5Y 4/1); calcareous	4.0	(13)	53.7	(176)
Undivided	12	Gravel and sand: 1.2 m diameter granite boulder in upper zone	3.7	(12)	57.3	(188)
Undivided	11	Till: oxidized olive grey (5Y 4/2); sandy stony	3.4	(11)	60.7	(199)
Undivided	10	Gravel and sand: partly cemented	25.9	(85)	86.6	(284)
Tee Lakes	9	Till: unoxidized dark grey (5Y 4/1); sand 51%, silt 13%, clay 36%; carbonate 25% and ca/dol 1.0 (1 sample)	29.9	(98)	116.5	(382)
Tee Lakes	8	Silt: grey (5Y 5/1); calcareous	7.3	(24)	123.7	(406)
Tee Lakes	7	Till: unoxidized dark grey (5Y 4/1); hard; sand 42%, silt 30%, clay 28%; carbonate 23% and ca/dol 0.7 (average 3 samples)	14.9	(49)	138.6	(455)
Largs	6	Clay, silt, sand, gravel	11.0	(36)	149.6	(491)
Largs	5	Till: unoxidized dark olive grey (5Y 3/2); very hard; sand 35%, silt 32%, clay 33%; carbonate 18% and ca/dol 1.1 (average 8 samples)	46.6	(153)	196.2	(644)
Wynyard ?	4	Clay and silt	31.1	(102)	227.3	(746)
Riding Mountain	3	Shale: very dark grey (5Y 3/1); noncalcareous	4.0	(13)	231.3	(759)
Riding Mountain	2	Sand: olive grey (5Y 5/2) noncalcareous	8.2	(27)	239.5	(786)
Riding Mountain	1	Shale: very dark grey (5Y 3/1); waxy; noncalcareous	>4.3	(14)	243.8	(800)

Section 17

This is the type section for the Tee Lakes Till, which is formally named after the Tee Lakes. It is from a borehole (7-69) along a forestry road (SW ¼ sec. 11, tp. 32, rge. 27) about 3 km southwest of the Tee Lakes, in the north-central part of the Duck Mountain upland.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Undivided	23	Clay: dark greyish brown (2.5Y 4/2); some pebbly clay beds; calcareous	7.6	(25)	7.6	(25)
Undivided	22	Clay: dark olive grey (5Y 3/2); calcareous	9.8	(32)	17.4	(57)
Undivided	21	Till: unoxidized dark olive grey (5Y 3/2); sand 32%, silt 29%, clay 39%; carbonate 27% and ca/dol 0.6 (1 sample)	3.0	(10)	20.4	(67)
Undivided	20	Clay: dark olive grey (5Y 3/2); calcareous	3.4	(11)	23.7	(78)
Undivided	19	Till: unoxidized dark olive grey (5Y 3/2); sand 42%, silt 23%, clay 35%; carbonate 29% and ca/dol 0.5 (1 sample)	3.1	(10)	26.8	(88)
Undivided	18	Clay: dark olive grey (5Y 3/2); calcareous	8.5	(28)	35.4	(116)
Undivided	17	Sand	2.7	(9)	38.1	(125)
Undivided	16	Till: unoxidized dark olive grey (5Y 3/2); sand 46%, silt 26%, clay 28%; carbonate 29% and ca/dol 0.6 (2 samples)	3.1	(10)	41.1	(135)
Undivided	15	Sand	1.5	(5)	42.7	(140)
Undivided	14	Clay: dark grey (5Y 4/1); sandy and pebbly zones; calcareous	7.0	(23)	49.7	(163)
Undivided	13	Till: unoxidized very dark grey (5Y 3/1); hard; sand 39%, silt 27%, clay 34%; carbonate 29% and ca/dol 0.8 (1 sample); numerous boulders occur in upper zone	3.1	(10)	52.7	(173)
Undivided	12	Clay: dark olive grey (5Y 3/1); calcareous	2.1	(7)	54.9	(180)
Undivided	11	Till: unoxidized dark olive grey (5Y 3/2) or very dark grey (5Y 3/1); sand 48%, silt 27%, clay 25%, carbonate 25% and ca/dol 0.7 (average 2 samples)	4.6	(15)	59.5	(195)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Undivided	10	Gravel	18.0	(59)	77.4	(254)
Tee Lakes	9	Till: unoxidized very dark grey (5Y 3/1); sand 43%, silt 28%, clay 29%; carbonate 21% and ca/dol 1.4 (average 2 samples)	12.8	(42)	90.2	(296)
Tee Lakes	8	Sand and gravel	3.1	(10)	93.3	(306)
Tee Lakes	7	Till: unoxidized very dark grey (5Y 3/1); sand 42%, silt 25%, clay 33%; carbonate 22% and ca/dol 1.3 (1 sample)	2.7	(9)	96.0	(315)
Tee Lakes	6	Clay: very dark grey (5Y 3/1); calcareous	1.5	(5)	97.6	(320)
Tee Lakes	5	Till: unoxidized very dark grey (5Y 3/1); sand 31%, silt 32%, clay 37%; carbonate 21% and ca/dol 2.6 (1 sample)	9.8	(32)	107.3	(352)
Largs	4	Till: unoxidized dark grey (5Y 4/1); sand 31%, silt 33%, clay 36% (average 8 samples); carbonate 16% and ca/dol 1.0 (average 21 samples)	42.7	(140)	150.0	(492)
Wynyard ?	3	Clay and silt: (5Y 5/1) with olive green tone or olive grey (5Y 4/2); noncalcareous or calcareous; includes hard (cemented) beds	21.3	(70)	171.3	(562)
Riding Mountain	2	Shale: olive grey (5Y 4/2); noncalcareous; waxy	2.4	(8)	173.8	(570)
Riding Mountain	1	Sand: olive grey (5Y 5/2) with greenish tone; noncalcareous	4.6	(15)	178.4	(585)
Riding Mountain		Shale: very dark grey (5Y 3/1); noncalcareous; waxy	36.6	(120)	214.9	(705)
Section 18						
This section is from a borehole (2-68) near the boundary of the Duck Mountain upland and Riding Mountain upland (SW ¼ LSD, sec. 29, tp. 25, rge. 27) about 1.5 km southwest of Shevlin, Manitoba.						
Zelena ?	12	Till: oxidized dark yellowish brown (10YR 4/4) or dark greyish brown (2.5Y 4/2); sand 19%, silt 49%, clay 32%; carbonate 21% and ca/dol 0.6 (1 sample)	6.7	(22)	6.7	(22)
Minnedosa	11	Till: unoxidized very dark grey (5Y 3/1); sand 40%, silt 26%, clay 34% (average 4 samples); carbonate 20% and ca/dol 0.7 (average 3 samples)	16.2	(53)	22.9	(75)
Shell	10	Till: unoxidized very dark grey (5Y 3/1) or dark olive grey (5Y 3/2); sand 35%, silt 29%, clay 36% (average 3 samples); 3 m upper zone (weathered ?), carbonate 13% and ca/dol 0.9 (1 sample), lower zone, carbonate 35% and ca/dol 0.6 (2 samples)	4.6	(15)	27.4	(90)
Shell	9	Gravel	9.8	(32)	32.2	(122)
Shell	8	Till: unoxidized very dark grey (5Y 3/1)	1.2	(4)	38.4	(126)
Shell	7	Gravel	1.8	(6)	40.2	(132)
Shell	6	Till: unoxidized dark grey (5Y 4/1); sand 37%, silt 29%, clay 34%; carbonate 28% and ca/dol 0.9 (average 4 samples)	15.2	(50)	55.5	(182)
Tee Lakes	5	Till: unoxidized very dark grey (5Y 3/1); sand 45%, silt 26%, clay 29%; carbonate 25% and ca/dol 1.0 (average 6 samples)	26.5	(87)	82.0	(269)
Tee Lakes	4	Clay: dark grey (5Y 4/1); calcareous dense and greasy	10.1	(33)	92.1	(301)
Tee Lakes	3	Till: unoxidized very dark grey (5Y 3/1); sand 44%, silt 26%, clay 30%; carbonate 23% and ca/dol 1.3 (average 2 samples)	32.9	(108)	125.0	(410)
Wynyard ?	2	Sand and silt: grey (5Y 4/1); minor gravel; calcareous	53.7	(176)	178.7	(586)
Riding Mountain	1	Shale: very dark grey (5Y 3/1); noncalcareous; waxy	8.8	(29)	187.5	(615)
Section 19						
This section is along the west wall of Roaring River valley (NE ¼ LSD 2, sec. 30, tp. 33, rge. 26) in the northwestern part of the Duck Mountain upland at about 600 m a.s.l. (see Klassen et al., 1967, p. 435).						
Zelena	5	Till: oxidized yellowish brown (10YR 5/4) or unoxidized very dark greyish brown (2.5Y 3/2); compact; sand 42%, silt 30%, clay 28% (average 3 samples); carbonate content 27% and ca/dol 1.3 (average 3 samples)	4.6	(15)	4.6	(15)
Minnedosa	4	Till: oxidized yellowish brown (10YR 5/6) or dark olive grey (5Y 3/2); jointed with strong limonite staining along joints; sand 40%, silt 32%, clay 28%; carbonate 25% and ca/dol 1.7 (average 4 samples); contact with Zelena Till is marked by a boulder line and weakly developed paleosol	12.2	(40)	16.8	(55)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Roaring River	3	Clay and silt: thinly bedded; fossiliferous scattered plant detritus yielded radiocarbon age of greater than 37 760 years B.P. (GSC-284[4], Dyck et al., 1966, p. 12); stony in part	2.7	(9)	19.5	(64)
Roaring River	2	Sand and gravel: interbedded	7.6	(25)	27.1	(89)
	1	Covered to river level	17.7	(58)	44.8	(147)

Section 20

This section is from a borehole (1-69) in the north ditch (SW ¼ LSD 4, sec. 14, tp. 28, rge. 28) of the east-west road opposite the Zelena post office.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Zelena	13	Till: oxidized light olive brown (2.5Y 5/4) or very dark greyish brown (10YR 3/2); sand 44%, silt 28%, clay 28% (average 2 samples); carbonate 28% and ca/dol 1.0 (average 5 samples)	9.1	(30)	9.1	(30)
Minnedosa	12	Till: unoxidized very dark grey (5Y 3/1); sand 44%, silt 27%, clay 29% (average 4 samples); carbonate 24% and ca/dol 0.8 (average 6 samples)	11.0	(36)	20.1	(66)
Shell	11	Till: oxidized light olive brown (2.5Y 5/4); sand 44%, silt 30%, clay 26%; carbonate 30% and ca/dol 0.6 (1 sample)	1.5	(5)	21.6	(71)
Shell	10	Till: unoxidized very dark grey (5Y 3/1); sand 43%, silt 30%, clay 27% (average 6 samples); carbonate 31% and ca/dol 0.9 (average 12 samples)	28.0	(92)	49.7	(163)
Tee Lakes	9	Gravel	11.3	(37)	61.0	(200)
Tee Lakes	8	Till: unoxidized very dark grey (5Y 3/1); sand 41%, silt 31%, clay 28% (average 2 samples); carbonate 25% and ca/dol 1.6 (average 4 samples)	7.0	(23)	68.0	(223)
Tee Lakes	7	Gravel	5.2	(17)	73.2	(240)
Tee Lakes	6	Till: unoxidized very dark grey (5Y 3/1); sand 43%, silt 28%, clay 29% (average 2 samples); carbonate 22% and ca/dol 1.3 (average 3 samples)	9.8	(32)	82.9	(272)
Tee Lakes	5	Sand and gravel	3.1	(10)	86.0	(282)
Largs	4	Till: oxidized olive grey (5Y 4/2); sand 29%, silt 30%, clay 41% (average 2 samples); carbonate 17% and ca/dol 1.7 (average 3 samples)	5.5	(18)	91.5	(300)
Largs	3	Till: unoxidized very dark grey (5Y 3/1); sand 28%, silt 34%, clay 38% (1 sample); carbonate 15% and ca/dol 1.8 (average 2 samples)	16.8	(55)	108.2	(355)
Wynyard ?	2	Sand, silt and clay: olive (5Y 4/3) and dark olive grey (5Y 3/2); thinly bedded; minor gravel; hard	57.9	(157)	156.1	(512)
Riding Mountain	1	Shale, very dark grey (5Y 3/1); noncalcareous; waxy	>8.5	(28)	164.6	(540)

Section 21

This is the type section for the Zelena Till. It is in a roadcut at about 595 m a.s.l. on the east side of Shell Valley (NE ¼ LSD 13, sec. 17, tp. 28, rge. 27) about 1.5 km north and 5 km east of the hamlet of Zelena, Manitoba (Fig. 63).

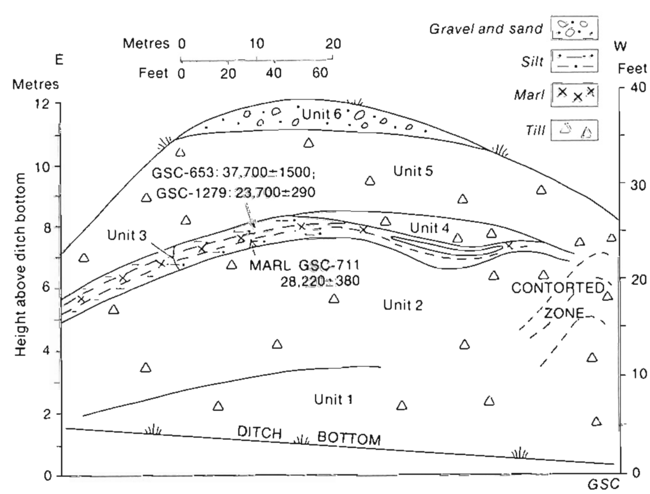

Figure 63. Type section for the Zelena Formation.

[4]This date was mistakenly reported as GSC-286 in Klassen et al. (1967, p. 436).

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Zelena	6	Gravel and sand: numerous boulders	1.2	(4)	1.2	(4)
Zelena	5	Till: oxidized dark yellowish brown (10YR 4/4); loose or compact; sand 38%, silt 31%, clay 31% (average 2 samples); carbonate 30% and ca/dol 1.5 (average 5 samples); elongate pebbles trend weakly southeast	2.4	(8)	3.7	(12)
Zelena	4	Till: oxidized olive brown (2.5Y 4/4); compact; sand 49%, silt 27%, clay 24% (1 sample); carbonate 32% and ca/dol 1.4 (average 3 samples); sharp contact with overlying till	0.6	(2)	4.3	(14)
Minnedosa	3	Silt, clay and marl: interbedded carbonaceous detritus scattered within silt and clay yielded radiocarbon dates of 37 700±1500 years (GSC-653, Lowdon and Blake, 1968, p. 217) and 23 700±290 years (GSC-1279, Lowdon and Blake, 1973, p. 22); marl was dated at 28 220±380 years (GSC-711, Lowdon and Blake, 1968); sharp contact with enclosing till units	0.6	(2)	4.9	(16)
Minnedosa	2	Till: oxidized dark greyish brown (2.5Y 4/2); compact; jointed; sand 42%, silt 32%, clay 26% (1 sample); carbonate 25% and ca/dol 2.2 (average 3 samples); elongate pebbles trend west-southwest	3.1	(10)	7.9	(26)
Minnedosa	1	Till: oxidized dark yellowish brown (10YR 4/4); compact; jointed; sand 42%, silt 30%, clay 28% (1 sample); carbonate 21% and ca/dol 2.2 (average 3 samples); pebbles trend west-southwest; this unit initially was identified as Shell Till (Klassen, 1969, p. 10)	3.1	(10)	11.0	(36)

Section 22

This section on the Duck Mountain upland is from a borehole (2-69), in the road ditch (SE ¼ LSD 1, sec. 29, tp. 30, rge. 28) opposite the entrance to an abandoned school yard.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Undivided	14	Silt, sand, and gravel: interbedded	37.8	(124)	37.8	(124)
Undivided	13	Till: unoxidized dark grey (5Y 4/1); sand 38%, silt 40%, clay 22%; carbonate 27% and ca/dol 0.7 (average 2 samples)	10.1	(33)	47.9	(157)
Undivided	12	Gravel	7.6	(25)	55.5	(182)
Undivided	11	Till: unoxidized very dark grey (5Y 3/1); sand 41%, silt 30%, clay 29%; carbonate 30% and ca/dol 0.7 (average 3 samples)	19.5	(64)	75.0	(246)
Undivided	10	Clay: dark olive grey (5Y 4/1); calcareous dense, greasy	0.9	(3)	75.9	(249)
Undivided	9	Till: unoxidized olive grey (5Y 4/2); sand 43%, silt 31%, clay 26%, carbonate 32% and ca/dol 0.7 (1 sample)	4.6	(15)	80.5	(264)
Tee Lakes ?	8	Gravel and sand	18.9	(62)	99.4	(326)
Tee Lakes ?	7	Silt and sand	11.0	(36)	110.4	(362)
Tee Lakes ?	6	Clay: dark grey (5Y 4/1); calcareous; dense, greasy	13.4	(44)	123.8	(406)
Tee Lakes	5	Till: unoxidized dark grey (5Y 4/1); sand 33%, silt 36%, clay 31% (average 5 samples); upper 4.5 m zone, carbonate 14% and ca/dol 1.0 (1 sample), lower zone, carbonate 23% and ca/dol 1.1 (average 4 samples)	17.4	(57)	141.2	(463)
Largs	4	Silt, sand and gravel	1.5	(5)	142.7	(468)
Largs	3	Till: unoxidized dark grey (5Y 4/1); very hard; sand 33%, silt 39%, clay 28%; carbonate 16% and ca/dol 1.2 (average 2 samples)	22.6	(74)	165.2	(542)
Wynyard ?	2	Sand and silt: olive grey (5Y 4/2); fairly hard and compact; calcareous; thinly bedded; stony zones composed mostly of carbonate and some chert	32.9	(108)	198.2	(650)
Riding Mountain	1	Shale: very dark grey (5Y 3/1); noncalcareous; waxy	9.1	(30)	207.3	(680)

Section 23

This section is from a borehole (3-69) near the entrance to an abandoned school yard (SW ¼ LSD 4, sec. 1, tp. 35, rge. 28) 1.5 km west and 3 km south of Kenville, Manitoba.

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Arran	9	Silt: oxidized light olive brown (2.5Y 5/4) or olive brown (2.5Y 4/4); calcareous; massive	3.7	(12)	3.7	(12)
Arran	8	Clay: oxidized olive brown (2.5Y 4/4); mottled appearance; calcareous; scattered bits of carbonaceous detritus	3.4	(11)	7.0	(23)
Arran	7	Gravel and sand: high in shale clasts	1.5	(5)	8.5	(28)

Formation	Unit no.	Description	Unit thickness m	(ft)	Total depth m	(ft)
Undivided	6	Till: unoxidized very dark grey (5Y 3/1); sandy; carbonate 19% and ca/dol 0.7 (average 8 samples)	5.8	(19)	14.3	(47)
Undivided	5	Shale: very dark grey (5Y 3/1); noncalcareous; fairly soft; includes thin beds of till	4.0	(13)	18.3	(60)
Undivided	4	Till: very dark grey (5Y 3/1); sandy; carbonate 21% and ca/dol 0.8 (average 6 samples); includes thin beds of olive grey (5Y 4/2) till	8.2	(27)	26.5	(87)
Undivided	3	Till: unoxidized olive grey (5Y 4/2); hard; sandy; carbonate 29% and ca/dol 1.1 (average 7 samples)	14.9	(49)	41.5	(136)
Undivided	2	Gravel and sand	1.2	(4)	42.7	(140)
Vermilion River	1	Shale: very dark grey (5Y 3/1); fissile in part; hard zones; white specks in places; calcareous; thin bentonitic beds	12.2	(40)	54.9	(180)

Section 24

This section is from a borehole (4-69) in the road ditch (NE ¼ LSD 13, sec. 8, tp. 35, rge. 28) about 7 km north of Durban, Manitoba.

Arran	8	Silt: oxidized dark greyish brown (2.5Y 4/2), olive brown (2.5Y 4/4), or brown (10YR 5/3); massive; scattered bits of plant detritus; highly calcareous, with blebs in lower zone	9.5	(31)	9.5	(31)
Arran	7	Clay: unoxidized dark grey (5Y 4/1); massive or laminated; calcareous	11.0	(36)	20.4	(67)
Arran	6	Till: oxidized very dark greyish brown (10YR 3/2); sandy; carbonate 43% and ca/dol 0.7 (1 sample)	3.4	(11)	23.8	(78)
Undivided	5	Silt, sand and gravel: interbedded	9.8	(32)	33.5	(110)
Undivided	4	Till: unoxidized dark olive grey (5Y 3/2); very hard; sandy; carbonate 21% and ca/dol 1.0 (1 sample)	0.9	(3)	34.5	(113)
Undivided	3	Silt and sand: unoxidized olive grey (5Y 4/2); calcareous	2.1	(7)	36.6	(120)
Undivided	2	Till and shale: unoxidized very dark grey (5Y 3/1); clayey; very hard; carbonate 10% and ca/dol 0.6 (3 samples); some shale stringers	1.8	(6)	38.4	(126)
Riding Mountain ?	1	Shale: very dark grey (5Y 3/1); noncalcareous; some white, calcareous specks; waxy zones; bentonitic beds	>22.6	(74)	61.0	(200)

Section 25

This section is from a borehole (6-69) in the road ditch (NE ¼ LSD 13, sec. 8, tp. 35, rge. 28) about 7 km north south of Arran, Saskatchewan.

Arran ?	9	Till: oxidized light yellowish brown (2.5Y 6/4); sandy; carbonate 26% and ca/dol 1.3 (average 2 samples)	1.5	(5)	1.5	(5)
Undivided	8	Till: oxidized olive brown (2.5Y 4/4) or unoxidized very dark grey (5Y 3/1); sandy; carbonate 24% and ca/dol 0.6 (average 6 samples)	4.3	(14)	5.8	(19)
Undivided	7	Silt: unoxidized dark grey (5Y 4/1)	2.7	(9)	8.5	(28)
Undivided	6	Till: oxidized greyish brown (2.5Y 5/2) or dark greyish brown (2.5Y 4/2); sandy; carbonate 22% and ca/dol 0.5 (average 3 samples)	4.6	(15)	13.1	(43)
Undivided	5	Till: unoxidized very dark grey (5Y 3/1); silty; carbonate 18% and ca/dol 0.7 (average 7 samples)	9.5	(31)	22.6	(74)
Undivided	4	Till: unoxidized dark grey (5Y 4/1) or dark olive grey (5Y 3/2); sandy; carbonate 20% and ca/dol 1.3 (average 11 samples)	19.5	(64)	42.1	(138)
Undivided	3	Shale: very dark grey (5Y 3/1); noncalcareous; waxy	4.9	(16)	47.0	(154)
Undivided	2	Till: unoxidized dark olive grey 5Y 3/2); sandy; very hard; carbonate 26% and ca/dol 0.8 (average 3 samples) contains lenses of shale	12.2	(40)	59.1	(194)
Riding Mountain	1	Shale: very dark grey (5Y 3/1) or dark olive grey (5Y 3/2); noncalcareous or calcareous; waxy or fissile	7.3	(24)	66.5	(218)

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