Abstract

The Virden area study is part of the Southern Prairies NATMAP Project. In general, the area is flat and characterized by thick drift. Surface materials consist of till, clay, silt, sand, and gravel. The thickness of drift varies from as little as 1 m, where a single till sheet overlies bedrock, to more than 100 m in buried valleys and where multiple till units are present. During the last glaciation, ice movement was generally towards the southeast. During ice retreat, several glacial lakes formed at the margin of the retreating ice, and a number of catastrophic floods cut spillways and deposited extensive sheets of sand and gravel. The report package includes extensive databases of field-collected information, borehole records, and aggregate data. These databases have been used to produce a wide variety of derived products which include observed surface-material maps, drift-thickness maps etc. These have a number of uses such as showing potential aggregate deposits, making it possible to map aquifers prone to contamination, etc. The package includes innovative software for viewing maps and databases.

Résumé

L'étude de la région de Virden constitue un volet du Projet des Prairies méridionales du CARTNAT. En général, la région est plate et se caractérise par la présence de dépôts glaciaires épais. Les matériaux superficiels comprennent du till, de l'argile, du silt, du sable et du gravier. L'épaisseur des sédiments glaciaires varie d'aussi peu que 1 m, là où une seule nappe de till repose sur le substratum rocheux, à plus de 100 m dans les vallées enfouies et aux endroits où de multiples unités de till sont présentes. Au cours de la dernière glaciation, la glace s'est déplacée en général vers le sud-est. Au cours du retrait de la glace, plusieurs lacs glaciaires se sont formés en bordure de la glace en retrait, et un certain nombre d'inondations catastrophiques ont entaillé des déversoirs et déposés de vastes nappes de sable et de gravier. Le présent rapport inclut de grandes bases de données recueillies sur le terrain, des diagraphies de forage et des données d'ensemble. Ces bases de données ont permis de générer une vaste gamme de produits, par exemple des cartes des matériaux superficiels observés et des cartes de l'épaisseur des sédiments glaciaires. Ces produits sont utilisés notamment pour localiser les éventuels dépôts d'agrégats et pour cartographier les aquifères exposés à la contamination. Le rapport inclut un logiciel novateur pour la visualiation des cartes et des bases de données.

SUMMARY

This study of the Virden map area (NTS 62 F) is part of the Southern Prairies NATMAP Project. This project is a part of the Geological Survey of Canada's National Geoscience Mapping Program (NATMAP). The NATMAP Program was developed at the end of the 1980s as a means of raising the profile, improving the art, and injecting additional resources into geological mapping.

The Southern Prairies NATMAP Project was started in 1992 and completed in 1997. The major goals were 1) to provide maps, reports, and GIS databases that described and explained the surficial materials in areas typical of the Canadian Prairies, and 2) to develop a new generation of field and laboratory protocols, and GIS and computer-database handling techniques that could be used as standards for future work.

An understanding of the nature of materials at the Earth's surface is required for almost every human activity. The following is a list of some of the specific uses that can be made of surficial-geology information such as that gathered through this project: development and protection of groundwater resources; exploration for, and extraction of, mineral, aggregate, and petroleum resources; waste-disposal concerns; soil fertility and degradation concerns; urban development and land-use planning; surface-materials characterization and distribution; deciphering the geological history of the area and the sequence of events and processes that have had an impact on surficial deposits.

This project was done largely through collaboration between Terrain Sciences Division, Geological Survey of Canada, Ottawa; Manitoba Land Resource Unit, Agriculture and Agri-Foods Canada, Winnipeg; Manitoba Water Resources Branch, Winnipeg, Manitoba; Geological Services Division, Department of Energy and Mines, Winnipeg; and Pole Star Geomatics Inc., Ottawa.

This CD-ROM includes all the maps, illustrations, and reports that are normally included in a printed final surficial geological report. In addition, it includes an extensive series of databases that go beyond what is commonly published.

The Virden map area is in the southwestern corner of Manitoba and southeastern corner of Saskatchewan (49° to 50° north latitude and 100° to 102° west longitude). It lies near the eastern edge of the Saskatchewan Plains of the Great Plains of central North America. The maximum relief is about 425 m. In general, the area is flat with glacial spillways as the main local relief features.

Even though the area is characterized by a thick blanket of drift, bedrock plays a role in the regional pattern of relief. The low plain that surrounds Oak Lake

SOMMAIRE

Cette étude de la région cartographique de Virden (SNRC 62 F) constitue un volet du Projet des Prairies méridionales du Programme national de cartographie géoscientifique du Canada (CARTNAT) de la Commission géologique du Canada. Le CARTNAT a été élaboré à la fin des années 1980 dans le but d'augmenter la visibilité de la cartographie géologique, d'en améliorer la qualité et d'y contribuer des ressources supplémentaires.

Le Projet des Prairies méridionales du CARTNAT a commencé en 1992 et s'est terminé en 1997. Les objectifs principaux étaient 1) de fournir des cartes, des rapports et des bases de données de SIG décrivant et expliquant les matériaux superficiels dans des régions types des Prairies canadiennes et 2) d'élaborer une nouvelle génération de protocoles pour les travaux sur le terrain et en laboratoire, et de techniques de SIG et de gestion de bases de données numériques qui pourraient servir de normes pour les travaux à venir.

Presque toutes les activités humaines exigent de comprendre la nature des matériaux à la surface de la Terre. La liste suivante indique certains usages spécifiques que l'on peut faire des données de la géologie des matériaux superficiels comme celles qui ont été recueillies au cours de ce projet : mise en valeur et protection des ressources en eaux souterraines; exploration et extraction des ressources minérales, des ressources en agrégats et des ressources pétrolières; problèmes d'élimination des déchets; problèmes de fertilité et de dégradation du sol; développement urbain et aménagement du territoire; caractérisation et répartition des matériaux superficiels; interprétation de l'histoire géologique régionale et de la série d'événements et de processus qui ont influencé le dépôt des matériaux superficiels.

Ce projet a été mené à bien en grande partie grâce à la collaboration entre la Division de la science des terrains de la Commission géologique du Canada, à Ottawa, la Section des ressources foncières du Manitoba d'Agriculture et Agroalimentaire Canada, à Winnipeg, la Direction des ressources hydrauliques du Manitoba, à Winnipeg, la Direction des services géologiques du ministère de l'Énergie et des Mines du Manitoba, à Winnipeg, et Pole Star Geomatics Inc., à Ottawa.

Ce CD-ROM contient toutes les cartes, toutes les illustrations et tous les rapports généralement inclus dans un rapport final imprimé sur la géologie des matériaux superficiels. De plus, il inclut une vaste collection de bases de données, information qui va au-delà de ce qui est publié habituellement.

La région cartographique de Virden se trouve dans le coin sud-ouest du Manitoba et le coin sud-est de la Saskatchewan (de 49° à 50° de latitude nord et de 100° à 102° de longitude ouest). Elle se situe près de la bordure est de la Plaine de la Saskatchewan qui fait partie de la Région des grandes plaines du centre de l'Amérique du Nord. L'altitude la plus élevée est d'environ 425 m. En général, la région est plate avec des déversoirs glaciaires par endroits comme principales formes de relief.

Même si une épaisse couverture de sédiments glaciaires caractérise la région, le substratum rocheux contribue à la configuration régionale de la topographie. La plaine basse qui ceinture le

occupies a broad low in the bedrock surface, and Turtle Mountain and higher areas in the southwestern corner of the area are bedrock highs. This general distribution of bedrock relief features reflects the physiography of the area prior to the glaciations of the last two million years. The preglacial valley of the Missouri River is thought to enter the southwestern corner of the area and to underlie the general low that extends from that point to Brandon. Other well defined drift-filled valleys have been identified in the Waskada–Medora area and north of Virden. These valleys are good targets for groundwater exploration. The Precambrian basement in the Virden map area is overlain by 1200 to 1600 m of younger rocks. These consist of a largely carbonate sequence of Paleozoic rocks and a succession of Mesozoic and Tertiary clastic rocks.

Oil is obtained largely from the carbonates with the Birdtail–Waskada axis, which appears as a major structural trend that is associated with oil production. The bedrock underlying drift, and locally outcropping, consists largely of late Cretaceous Pierre Formation shales. The southeastern and southwestern corners of the area are underlain by latest Cretaceous and earliest Tertiary sandstones and shales of the Boissevain, Eastend, Whitemud, Battle, Turtle Mountain, Frenchman, and Ravenscrag formations.

At the surface, the soft bedrock weathers readily to a clay or sand that quickly becomes part of the overburden. As a consequence of its soft nature and a generally thick drift cover, bedrock rarely outcrops over a large enough area to be mapped as a surficial unit. Surficial materials in the Virden map area consist of till (sandy silt diamicton), clay, silt, and sand, deposited during glaciations, and silt, clay, and sand deposited during nonglacial time. These generally underlie flat to gently rolling surfaces marked by low rises, ridges, and mounds, but locally underlie hummocky to hilly landforms.

Till layers of different ages commonly underlie the surface with a discontinuous layer of large (up to 1.5 m diameter) faceted boulders at the base of the surface till layer in many places. The thickness of drift varies from as little as 1 m where a single till sheet overlies bedrock, to more than 100 m in buried valleys and where multiple till units are present.

The glacial deposits at the surface were deposited largely by ice that moved southeast across the entire area, but late during the last glacial period, ice moving southwest and westward pushed into the northeast corner of the area. The deposits of the two ice flows are similar lithologically and appear to have not been widely separated in time. Evidence that two different flows occurred is based on distribution and orientation of landforms, minor differences in carbonate content of

lac Oak occupe une vaste dépression à la surface du substratum, et le mont Turtle ainsi que les hautes terres du coin sud-ouest de la région correspondent à des zones élevées du substratum. La configuration générale des formes du relief rocheux reflète la physiographie de la région avant les glaciations des deux derniers millions d'années. On pense que la vallée préglaciaire du fleuve Missouri pénètre dans le coin sud-ouest de la région et se trouve sous la vaste dépression qui s'étend de ce point jusqu'à Brandon. On a reconnu d'autres vallées bien délimitées, remplies de sédiments glaciaires, dans le secteur Waskada-Medora et au nord de Virden. Ces vallées sont des cibles de choix pour l'exploration à la recherche des eaux souterraines. Le socle précambrien de la région cartographique de Virden est recouvert de 1 200 à 1 600 m de roches plus récentes. Ces dernières se composent d'une séquence de roches paléozoïques en grande partie carbonatées et d'une succession de roches clastiques remontant au Mésozoïque et au Tertiaire.

On extrait du pétrole surtout des roches carbonatées dans l'axe Birdtail-Waskada, qui semble être un alignement structural majeur associé à la production de pétrole. Le substratum rocheux sous les sédiments glaciaires affleure par endroits et se compose en grande partie de shale de la Formation de Pierre datant du Crétacé tardif. Les coins sud-est et sud-ouest de la région sont consitués de grès et de shale du Crétacé terminal et du Tertiaire initial des formations de Boissevain, d'Eastend, de Whitemud, de Battle, de Turtle Mountain, de Frenchman et de Ravenscrag.

À la surface, la roche tendre du substratum se désagrège facilement en argile ou en sable qui s'intègre rapidement à la couverture de dépôts meubles. En raison de sa friabilité et de la couche généralement épaisse de sédiments glaciaires qui le recouvrent, le substratum affleure rarement sur une étendue suffisamment grande pour qu'on puisse le représenter comme une entité de surface sur les cartes. Les matériaux superficiels de la région cartographique de Virden comprennent du till (diamicton silto-sableux), de l'argile, du silt et du sable, tous déposés pendant les glaciations, et du silt, de l'argile et du sable déposés pendant des périodes non glaciaires. Ces dépôts forment généralement des surfaces planes ou légèrement ondulées, marquées de faibles élévations, de crêtes et de bosses, mais constituent par endroits des formes de relief en bosses et en creux allant même jusqu'à des reliefs valonnés.

Des couches de till d'âges différents reposent couramment en subsurface, et une couche discontinue de gros blocs (jusqu'à 1,5 m de diamètre) à facettes se rencontre à la base de la couche de till superficiel à de nombreux endroits. L'épaisseur des sédiments glaciaires varie d'aussi peu que 1 m, là où une seule couche de till repose sur le substratum, à plus de 100 m dans les vallées enfouies et aux endroits où de multiples unités de till sont présentes.

Les sédiments glaciaires en surface ont été déposés en grande partie par de la glace qui se déplaçait vers le sud-est, traversant toute la région; toutefois, vers la fin de la dernière période glaciaire, de la glace s'avançant vers le sud-ouest et l'ouest a atteint le coin nord-est de la région. Les dépôts laissés par les deux écoulements glaciaires sont semblables par leur lithologie et ne semblent pas très éloignés dans le temps. Les indications de l'existence de deux écoulements glaciaires distincts s'appuient sur la répartition et l'orientation des formes de terrain, les différences mineures dans la teneur en carbonates des tills et tills, and the glacial history developed for the adjacent Brandon area to the east. Evidence of earlier glaciations is present. Locally, a boulder pavement separates an upper sandy brown till from a lower dark grey, more compact, clayey till, but there is no associated weathered zone that might confirm a prolonged nonglacial interval.

Water wells and other boreholes penetrate more than 100 m of Quaternary materials, but the information obtained from these is not easily interpreted and in many instances even the position of the contact between the drift and bedrock is difficult to determine. In some of the boreholes, stratified materials were encountered between till units, but in the absence of organic materials, it could not be determined whether these were nonglacial in origin.

The Saskatchewan Research Council has used carbonate content, geochemical analyses, and geophysical logs to correlate borehole records of many of the best quality boreholes from this area with the standard Quaternary stratigraphic scheme that is used in Saskatchewan. The results of these correlations are shown in a series of cross-sections that are part of this report and as a series of maps showing the modelled distribution and thickness of individual units.

Little is known of the Quaternary history of the area prior to the last glaciation. Multiple tills and nonglacial deposits of interglacial origin indicate that the area was subject to several glaciations and interglaciations, but the number is unknown. In addition, in several areas, older successions of drift are cut by valleys thought to be of nonglacial origin. A fragment of tusk that apparently came from gravel underlying the surface till indicates that large mammals occupied the area prior to the last ice advance.

Radiocarbon ages and regional considerations indicate that deglaciation occurred between 13 000 and 10 500 years ago, but an exact chronology of ice retreat is not available. Ice first stagnated on Turtle Mountain and hummocky moraine developed while this stagnant ice melted. Evidence from North Dakota indicates that a readvance occurred early during deglaciation. An east-draining glacial lake formed as ice retreated from the eastern and northern flank of Turtle Mountain and expanded westward. Prior to disappearance, this lake drained into south-draining glacial Lake Souris which entered the Virden area from the south. A major overland flood washed over the lower Antler River valley as glacial Lake Souris expanded northward in the Souris River valley. Continuing ice retreat permitted eastward drainage of glacial Lake Souris, which joined with glacial Lake Hind. Glacial Lake Hind was an interlobate lake that began forming in the eastern part of the Virden area between the southward-directed Assiniboine Ice Lobe and westward-directed Red River Ice Lobe.

l'histoire glaciaire reconstituée pour la région adjacente de Brandon à l'est. Des indications de glaciations antérieures sont présentes. Par endroits, un pavage de blocs sépare un till supérieur brun, sablonneux, d'un till inférieur gris foncé, argileux et plus compact, mais on ne trouve pas de zone altérée associée qui pourrait confirmer un intervalle non glaciaire prolongé.

Des puits d'eau et d'autres sondages pénètrent plus de 100 m de matériaux du Quaternaire, mais on ne peut pas interpréter facilement les données fournies par ceux-ci et, dans de nombreux cas, même la position du contact entre les sédiments glaciaires et le substratum est difficile à déterminer. Dans certains des sondages, on a rencontré des matériaux stratifiés entre des unités de till, mais, en l'absence de matière organique, il a été impossible de déterminer s'ils sont d'origine non glaciaire.

Le Saskatchewan Research Council a utilisé la teneur en carbonates, des analyses géochimiques et des diagraphies de puits pour établir des corrélations entre les diagraphies de forage d'un grand nombre des sondages de meilleure qualité forés dans la région, d'une part, et le modèle stratigraphique du Quaternaire habituellement en usage en Saskatchewan, d'autre part. Les résultats de ces corrélations sont illustrés sur une série de coupes transversales qui font partie de ce rapport et sont représentés sur une série de cartes qui montrent la répartition et l'épaisseur modélisées d'unités individuelles.

On connaît peu l'histoire quaternaire de la région avant la dernière glaciation. La présence de nombreux tills et dépôts non glaciaires d'origine interglaciaire indique qu'il y a eu plusieurs périodes glaciaires et interglaciaires dans la région, mais leur nombre demeure inconnu. En outre, dans plusieurs secteurs, des successions plus anciennes de sédiments glaciaires sont coupées par des vallées qu'on croit d'origine non glaciaire. Un fragment de défense provenant semble-t-il de gravier sous le till de surface indique que de grands mammifères ont occupé la région avant la dernière avancée glaciaire.

La datation au radiocarbone et les observations régionales indiquent que la déglaciation a eu lieu il y a entre 13 000 et 10 500 ans, mais on ne dispose pas d'une chronologie exacte du retrait glaciaire. La glace a d'abord stagné sur le mont Turtle et une moraine bosselée s'est formée pendant que cette glace morte fondait. Des observations au Dakota du Nord indiquent qu'une récurrence a eu lieu au début de la déglaciation. Un lac glaciaire se déversant à l'est s'est formé pendant que la glace se retirait des versants est et nord du mont Turtle, puis s'est agrandi vers l'ouest. Avant sa disparition, ce lac se déversait dans le Lac glaciaire Souris, lequel se déversait vers le sud et pénétrait la région de Virden depuis le sud. Une importante inondation terrestre a balayé la vallée inférieure de la rivière Antler alors que le Lac glaciaire Souris s'agrandissait vers le nord dans la vallée de la rivière Souris. Le retrait continu de la glace a permis le déversement vers l'est du Lac glaciaire Souris, qui a fini par d'intégrer au Lac glaciaire Hind. Le Lac glaciaire Hind était un lac interlobaire qui a commencé à se former dans la partie est de la région de Virden entre le Lobe glaciaire Assiniboine à écoulement vers le sud et le Lobe glaciaire Red River à écoulement vers l'ouest. Au cours de la période d'existence du

During the period glacial Lake Hind existed, floods of meltwater entered the lake basin from beneath the retreating ice to the north, from the Souris River valley to the south, and eventually from the north via the Assiniboine River valley. Retreat of the Red River Ice Lobe from the Assiniboine River valley near Brandon permitted glacial Lake Hind to drain eastward into glacial Lake Agassiz.

Immediately following deglaciation, spruce forests apparently occupied the area. Grasslands, however, were soon established and once postglacial conditions were established, climate and vegetation varied little from what we see today. The warmest period of postglacial climate was between 8000 and 6000 years ago and cooler conditions have since prevailed.

Abundant gravel and sand resources were deposited in most parts of the area during retreat of the last ice sheet. One problem with much of the aggregate resources of this area is an abundance of soft shale. The Assiniboine river valley west of Brandon contains a particularly good deposit of gravel at Assiniboine Flats. The area east of where the Assiniboine River enters the area has abundant gravel, but it includes a particularly high content of shale. Good gravel supplies are scarce in the southeastern corner of the area, although there are scattered deposits on the flanks of and within the Turtle Mountain uplands. The basin once occupied by glacial Lake Hind (the area from Oak Lake eastward) has few gravel deposits, although gravel is generally abundant at the margins of the former lake basin.

This report includes data on the geochemistry of surface tills. Till samples were analyzed for twenty-five elements and major element oxides, and for total per cent carbonate values: Al_2O_3, Ba, Be, CaO, $Ca(Mg)CO_3$, Cd, Co, Cr, Cu, Fe_2O_3, K_2O, La, MgO, MnO, Mo, Na_2O, Ni, P_2O_5, Pb, Sr, Th, TiO_2, V, Y, Zn, and Zr. In general, the content of these items has little regional variation. Data on surface-till grain-size distribution and engineering properties are also included.

Groundwater is obtained from sand and gravel lying at the surface, from porous layers within the surficial deposits, and from bedrock. Supplies of water are abundant in surface sediments in the general vicinity of Oak Lake, but because surface or unconfined aquifers are not protected by a sealing layer, they are particularly prone to contamination. Abundant water can be obtained from buried valleys within surficial deposits, but few of these aquifers have been found in this area. Isolated pockets of sand and gravel that are scattered throughout the surficial sediments yield groundwater, but these aquifers are difficult to locate, generally provide small yields, and the water is, in many places, of low quality. Some groundwater can be obtained from the sandy bedrock that underlies the southeastern and southwestern corners of the area, but yields are generally small and quality poor. Water can

Lac glaciaire Hind, des crues d'eau de fonte ont alimenté le bassin du lac depuis le dessous de la glace en retrait au nord, depuis la vallée de la rivière Souris au sud et finalement depuis le nord par la vallée de la rivière Assiniboine. Le retrait du Lobe glaciaire Red River de la vallée de la rivière Assiniboine près de Brandon a permis au Lac glaciaire Hind de se déverser vers l'est dans le Lac glaciaire Agassiz.

Immédiatement après la déglaciation, des pessières auraient occupé la région. Toutefois, des prairies se sont rapidement implantées et, une fois les conditions postglaciaires établies, le climat et la végétation ont peu différé de ce que l'on observe aujourd'hui. La période la plus chaude du climat postglaciaire a eu lieu il y a entre 8 000 et 6 000 ans. Des conditions plus froides ont prévalu depuis lors.

D'abondantes ressources en gravier et en sable se sont déposées dans la plupart des secteurs de la région au cours du retrait de la dernière nappe glaciaire. La plupart des ressources en agrégats présentent un problème d'abondance de shale tendre. La vallée de la rivière Assiniboine à l'ouest de Brandon renferme un dépôt de gravier particulièrement intéressant à Assiniboine Flats. Le secteur à l'est de l'endroit où la rivière Assiniboine entre dans la région recèle une abondance de gravier, mais celui-ci contient une quantité particulièrement élevée de shale. Les réserves de bon gravier sont rares dans le coin sud-est de la région, bien qu'il y ait des dépôts dispersés sur les versants et les hautes terres du mont Turtle. Le bassin autrefois occupé par le Lac glaciaire Hind (du secteur du lac Oak vers l'est) renferme peu de dépôts de gravier, bien que le gravier soit généralement abondant en bordure de l'ancien bassin du lac.

Ce rapport inclut des données géochimiques sur les tills de surface. On a dosé 25 éléments et oxydes d'éléments majeurs et déterminé le pourcentage total de carbonates dans des échantillons de till : Al_2O_3, Ba, Be, CaO, $Ca(Mg)CO_3$, Cd, Co, Cr, Cu, Fe_2O_3, K_2O, La, MgO, MnO, Mo, Na_2O, Ni, P_2O_5, Pb, Sr, Th, TiO_2, V, Y, Zn et Zr. En général, la teneur en ces éléments présente peu de variations régionales. Le rapport inclut aussi des données sur la répartition granulométrique et sur ses caractéristiques géotechniques du till de surface.

On trouve des eaux souterraines dans le gravier et le sable en surface, dans des couches poreuses à l'intérieur des matériaux superficiels et dans le substratum rocheux. Les réserves d'eau sont abondantes dans les sédiments de surface aux environs du lac Oak, mais comme les aquifères en surface ou aquifères libres ne sont pas protégés par une couche imperméable, ils sont particulièrement exposés à la contamination. On peut tirer de grandes quantités d'eau des vallées enfouies dans des matériaux superficiels; cependant, on a trouvé peu de ces aquifères dans la région. Des poches isolées de sable et de gravier, dispersées dans les sédiments de surface, peuvent fournir de l'eau, mais ces aquifères sont difficiles à trouver et ne rendent généralement que de petites quantités d'eau, laquelle est de piètre qualité en de nombreux endroits. On peut tirer une certaine quantité d'eau du substratum arénacé dans les coins sud-est et sud-ouest de la région, mais le rendement est généralement faible et l'eau est de mauvaise qualité. On peut aussi tirer de l'eau de la also be drawn from fractured rock at the top of the shale that underlies much of the area, but here too, yields are limited and quality poor.

The most productive soils in the area are the chernozems. The most fertile of these are the black chernozems developed under a combination of relatively low rainfall and high summer temperatures, and predominantly in areas of grassland and aspen parkland vegetation. These soils are capable of growing wheat, coarse grains, and a wide range of regionally adapted crops. Dark grey chernozems are developed in the cooler more humid mixed forest and grasslands of the Turtle Mountain area. These soils will grow all of the regionally adapted crops found in Western Canada, but the cooler climate prohibits production of special crops requiring a high accumulation of heat units. Groundwater seepage and poor drainage locally lead to soils of limited fertility due to high content of salt and waterlogging. Coarse materials present special problems to agriculture. Where soils are well drained, lack of soil moisture generally limits production; where the water table is high, waterlogging is a problem. However, where these materials are well drained, and a source of water is present, irrigation can provide excellent crops.

roche fracturée qui surmonte le shale présent dans une bonne partie de la région, mais là encore le rendement est limité et l'eau de piètre qualité.

Les sols les plus productifs de la région sont les chernozems. Les plus fertiles d'entre eux, les chernozems noirs, se sont développés dans des conditions réunissant des précipitations relativement faibles et des températures estivales élevées, principalement dans des zones de végétation de la prairie et de la prairie-parc. Ces sols permettent la culture du blé, des céréales secondaires et d'une grande variété de cultures adaptées à la région. Les chernozems gris foncé se sont développés dans des conditions plus froides et plus humides de la forêt mixte et des prairies dans le secteur du mont Turtle. Ces sols permettent toutes les cultures adaptées à la région que l'on trouve dans l'Ouest du Canada, mais le climat plus froid exclut les cultures spéciales qui demandent une grande accumulation d'unités thermiques de croissance. L'infiltration des eaux souterraines et le mauvais drainage limitent par endroits la fertilité des sols en raison de la haute teneur en sel et de l'engorgement du sol. Les matériaux grossiers posent des problèmes particuliers à l'agriculture. En général, là où les sols sont bien drainés, le manque d'humidité dans le sol impose des contraintes à la production; là où le niveau phréatique est élevé, l'engorgement du sol cause des problèmes. Cependant, là où les matériaux sont bien drainés et où on dispose d'une source d'eau, l'irrigation peut permettre d'excellentes récoltes.

INTRODUCTION

NATMAP

The Southern Prairies NATMAP project is a part of the Geological Survey of Canada's National Geoscience Mapping Program (NATMAP). NATMAP was developed at the end of the 1980s as a means of raising the profile of, improving the art of, and injecting additional resources into geological mapping. It was designed to fill gaps in Canada's fundamental geoscience knowledge base; to respond to resource exploitation, environmental, and societal needs; to develop methodologies that exploit digital technologies; and to promote scientific synergy and economy of operation through promotion of integrated projects (St-Onge, 1990). An additional NATMAP objective was to provide training opportunities for Canadian geoscience students. Active and proposed NATMAP projects are now located in all parts of the country.

Southern Prairies NATMAP Project

The Southern Prairies NATMAP Project was started in 1992 and completed in 1997. The major goals of the project were 1) to provide maps, reports, and geographic information systems (GIS) databases that described and explained the surficial materials in two typical areas of the Canadian prairies, and 2) to develop a new generation of field and laboratory protocols, and GIS and computer database handling techniques, that could be used as standards for future work in the Prairies.

Collaboration and integration of disciplines is a prime objective of NATMAP work. Consequently, collaboration and interdisciplinary work have been a major feature of this work. Authors of this report are listed in Table 1. Collaborating organizations are listed in Table 2.

An understanding of the nature of materials at the earth's surface is required for almost every human activity. The following list includes some of the specific uses that can be made of surficial geology information such as that gathered through this project.

Development and protection of groundwater resources;

Exploration for, and extraction of, mineral, aggregate resources, petroleum, and natural gas resources;

Waste disposal concerns;

Soil fertility and degradation concerns;

Urban development and land-use planning;

Materials characterization and distribution information (required for the identification of natural and anthropogenic health hazards);

Deciphering the geological history of the area and the sequence of events and processes that have affected the surficial deposits.

Table 1. Author affiliations and addresses.

Author	Affiliation	Address
R.J. Fulton	Geological Survey of Canada	Terrain Sciences Division, 601 Booth St. Ottawa, Ontario K1A 0E8
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A. Blais-Stevens	Geological Survey of Canada	Terrain Sciences Division, 601 Booth St. Ottawa, Ontario K1A 0E8
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Table 2. Co-operating agencies.

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Saskatchewan Research Council, Resource Technology Division	15 Innovation Blvd., Saskatoon, Saskatchewan S7N 2X8
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Virden map area

Location

The Virden map area (NTS sheet 62 F) occupies the southwestern corner of Manitoba and southeastern corner of Saskatchewan (Fig. 1). It extends from 49 to 50° north latitude and 100 to 102° west longitude.

General physiography

The physiography section of this report outlines the general nature of the area. It is a typical Canadian prairie area and embraces a cross-section of the surficial geology elements that are commonly found in the northern part of the Great Plains. Some of these components and characteristics are areas of thick drift and multiple till sheets, drift-filled valleys cut in bedrock, glacial lake basins, flood-scoured areas, meltwater spillways, areas of hummocky moraine, and areas of thrust till and bedrock.

Industries

Agriculture is the dominant industry in the area. Grain (primarily wheat, oats, barley, and canola) is grown on the better lands. Cattle (beef cows and female horses for pregnant mare urine (PMU)) are raised on sandy and waterlogged areas, such as in the vicinity of Oak Lake, and steeply sloping lands, such as those on the flanks of Turtle Mountain. The Virden area lies at the northeastern margin of the Williston Basin Oil and Gas Province. More than 70 individual oil and gas fields occur in the area (Fig. 2). Production from the Virden area is not large when compared to Western Canada's production as a whole, but the oil produced from the Manitoba part of the area (657 870 m^3 in 1994) constitutes the major portion of the oil produced in the province.

Previous work

This project draws on a body of earlier work. Johnston (1934) prepared the first regional report and map covering this area. Johnston et al. (1948) compiled a map of the surficial deposits of southern Saskatchewan on the scale of 1 inch to 6 miles that included the western part of the Virden map area. The original

62 F NW Pipestone Creek OF 3424	62 F NE Oak Lake OF 3065
62 F SW Gainsborough Creek OF 3425	62 F SE Whitewater Lake OF 3056

Virden (NTS 62 F)

OF 3233 Open File Map Available from the Geological Survey of Canada

Figure 1.

Location map and key to published maps of the Virden map area.

field studies in this sector were made by B.R. Mackay and H.N. Hainstock, and were presented in seven preliminary groundwater reports, by municipality (Mackay and Hainstock, 1936).

From 1946 to 1954, groundwater inventories on municipalities within the Virden and adjacent Brandon map areas were made by E.C. Halstead and J.A. Elson, and were published in a series of water-supply papers by the Geological Survey of Canada (Halstead and Elson, 1948, 1949a, b). In most of these publications, the surface deposits were mapped by Elson and the groundwater data were collected and the report written by Halstead. Elson (1956) included much information pertinent to this area in his Ph.D. thesis and provided an excellent surficial materials map of the area (Elson, 1962). The recession of the last ice sheet from southwestern Manitoba was described by Elson (1958), illustrated by a series of 12 maps showing the successive positions of ice margins, glacial lakes, and drainage lines. Klassen and Wyder (1970) conducted a major drilling project in the area that provided the main stratigraphic records used in this report. Freeze (1962) prepared a groundwater probability map that covered the eastern half of the area, and Meyboom (1966a) prepared a similar map that covered the western half. Betcher (1983) published a regional synthesis of groundwater data, the Manitoba Water Control and Conservation Branch (1968) assessed the groundwater availability for the south-central part of the map area, and Kohut (1972) and Bakhtiari (1971) wrote groundwater-related theses on parts of the area. Aggregate-related maps were prepared for the entire Manitoba part of the area by Aggregate Resource Section (1980) and Manitoba Energy and Mines (1988). Detailed aggregate reports and maps were prepared by H. Groom (1987a, b; 1993, 1994). A soils map for the Saskatchewan part of the area was prepared by the Saskatchewan Institute of Pedology (1987). Published soils information for the Manitoba part of the area includes Ehrlich et al. (1956) and Eilers et al. (1978). Eilers (1973) wrote an M.A. thesis that is a hybrid study relating to both soils and groundwater.

In addition to work that has been done within the Virden map area, reference has been made to work in adjacent areas. Adjacent maps include those by Elson (1960) to the east, Klassen (1979) to the north, Christiansen (1956) and Whitaker (1974) to the west, and Moran et al. (1985) and Bluemle (1989) to the south. Geological reports on surrounding areas include, Klassen, (1975 and 1979) and Bluemle (1985, 1989). Groundwater information for surrounding areas includes publications by Halstead (1959) to the east and Randich and Kuzniar (1984) to the south.

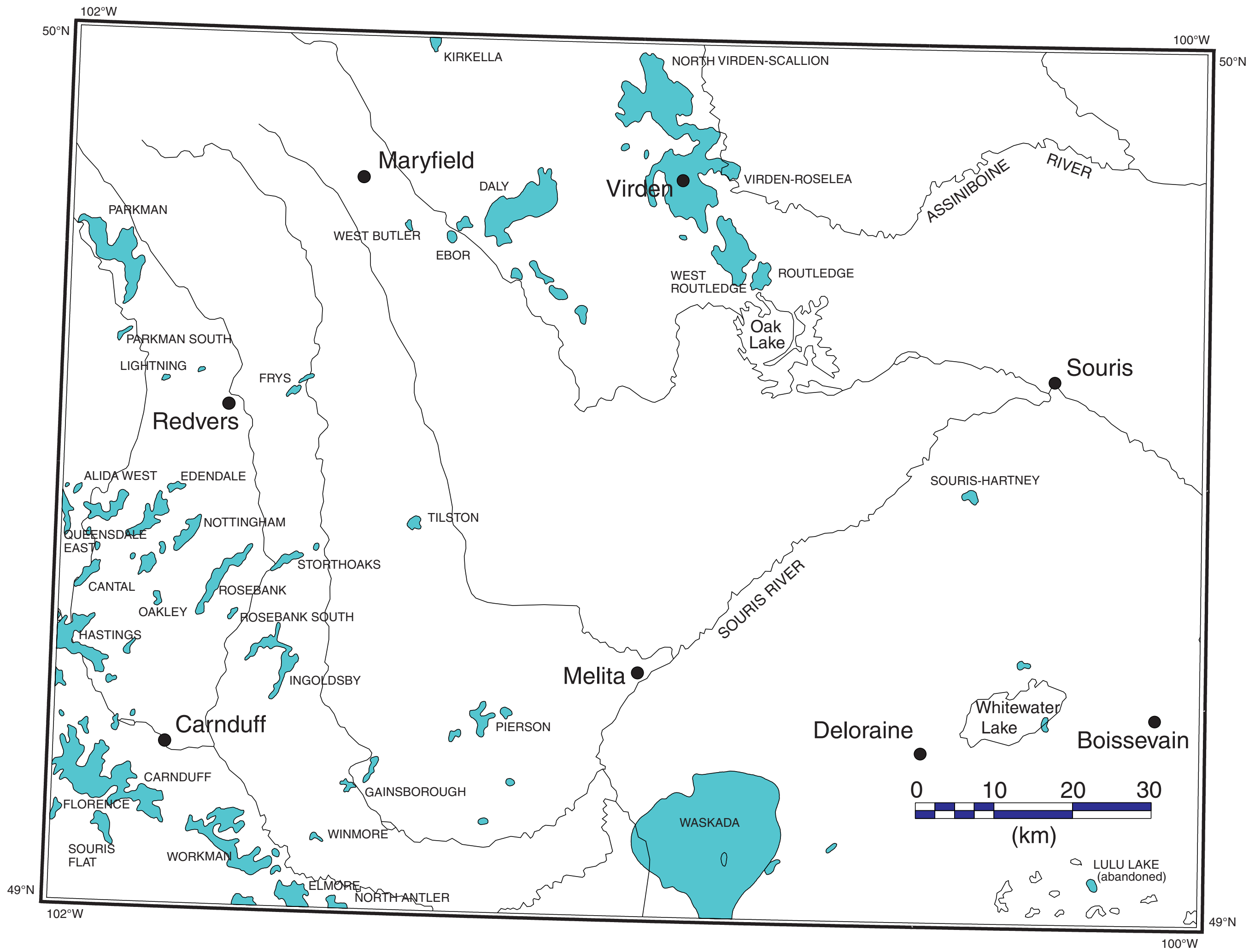


*Figure 2. Oil fields in the Virden map area (*after *Wallace-Dudley, 1991). Blue-shaded areas are oil fields.*

Division of labour

C. (Stephen) Sun, University of Manitoba, conducted field mapping in NTS map areas 62 F/02, 03, 07, 08, 09, 10, 15, and 16 and used the information gathered to write a Ph.D. thesis that was presented at the University of Manitoba (Sun, 1996). Many items from this thesis, such as samples, maps, and figures, have been used in this report. A. Blais-Stevens conducted field mapping in NTS map areas 62 F/03, 04, 05, 06, 11, 12, and 13, was responsible for interpretation of analytical results, and prepared the geochemical part of this report. Towards the end of the project, she supervised the complete restructuring of the bulletin in CD format. R.J. Fulton was the overall project co-ordinator, conducted field mapping in 62 F/01 and 14, and prepared the parts of this report not ascribed to anyone else. R.G. Eilers, H. Veldhuis, and W.R. Fraser were responsible for the agricultural soils input and R. Betcher for the hydrogeology. J.A. Elson provided an unpublished manuscript summarizing his work in southwestern Manitoba. This manuscript was liberally drawn on for all parts of this report.

Acknowledgments

Able assistance in the field was provided by J. Bjornson, B.R. Spence, K. Hodge, M. Taylor, E. Keane, and S.W. Wetherup. L. Murray of Environmental Earth Science Associates, Calgary, Alberta, aided in the construction of the initial borehole database, extracted borehole records from the databases maintained by the Manitoba Water Resources Branch and Saskatchewan Water Corporation, and put aggregate information from the Manitoba Highways Department and Manitoba Energy and Mines into a digital database. B.T. Schreiner, M. Millard, and M. Simpson, Saskatchewan Research Council, provided advice on the correlation of borehole records in the area covered by this project with the Quaternary stratigraphic scheme used by the Saskatchewan Research Council, and tested electromagnetic profiling as a means of tracing buried valleys. M. Ballard of Pole Star Geomatics was responsible for software development and integration, and for modifying and loading the data files that are presented on this CD-ROM. J.D. Hughes and W.J. Hughes, Geological Survey of Canada, Calgary, used their layer-modelling system to prepare a three-dimensional model of the drift and to prepare gridded data for preparation of isopach and interval maps. G. Lelyk, Manitoba Land Resource Unit, Brandon Research Centre, Research Branch, Agriculture and Agri-Food Canada, Winnipeg, helped in preparation of the digital soils maps. R.W. Klassen, retired, Geological Survey of Canada, provided invaluable general information on the Quaternary stratigraphy of southwestern Manitoba, and borehole logs and samples from the stratigraphic drilling project that he, in conjunction with J.E. Wyder, conducted in the area 1967 and 1968. J.A. Elson, formerly of McGill University, generously provided all information he collected while working in the area between 1952 and 1955. Many others provided information on scientific aspects of this project. G. Matile and H. Groom, Manitoba Energy and Mines, provided information and critique of the aggregate part of this report; F. Haidl, Saskatchewan Energy and Mines, and C.D. Martiniuk, Manitoba Energy and Mines, provided information on the oil industry in Saskatchewan and Manitoba; J. Bamburak provided information on the bedrock stratigraphy of the area. Database management and computer graphics were provided by M. Pyne. Satellite-image processing was carried out by J. Paquette. H. Thorleifson critically reviewed the bulletin and provided helpful comments and suggestions.

Data on CD-ROM

This CD-ROM includes all the maps, illustrations, and reports that are normally included in a printed final surficial geological report. In addition, it includes an extensive series of databases that go beyond what is commonly published. Table 3 lists the maps, databases, and illustrations available on the CD-ROM. Comments and suggestions concerning this CD-ROM should be directed to A. Blais-Stevens, Geological Survey of Canada, 601 Booth St. Ottawa, Ontario, K1A OE8; email: ablais@nrcan.gc.ca.

BEDROCK GEOLOGY

Introduction

The Virden area lies at the eastern edge of the Williston Basin of the Interior Platform tectonostratigraphic province of Western Canada (Fig. 3); (Stott and Aitken, 1993a). The succession consists of a basement of Precambrian rocks overlain by a gently westward-dipping succession of Paleozoic, Mesozoic, and Tertiary sedimentary rocks. A regional picture of the geology of the area can be obtained from Stott and Aitken (1993b) and Mossop and Shetsen (1994). Other sources of information related to the bedrock geology of the Virden map area include a study of the Cretaceous rocks of the Manitoba escarpment (McNeil and Caldwell, 1981) and a report on the latest Cretaceous and Tertiary stratigraphy of Turtle Mountain (Bamburak, 1978). Additional information on the subsurface geology can be obtained from reports of the Manitoba Energy and Mines Petroleum Branch (e.g. Martiniuk and Barchyn, 1993), Saskatchewan Energy and Mines (e.g. Kendall, 1976), and from transactions of the Williston Basin Symposia (e.g. Husain, 1991).

Precambrian basement

In the Virden area, the Precambrian basement lies from 1200 to more than 2600 m below the surface (Wright et al., 1994). The eastern part of the area is underlain by the Superior Province, the western part by the Trans-Hudson Medial Zone of the Churchill Province, and the two are separated by the Thompson magnetic quiet zone (Burwash et al., 1993). The various structural units of the Precambrian basement each reacted slightly differently to later tectonic forces (McCabe, 1967). This influence of the underlying basement on later sequences is best seen in the Birdtail–Waskada Axis, a zone of anomalous stratigraphy and structure that overlies the suture between the Churchill and Superior provinces (Dietrich et al., 1996).

Phanerozoic stratigraphic succession

The Virden map area lies at the northeastern corner of the Williston Basin (Fig. 3). The Williston Basin was a depocentre that lay near the eastern edge of the Western Canada Basin (Stott and Aitken, 1993c). The basin had its inception during the Early Ordovician and was intermittently downwarped and received sediment during the Paleozoic and Mesozoic. It has been referred to as both an intracratonic and cratonic basin. It is defined by the distribution of its Middle Ordovician rocks, but contains older deposits. The geological development of the basin can best be described through the use of sedimentary sequences (Sloss, 1963).

Sauk Sequence

The Sauk Sequence was deposited from the end of the Precambrian until the beginning of the Middle Ordovician. During this time, the Williston Basin did not exist as a depocentre, but instead received sediment as part of the Western Canada Basin (Aitken, 1993). The materials deposited in this part of the basin at this time generally consisted of fine-grained clastic rocks (Deadwood Formation) about 60 m thick (Martiniuk and Barchyn, 1993). Erosion at the close of the Sauk removed some of this unit and trimmed its eastern limit to approximately a line drawn form Wascada to the northwestern corner of the map area (Slind et al., 1994).

Tippecanoe Sequence

Tippecanoe depositional sequence was deposited from the Middle Ordovician until the Early Devonian. Deposition in the Williston Basin began with the transgressive Winnipeg sandstone (about 70 m thick). This was overlain by the dolomite, limestone, and minor argillaceous beds of the Red River, Stony Mountain and Stonewall formations and the Interlake Group. These sedimentary rocks have an aggregate thickness of about 440 m (Martiniuk and Barchyn, 1993). These rocks underlie the entire Virden area and extend to the current margin of the Precambrian Shield (Fig. 3). Tippecanoe deposition was followed by widespread erosion.

Table 3. Maps and databases included on this CD-ROM.

Data category	Name	Description	Source
Map	Surficial geology	Shows the materials that underlie the surface and groups them according to their origin. (Display surficial geology map 62 F SE,62 F_NE, 62 F NW, 62 F SW.)	Sun and Fulton, 1995a, b; Blais-Stevens and Fulton, 1997; Blais-Stevens et al., 1997
	Spot surface materials	Shows materials within 1 m of surface as observed in field or recorded in borehole record. (Display spot surficial materials map 62 F BORDAT, 62 F_FIELDAT.)	This report.
	Bedrock geology	Shows the distribution of bedrock that underlies the surficial materials. (Display bedrock geology map.)	Betcher, 1983; Bambuak, 1978; Whitaker, 1974
	Aquifers	Map showing location of the main known aquifers. From information provided by Manitoba Water Resources Branch and Saskatchewan Research Council. (Display aquifer map.)	This report.
	Soil taxonomy	Shows the distribution of soils subdivided by order and great group and into 3 texture groups. (display soils map 62 F SE, 62 F NE, 62 F NW, 62 F SW.)	Manitoba Land Resource Unit
	Bedrock surface	Contour map showing the elevation of bedrock based on information contained in the borehole database. (Display bedrock surface.)	This report.
	Stratigraphic unit isopach maps	Maps showing the extent and thickness of the seven stratigraphic units that have been recognized. (See stratigraphic unit isopach maps, SSD, Battleford, Floral, Warman, Suther_B, Suther_A, Empress.)	This report.
	Aquifer materials content	Shows the proportion of sand and gravel that the borehole database suggests lies within the specified depth intervals. (See aquifer materials content map, 0–5 m, 0–10 m, 0–20 m, 0–30 m, 0–40 m, 0–50 m, 0–60 m, 0–70 m, 0–80 m, 0–90 m, 0–100 m, 0–120 m, 5–10 m, 10–20 m, 20–30 m, 30–40 m.)	This report.
	Natural aggregate suitability	This is a derived map that shows one interpretation of the suitability of the various surficial materials deposits as sources of natural aggregate. (Display aggregate suitability map 62 F SE, 62 F NE, 62 F NW, 62 F SW.)	This report.
	Atterberg limits	Shows the Atterberg limits for analyzed till samples. (Display Atterberg limit map.)	This report.
	Till texture	Shows sand, silt, and clay content for analyzed till samples. (Display till texture map.)	This report.
	Pebble count	Shows proportions of pebbles from various sources for analyzed till samples. (Display pebble count map.)	This report.
	Analyses	Maps showing geochemical information included in the FIELDAT database. (Display analyses maps Al_2O3, Fe_2O_3, CaO, $CaCO_3$, MgO, K_2O, Na_2O, Ni, Pb, Mo, P_2O_5, Zn, Cd, Co, MnO, Cr, V, Be, Cu, TiO_2, Zr, Y, La, Th, Sr, Ba, and $CaCO_3$.)	This report.
Databases	BORDAT	Database containing borehole records. Accessed by clicking on a borehole site. (Display borehole data.)	GWDrill (ND)
	FIELDAT	Database containing information gathered during field mapping. Accessed by clicking on a field observation site. (Display field data.)	This report.
	AGGDAT	Database containing aggregate information from files of Manitoba Department of Highways and Aggregate Unit of Manitoba Energy and Minerals. Accessed by clicking on a gravel pit symbol. (Display aggregate data.)	This report.
Stratigraphic cross-section	Cross-section	Cross-sections showing the subsurface extent of surficial geology stratigraphic units. (Display cross-section index map; display Fig. 11–50.)	This report.

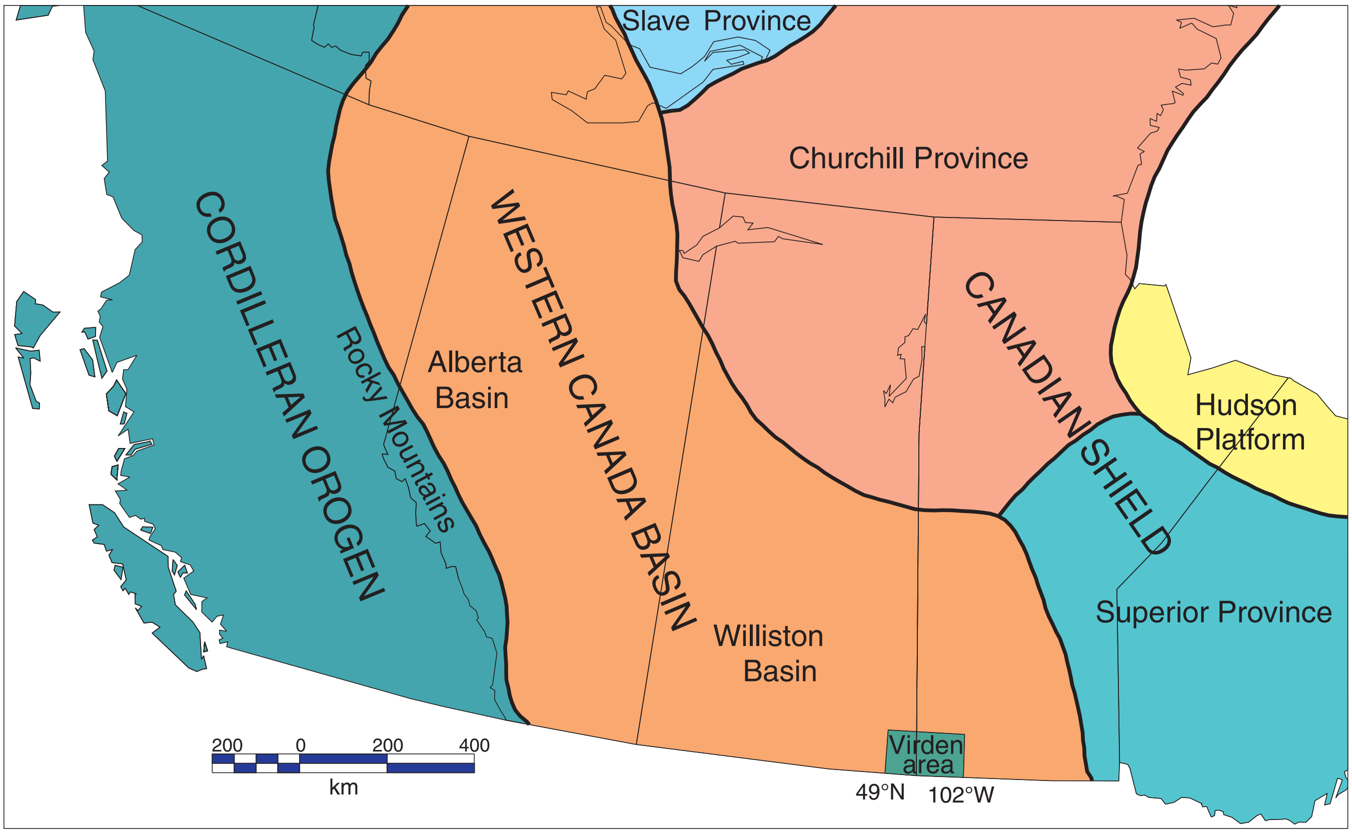


Figure 3. *Main geological provinces of western Canada.*

Kaskaskia Sequence

Deposition of the Kaskaskia Sequence began during the Middle Devonian and lasted through most of the Mississippian. The main geological units formed during this depositional cycle were the Elk Point, Manitoba, Saskatchewan, and Qu'Appelle groups, followed by the Bakken Formation and the Madison Group. Aggregate thickness is about 790 m (Martiniuk and Barchyn, 1993). These rocks are mainly carbonate units, but in the area west of the Birdtail–Waskada Axis, the Elk Point Group includes more than 50 m of salt and other evaporites.

The Kaskaskia was followed by a major period of erosion that resulted in relief of as much as 250 m (Stott, 1955). Rocks of the Absaraka Sequence (end of Mississippian to Middle Jurassic) are missing from the area. It is not known how much of this was due to erosion and how much to nondeposition.

Zuni Sequence

The Zuni Sequence was deposited from the Middle Jurassic until the early Paleocene. Stratigraphic units recognized in the Zuni Sequence succession are the Watrous (also Amaranth), Reston, Melita, Waskada, Ashville, Favel, Morden, Niobrara, Pierre, Boissevain (Eastend, Whitemud, and Battle) and Turtle Mountain (Frenchman and Ravenscrag) formations (Poulton et al., 1993; Stott et al., 1993; McNeil and Caldwell, 1981; Bamburak. 1978). The basal part of this succession consists of redbeds and evaporite units that pass upwards into shale and minor carbonate units. The total thickness of this succession varies from about 870 to 1250 m in the Virden area. The upper part of this unit outcrops locally, and consequently is described in more detail below. The units described below are the upper part of the Cretaceous strata and the lowest part of the Tertiary strata. For a complete description of the Cretaceous rocks in the area, the reader is referred to McNeil and Caldwell (1981). For a description of the Tertiary rocks, the reader is referred to Bamburak (1978)

Morden Formation

Formerly, this was a member of the Vermillion River Formation (Fig. 4), but was elevated to Formation rank by McNeil and Caldwell (1981). Outcrop or subcrop at the base of the drift in this area is limited to a small area in the Assiniboine River valley near Brandon (approximate elevation of the top of the Morden is 350 m (Bamburak, 1996)). This formation is a noncalcareous, dark grey to black, carbonaceous shale. As described by Wickenden (1945, p. 34) the Morden Shale is "fairly soft, somewhat fissile, dark grey non-calcareous shale that contains large ellipsoidal septarian concretions". Crystals of selenite are common. The concretions, some as large 3 m in diameter, are concentrated in zones. The Morden Formation is about 65 m thick in this area (Bamburak, 1996).

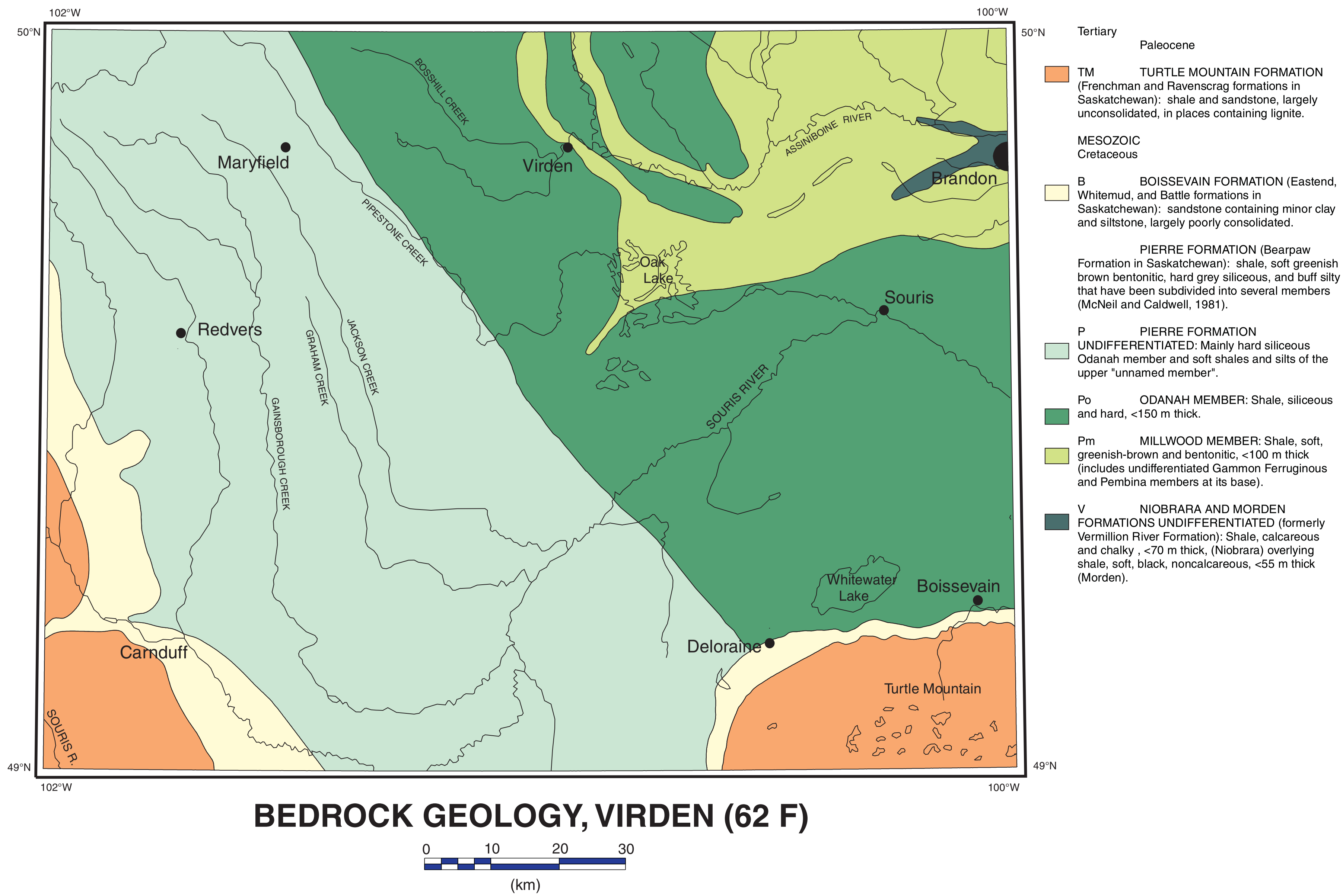


Figure 4. *Bedrock geology of the Virden map area.*

Niobrara Formation

The Niobrara Formation, formerly the Boyne Member of the Vermillion River Formation, was elevated to formation status by McNeil and Caldwell (1981). It is exposed or subcrops at the base of the drift in the Assiniboine River valley near the eastern edge of the area (*see* bedrock geology map). This grey and buff, chalky, calcareous shale is also known as the 'First White Speckled Shale'. It contains thin bentonite layers throughout. The Niobrara is about 45 m thick (Bamburak, 1996).

Pierre Formation

The shale units overlying the Niobrara Formation have been renamed the Pierre Formation (McNeil and Caldwell, 1981). Prior to that they were referred to as the Riding Mountain Formation (Wickenden, 1945). They had been originally referred to as the Pierre Formation by Tyrrell (1890). According to McNeil and Caldwell (1981), the maximum preserved thickness of the Pierre Formation is 500 m. Complete successions of the formation are present under Turtle Mountain and Moose Mountain, where it is overlain by younger Cretaceous rocks. Because of its generally soft nature, exposures of shale quickly weather to a clay that is difficult to distinguish from Quaternary sediments. The general lack of Pierre Formation outcrops makes producing a map which accurately shows the distribution of the various formation members difficult. The map used in this report follows Manitoba Mineral Resources Division (1979) and Whitaker (1974). Contacts over much of this map are based on logs from water wells and other boreholes.

The Pierre Formation has been subdivided into the Gammon Ferruginous, Pembina, Millwood, and Odanah members, with unnamed beds at the top (McNeil and Caldwell, 1981). In the eastern half of the Virden area, the Pierre Formation is subdivided into two members, the Odanah and Millwood members, but in the western part, the formation is left undivided. In the western part of the area, drift is thick, outcrops are largely missing, and the Odonah Member, which in the east is siliceous, resistant, and distinctive, appears to blend in with the underlying Millwood Member (Stott et al., 1993).

The Gammon Ferruginous Member is a dark, blocky fracturing shale containing ferruginous (ironstone) concretions. It was once a member of the now-discarded Vermillion River Formation (McNeil and Caldwell, 1981). It reaches a maximum thickness of 55 m in southwestern Manitoba, but is absent in the Manitoba Escarpment east of the map area (McNeil and Caldwell, 1981). This member was not included as a unit on the bedrock geology map of the area.

The Pembina Member was once a member of the now-discarded Vermillion River Formation (McNeil and Caldwell, 1981). It is variable in thickness (6 to 27 m) and consists of interlayered black marine shales and buff bentonitic shales. It occurs in outcrop or subcrops at the base of the drift only in a small area near where the Assiniboine River leaves the map area. On the bedrock geological map it has been lumped with the overlying Millwood Member (*see* bedrock geology map).

The Millwood Member is a 23–76 m succession of soft, greenish-grey, bentonitic, waxy, noncarbonaceous, silty-clay shales (Bamburak, 1978). Locally, the Millwood Member includes abundant ironstone concretions. It occurs in outcrop and subcrops at the base of drift largely in the Assiniboine River valley and in an area adjacent to the Assiniboine River at the eastern edge of the area (*see* bedrock geology map). Because of its soft nature, the Millwood Member slumps readily. Where deep valleys have been cut into this unit, rotational slumping occurs. This can be seen along the Assiniboine River valley (*see* surficial geology map 62 F/NE).

The Odonah Member is a hard, olive-grey, siliceous shale that is up to 150 m thick (McNeil and Caldwell, 1981). Purple-stained ironstone concretions are distributed irregularly through the shale, and purple staining of the rock itself is common. Most Odonah Shale beds are massive and break into fissile fragments when weathered. Locally, the rock forms cliffs and, where drift is thin, it constitutes the cores of glacially moulded ridges. This hard shale is the most competent rock in the area and forms a large proportion of the shale pebbles in glacial deposits. The Odonah shale is mapped largely in the eastern part of the area, but not in the western part because, as mentioned above, it appears to lose its distinctive properties in that part of the area (*see* bedrock geology map).

Bentonitic, soft, silty-clay shales, 45 to 60 m thick were noted above the Odonah by Bannatyne (1970). Bamburak (1978) referred to these beds as the Coulter member. McNeil and Caldwell (1981) did not recognize this as a formal subdivision and instead referred to it as the 'Unnamed Member' because a type section was not designated, and too little was known about regional distribution of the beds and their relationship to other units.

Boissevain Formation (also Eastend, Whitemud, Battle and Frenchman)

The uppermost Cretaceous unit in the area is the Boissevain Formation. This resistant unit forms a lithological terrace around the northern side of Turtle Mountain. It consists of up to 45 m of medium-grained 'salt-and-pepper' sand, with minor interbedded shales and ironstone concretionary layers, (Bannatyne, 1970; *see* bedrock geology map). The largely poorly consolidated Boissevain Formation is greenish grey and weathers to a rusty yellow. Locally, lenses are cemented to form a hard rock suitable for use as building stone. The unit is conformable with the underlying Pierre Formation, and is said to represent an offlap series consisting of deposits representing marginal marine and possibly terrestrial environments (Stott et al., 1993).

Poorly exposed and poorly consolidated sandstones and shales overlie the upper Cretaceous shales in the southwestern corner of the map area. These units conformably overlie the Bearpaw Formation shale (correlates with the Pierre Formation) of southern Saskatchewan (Stott et al., 1993). The succession is mapped as a single undifferentiated unit, but is described as consisting of fine-grained sand and silt of the Eastend Formation (at the base), kaolinitic sandstone, silt and clay of the Whitemud Formation, clays of the Battle Formation, and interbedded sand, silt, and clay, with local concretionary zones, of the Frenchman Formation (Whitaker, 1974). Bamburak (1978), correlates the lower three of these with the Boissevain Formation, and the Frenchman Formation with the Goodlands Member of the overlying Turtle Mountain Formation. However, on the bedrock-map geology that accompanies this report, this undifferentiated unit is shown as being entirely equivalent to the Boissevain Formation (*see* bedrock geology map).

Turtle Mountain Formation (also Ravenscrag)

The Turtle Mountain Formation is a series of poorly consolidated shales, sandstones, and lignite-bearing beds that overlie the Boissevain Formation in the Turtle Mountain area (Wickenden, 1945). According to Bamburak (1978) this formation, which is conformable with the underlying uppermost Cretaceous beds, is Paleocene. Bamburak subdivided the Turtle Mountain Formation into two members. The Goodlands Member is about 40 m thick and consists of nonmarine bentonitic carbonaceous sands, silts, and clays, including lignite seams ranging between 0.15 and 1.83 m (Bamburak, 1978). This lignite was locally mined and has been reported on by Dowling (1921). The Peace Garden Member is about 100 m thick and is made up of marine silty clay with minor, thin, very fine-grained sand beds (Bamburak, 1978).

The Ravenscrag Formation underlies glacial deposits in the extreme southeastern corner of the map area (Whitaker, 1974). Bamburak (1978) correlated the Ravenscrag Formation with the Peace Gardens Member of the Turtle Mountain Formation, and the Frenchman Formation, which underlies the Ravenscrag, with the Goodlands Member of the Turtle Mountain Formation. Whitaker (1974) did not differentiate the Frenchman Formation from the Eastend, Whitemud, and Battle formations. Because of this, the bedrock geology compilation accompanying this report shows the Turtle Mountain Formation in Manitoba as being equivalent to only the Ravenscrag Formation in Saskatchewan (*see* bedrock geology map).

Structural geology

The sedimentary succession in this part of the Williston Basin is characterized by a gentle regional dip to the southwest. A detailed examination of the isopach and structure contour maps indicates that there are small anomalies that may be due to major structural features in the underlying basement (McCabe, 1967). The premise is that the structural grain of the underlying Precambrian rocks has influenced the way in which the basin floor reacted in response to tectonic forces.

One of the prime features of the Precambrian basement that appears to have affected the overlying Phanerozoic succession is the Superior–Churchill boundary zone. The belt overlying this feature is referred to as the Birdtail–Waskada Axis (McCabe, 1967). The effect of this feature is most notable in rocks that postdate the Middle Devonian, which contain a large number of structure and isopach anomalies in the vicinity of the Birdtail–Waskada Axis. It apparently marks the western edge of the Winnipegosis fringing reefs, and the eastern edge of the Prairie Evaporite salt basin (McCabe, 1967). Martiniuk and Barchyn (1993) emphasized that salt removal and collapse is most evident along and near the Birdtail–Waskada Axis. They specifically commented on multiple-stage salt solutioning and 'compensated thickened' sections in pre-Mississippian beds that are commonly coincident with the Birdtail–Waskada Axis, and numerous structural and isopach anomalies in the Upper Mississippian strata. Martiniuk and Barchyn (1993) also mentioned significant faulting and isopach anomalies that are ascribed to a meteorite-impact structure near Hartney.

Glacial tectonics in the form of ice thrusting appears to have affected bedrock on the western side of Turtle Mountain. Unfortunately, much of the area is forest covered, and exposures are scarce, so it is difficult to determine the extent of disruption. Major topographic ridges are, however, present in the area — lineations that probably trace the edges of northeast-southwest-trending lithological units can be seen on air photos of the western edge of the area, and a small pit in the area of lineations exposes sheared blocks of Boissevain Formation sandstone interbedded with till, sand, silt, and gravel. In addition, linear thrust ridges that show a north-south orientation occur on the North Dakota side of the international border (Bluemle, 1985). Information that confirms that bedrock has been glacially disrupted in the western part of Turtle Mountain has been provided by a stratigraphic drilling program of Manitoba Energy and Mines 1976–1978 (Bamburak, pers. comm., 1996). Core from a hole drilled in the proposed thrust moraine area displayed high-angle shearing in contrast with core from other holes to the east that showed only horizontal partings. In addition, coal was encountered nearer to the surface in the western hole than in other holes in the area, and coal beds near the surface appeared to dip steeply, with dips becoming shallower at depth. Possible candidates for zones of weakness along which thrusting might have occurred are the water saturated Tertiary coal beds, clay beds within the Boissevain Formation, and the top of the Pierre Formation.

Petroleum

The Virden map area lies at the northeastern margin of the Williston Basin Oil and Gas Province. More than 60 individual fields occur in the area (Fig. 2). Production from the 12 fields in the Manitoba part of the Virden area is low (657 870 m^3 in 1994), but this is the province's main producing area. Many fields are present in the Saskatchewan part of the Virden area, but these provide only a small part of Saskatchewan's total production.

Main production in this part of the Williston Basin is from the Lower Carboniferous (Johnson and McMillan, 1993). The first commercial oil well in the Williston Basin was California Standard's Daly well, which began producing oil from the Mississippian Lodgepole Formation in February of 1951. In addition to the Mississippian production, oil is produced from the Lower Jurassic and locally from Ordovician formations. Reservoir lithologies are highly variable and the traps are generally paleotopographic, stratigraphic, or structural/stratigraphic (Kent et al., 1988). In Manitoba, structural and isopach anomalies that are associated with the Birdtail–Waskada Axis have provided traps for a number of fields and provide a promising target for further exploration (Martiniuk and Barchyn, 1993).

Bedrock legend units

Bedrock map

This report includes a bedrock geology map (*see* bedrock geology map). The map was complied from the 1: 1 000 000 scale map of Manitoba (Manitoba Mineral Resources Division, 1979) and the 1:250 000 scale map of the Weyburn map area in adjacent Saskatchewan (Whitaker, 1974). Three correlations were made in combining geology from two the maps. First, the undifferentiated Upper Cretaceous Bearpaw Formation of Saskatchewan was correlated with undifferentiated Upper Cretaceous Pierre Formation of western Manitoba (Stott et al., 1993). Second, the Boissevain Formation of Manitoba (Bamburak, 1978) was correlated with the undifferentiated Eastend, Whitemud, Battle, and Frenchman formations of adjacent Saskatchewan. (From a stratigraphic point of view this correlation is not completely correct because the Boissevain Formation is referred to the uppermost Cretaceous, whereas, the Frenchman Formation is referred to lowermost Tertiary (Bamburak, 1978). This correlation was, however, necessary from a map-compilation point of view, because geological mapping in eastern Saskatchewan did not separate the poorly exposed Frenchman Formation from the underlying uppermost Cretaceous rocks.) Finally, the Turtle Mountain Formation of Manitoba (Bamburak, 1978) was shown as correlating with the Ravenscrag Formation of Saskatchewan. (Once again this correlation is not completely correct because the Turtle Mountain Formation consists of two members, an upper member that correlates with the Ravenscrag Formation and a lower member that correlates with the Frenchman Formation (Bamburak, 1978). However, mapping in Saskatchewan did not differentiate the Frenchman Formation from the underlying uppermost Cretaceous rocks and mapping in Manitoba did not show the areal extent of each member of the Turtle Mountain Formation.). See Table 4 for an explanation of the bedrock map legend.

Surficial geology maps

The surface bedrock throughout the Virden map area is largely soft and weathers readily to a clay or sand that quickly becomes part of the overburden. Bedrock lies at or very near the surface on the floors of some meltwater-carved channels (such as the dry valleys east of the Souris River between Melita and the 49th Parallel and the valley occupied by Chain Lakes), in the walls of some segments of the Assiniboine and Pipestone Creek valleys, and in the escarpment and some of the gullies that mark the northern limit of the Boissevain Sandstone on the flanks of Turtle Mountain. Bedrock rarely outcrops over a large enough area to be mapped as a surficial unit. It is shown as a surficial unit on the northeastern side of the Assiniboine River valley north of Virden where relatively competent Odanah shale has been swept clean of overburden by the floods that cut the Assiniboine River valley. Throughout this same segment of the Assiniboine River valley it makes up much of the valley walls, but as it has largely slumped due to slope failure, it is mapped as colluvium. See Table 5 for a description of the bedrock map unit in the surficial geology map legend.

Table 4. Bedrock map legend.

CENOZOIC **Tertiary** **Paleocene**	
TM	TURTLE MOUNTAIN FORMATION (Ravenscrag Formation in Saskatchewan): shale and sandstone, largely unconsolidated, in places containing lignite, about 140 m thick (Bamburak, 1978).
MESOZOIC **Cretaceous**	
B	BOISSEVAIN FORMATION (Eastend, Whitemud, Battle and Frenchman Formations in Saskatchewan): sandstone containing minor clay and siltstone, largely poorly consolidated, about 45 m thick (Bamburak, 1978).
P	PIERRE FORMATION (Bearpaw Formation in Saskatchewan): shale, soft greenish-brown bentonitic, hard, grey siliceous, and buff silty shales that have been subdivided into several members (McNeil and Caldwell, 1981). UNDIFFERENTIATED: Mainly hard siliceous Odanah member and soft shales and silts of the upper 'unnamed member'.
Po	ODANAH MEMBER: Shale, siliceous and hard, <150 m thick.
Pm	MILLWOOD MEMBER: Shale, soft, greenish-brown and bentonitic, 23–76 m thick (includes undifferentiated Gammon Ferruginous and Pembina members at its base).
NM	NIOBRARA AND MORDEN FORMATIONS UNDIFFERENTIATED (formerlyVermillion River Formation): Shale, calcareous and chalky , about 45 m thick, (Niobrara) overlying shale, soft, black, non-calcareous, about 65 m thick (Morden).

Table 5. Bedrock description, surficial geology map units

MESOZOIC	**Cretaceous**
R	ROCK, PIERRE FORMATION (UNDIFFERENTIATED): soft greenish-brown bentonitic, hard grey siliceous, and buff silty shales; outcrops locally in roadcuts and valley walls; locally present in scoured floors of meltwater channels but in many places difficult to recognize because it quickly weathers to a clay that is difficult to distinguish from Quaternary sediments.

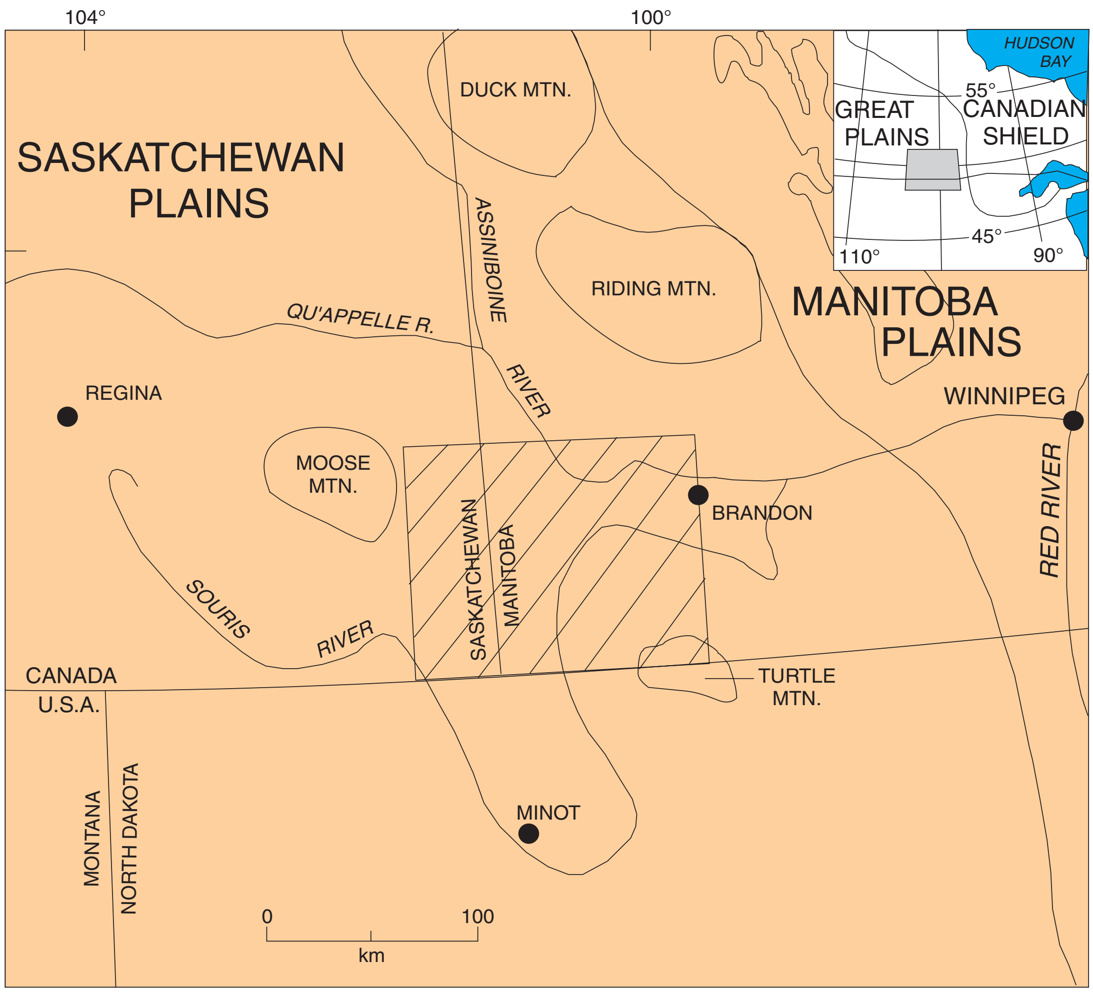


Figure 5. Regional physiographic setting of the Virden map area (shaded).

PHYSIOGRAPHY

Setting

The Virden area lies near the eastern edge of the Saskatchewan plains of the Great Plains of central North America (Fig. 5). According to Klassen (1979), the Saskatchewan plains are gently undulating to rolling prairie interrupted by broad hilly uplands, and locally cut by glacial spillway trenches. The area has been subdivided into a series of local plains, uplands, lowlands, and spillways (Fig. 6). The units named in this figure are used in the following discussion. Table 6 provides a brief description of each of these units and sets it in the context of the hierarchical physiographic scheme devised for Manitoba by the Manitoba Land Resource Unit of Agriculture and Agri-Foods Canada (unpublished information, 1993). The main units in this physiographic classification are 'Turtle Mountain Upland', 'Tiger Hills Upland', 'Pembina River Plain', 'Souris River Plain', and 'Assiniboine River Plain'.

The maximum relief is about 425 m. The area of lowest altitude, less than 335 m above sea level, is on the floor of the Assiniboine River valley west of Brandon. The highest altitude, more than 760 m, is in the western part of Turtle Mountain,

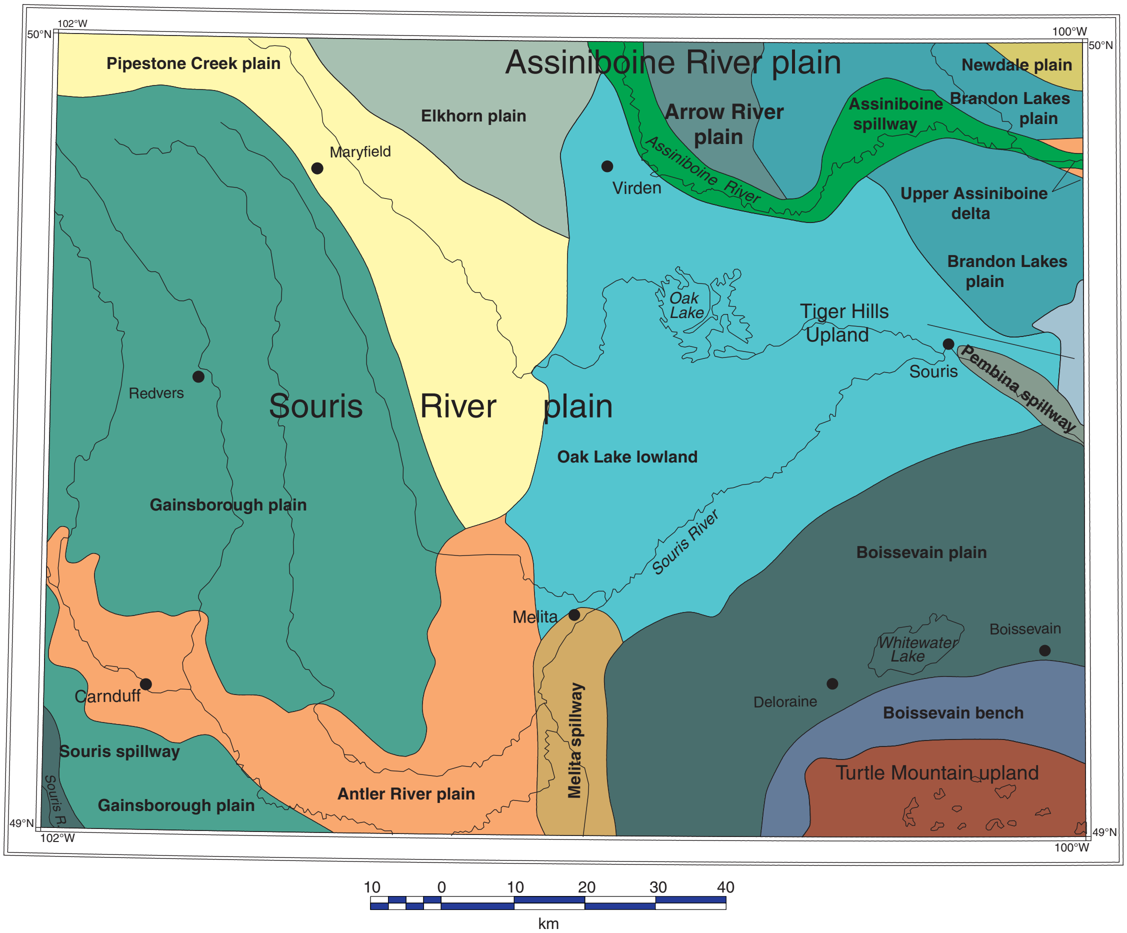


Figure 6. Physiographic subdivisions of the Virden map area (NTS 62 F).

close to the International Boundary. The Oak Lake lowland has an altitude of about 430 m; the Pipestone plain begins at an elevation of about 440 m at the western edge of Oak Lake lowland and the ground surface rises gradually to the west to reach and elevation of 655 m in the Gainsborough plain at the western edge of the map area. Moving from north to south near the eastern edge of the map area, the land rises in a series of steps. Leaving the floor of the Assiniboine spillway north of Alexander requires a 50 m step to get to the general level of the Brandon Lakes plain and Oak Lake lowlands. A further step upwards of about 50 m occurs at the northern edge of the Boissevain plain and there is an additional 50 m step near the northern edge of the Boissevain bench. The front of Turtle Mountain upland stands about 120 m above Boissevain bench and the upland itself has a local relief of about 50 m.

Relationship to bedrock

The bedrock that underlies the area is poorly consolidated shale, siltstone, and sandstone that ranges in age from late Cretaceous to early Tertiary (*see* bedrock map). The extent of the various bedrock units that are present is reflected to some extent in the physiographic subdivisions. The late Cretaceous Pierre Formation, a poorly consolidated shale, underlies the almost flat Boissevain plain, the Oak Lake lowland, and Melita and Assiniboine spillways. (Many earlier reports refer to the Pierre Formation as Riding Mountain Formation, but McNeil and Caldwell (1981) recommend it be referred to as Pierre Formation). The late Cretaceous Boissevain Formation, largely sandstone and siltstone, is generally more resistant to erosion than the other bedrock units and underlies the Boissevain bench, which skirts Turtle Mountain. The early Tertiary Turtle Mountain Formation caps Turtle Mountain (Bamburak, 1978). Bedrock underlying the gently sloping plains west of the Oak Lake lowland and Melita spillway are thickly covered by drift (*see* drift thickness map).

Preglacial topography

The bedrock surface topography of southwestern Manitoba and southeastern Saskatchewan is known from boreholes that were drilled for a variety of purposes. What follows is based on the data from this report (*see* borehole database and bedrock surface map) and the reports of earlier workers (principally Klassen and Wyder (1970) and Betcher (1983)). Based on these sources of information, it appears that the preglacial landscape differs from the present one in that the main valleys of the area were deeper and generally broader. In addition, the preglacial drainage system was well integrated whereas the present system has discordant sections caused by glacial

Table 6. Description of physiographic subdivisions of the Virden area.

Physiographic subdivision	Elevation (m a.s.l.)	Topography and landforms	Surface deposits	Bedrock geology	Drainage
E1 TURTLE MOUNTAIN UPLAND					
E1.1 Turtle Mountain upland	600–705	Undulating to hummocky moraine.	Moderately to strongly calcareous loamy till of mixed shale, igneous rock, and limestone origin; local areas of sandy to gravelly glaciofluvial deposits and clayey lacustrine veneers.	Tertiary sandy to silty shale, carbonaceous sand, silt, and clay (Turtle Mountain Formation).	Numerous small lakes; low-density, deranged network of tertiary drainageways flow to mountainside escarpment.
E2 TIGER HILLS UPLAND					
E2 Tiger Hills upland	390–480	Undulating to gently rolling moraine.	Moderately to strongly calcareous, stony loamy till, local areas of extremely calcareous loamy stony till, and sandy to gravelly glaciofluvial outwash.	Upper Cretaceous hard siliceous shale (Odonah Member of Pierre Formation).	Numerous very small lakes; nonuniform, low-density, poorly developed dendritic network of secondary and tertiary drainageways.
E7 PEMBINA RIVER PLAIN					
E7.3 Boissevain bench	510–570	Gently rolling, locally dissected, low escarpment at northern edge.	Moderately to strongly calcareous loamy till of mixed shale, limestone, and igneous rock origin underlain by sandstone (northern edge) and compact grey till. Depth to bedrock generally less than 20 m.	Upper Cretaceous sandstone (Boissevain Formation) and minor shale; Tertiary bentonitic, carbonaceous sand, silt, and clay (Turtle Mountain Formation).	Very few, very small lakes; moderate density of potholes; medium-density, dendritic secondary drainageways incised up to 20 m near outer margin of bench.
E7.4 Boissevain plain	510–450	Gently rolling moraine.	Moderately to strongly calcareous loamy till of mixed shale, limestone, and igneous origin. Local areas of water-modified till and sandy to gravelly glaciofluvial deposits.	Upper Cretaceous hard siliceous shale (Odonah Member) and minor bentonitic, carbonaceous shale (Millwood Member).	One small lake, scattered shallow ponds; nonuniform, medium-density, dendritic pattern of secondary and tertiary drainageways.
E7.5 Pembina spillway	400–450	Trench cut into adjacent plains and uplands; includes flat trench floor, steep valley walls, and a washed skirt extending a variable distance into the adjacent plains.	Trench floor: loamy alluvial deposits and moderate to strongly calcareous sand and gravel and shaley sand and gravel. Valley walls: shale, slumped shale, moderately to strongly calcareous till, and colluvium. Washed skirt outside trench includes thin, moderately to strongly calcareous sand and gravel, moderately to strongly calcareous washed till, and locally, shale bedrock.	Upper Cretaceous bentonitic shale and siliceous shale (Pierre Formation).	A few small lakes.
E8 SOURIS RIVER PLAIN					
E8.1 Pipestone Creek plain	450–650	Undulating moraine.	Moderately to strongly calcareous loamy till of mixed shale, limestone and igneous rock origin.	Upper Cretaceous shale (Pierre Formation).	No lakes; numerous small ponds; uniform, medium-density, parallel pattern of secondary and tertiary drainage (to Oak Lake lowland).

Table 6 (cont.)

Physiographic subdivision	Elevation (m a.s.l.)	Topography and landforms	Surface deposits	Bedrock geology	Drainage
E8.2 Gainsborough plain	450–650	Undulating moraine.	Moderately to strongly calcareous loamy till of mixed shale, limestone and igneous rock origin; depth to bedrock in places in excess of 100 m.	Upper Cretaceous shale (Pierre Formation), with Upper Cretaceous sandstone (Eastend, Whitemud, and Battle formations), and Tertiary carbonaceous silt, clay, and sand (Frenchman and Ravenscrag formations) in the area adjacent to Souris spillway.	No lakes; numerous small ponds; uniform, medium-density, parallel pattern of secondary and tertiary drainage (to Souris River).
E8.3 Souris spillway	495–640	Trench cut into adjacent plains; includes flat trench floor, steep valley walls, and a washed skirt extending a variable distance into the adjacent plains.	Trench floor: loamy alluvial deposits, and moderate to strongly calcareous sand and gravel and shaley sand and gravel. Valley walls: Tertiary silt, clay, and sand, moderately to strongly calcareous till, and colluvium. Washed skirt outside trench includes thin, moderately to strongly calcareous sand and gravel, and moderately to strongly calcareous washed till	Tertiary carbonaceous silts, clays and sand (Frenchman and Ravenscrag formations).	No lakes, areas adjacent to trenches well drained, trench floors in most places poorly drained.
E8.4 Antler River plain	450–570	Gently rolling to level glacial lake deposits, outwash and moraine; locally dissected by small meltwater channels.	Moderately to very strongly calcareous sandy to loamy lacustrine sediments (primarily adjacent to Melita spillway); moderate to strongly calcareous sand and gravel and shaley sand and gravel; moderately to strongly calcareous washed till and till.	Upper Cretaceous (Pierre Formation) in eastern parts of the unit; Upper Cretaceous sandstone (Eastend, Whitemud, and Battle formations) and Tertiary carbon-aceous silt, clay, and sand (Frenchman and Ravenscrag formations) in western parts of the unit.	Very few small shallow lakes; largely parallel secondary drainage channels drain eastward into primary drainageway (Souris River).
E8.5 Melita spillway	410–450	Main and subsidiary trenches cut into adjacent plains; trench floors flat, walls steep and of moderate height; sand and gravel terraces and a skirt of washed till extending a variable distance onto adjacent plains.	Floor of main trench covered by loamy alluvial deposits, subsidiary trenches underlain by shale or thin calcareous sand and gravel overlying shale. Valley walls: shale, moderately to strongly calcareous till, and colluvium. Terraced, moderate to strongly calcareous sand and gravel and shaley sand and gravel and a washed skirt of moderately to strongly calcareous till lie adjacent to the channels.	Upper Cretaceous shale (Pierre Formation).	No lakes, areas adjacent to trenches well drained, trench floors in most places poorly drained
E8.6 Oak Lake lowland	420–450	Broad basin floored by level to very gently undulating lacustrine deposits.	Moderately to very strongly calcar-eous sandy to loamy lacustrine sed-iments; areas of moderately to strongly calcareous sand, pebbly sand, and sandy gravel, in particular along western and southern edges of lowland; includes local washed, moderately to strongly calcareous till along western and southern margins of lowland.	Upper Cretaceous shale (Pierre Formation).	Contains several poorly drained marshy areas, a few shallow lakes and scattered small ephemeral lakes; nonuniform, low-density, dendritic drainage pattern of secondary drainageways flow into one primary drainageway (Souris River).

Table 6 (cont.)

Physiographic subdivision	Elevation (m a.s.l.)	Topography and landforms	Surface deposits	Bedrock geology	Drainage
E9 ASSINIBOINE RIVER PLAIN					
E9.1 Elkhorn plain	450–510	Undulating moraine dominated by low, broad ridges (washboard moraine).	Moderately to strongly calcareous loamy till of mixed shale, limestone, and igneous rock origin.	Upper Cretaceous shale (Pierre Formation).	No lakes; numerous small ponds; uniform, medium-density, parallel pattern of secondary and tertiary drainage (to Assiniboine River).
E9.2 Assiniboine spillway	360–450	Trench cut into adjacent plains; includes flat trench floor, steep valley walls, and a washed skirt extending a variable distance into the adjacent plains.	Trench floor: loamy alluvial deposits and moderate to strongly calcareous sand and gravel and shaley sand and gravel. Valley walls: shale, slumped shale, moderately to strongly calcareous till, and colluvium. Washed skirt outside trench includes thin, moderately to strongly calcareous sand and gravel, moderately to strongly calcareous washed till, and locally, shale bedrock.	Upper Cretaceous shale (Pierre Formation).	A few small lakes in abandoned river channels, areas adjacent to trench well drained, trench floors in many places poorly drained floodplain.
E9.3 Arrow River plain	420–480	Level to gently rolling with areas of hummocks and steep irregular ridges.	Complex of moderate to strongly calcareous shaley sand and gravel and bouldery shaley gravel; thin moderately to strongly calcareous washed till and till; and locally, shale bedrock.	Upper Cretaceous shale (Pierre Formation).	Scattered small lakes; numerous small ponds; nonuniform, low-density, dendritic and parallel pattern of secondary and tertiary drainage (to Assiniboine River).
E9.4 Brandon Lakes plain	350–480	Level to rolling lacustrine plain with moderate dissection near Assiniboine River	Moderately to very strongly calcareous loamy to clayey lacustrine sediments with till at variable depths; moderately calcareous sandy lacustrine sediment ranging from 30 to 60 m in thickness; minor sand and gravel.	Upper Cretaceous shale (Pierre Formation).	Very few small lakes; nonuniform, medium-density, dendritic pattern of tertiary and secondary drainageways flowing to Assiniboine River.
E9.5 Upper Assiniboine delta	330–390	Level to undulating deltaic lacustrine plain, local duned areas, level glaciofluvial plain, dissected escarpment and terrace area.	Sandy to silty deltaic lacustrine sediments exceeding 90 m in thickness; local sand and gravel.	Upper Cretaceous, soft carbonaceous shale, speckled shale, (Pierre, Niobara, and Morden formations). minor Jurassic siltstone, sandstone.	No lakes; uniform, high-density, dendritic and parallel pattern of tertiary and secondary drainageways.
E9.6 Newdale plain	390–600	Undulating to hummocky moraine and rolling morainal veneer.	Moderately to strongly calcareous loamy till of mixed shale, limestone, and igneous rock origin.	Upper Cretaceous bentonitic shale and hard siliceous shale (Pierre Formation).	Few small lakes, numerous ponds; nonuniform, medium-density, deranged glacial to dendritic pattern of tertiary and secondary drainageways.

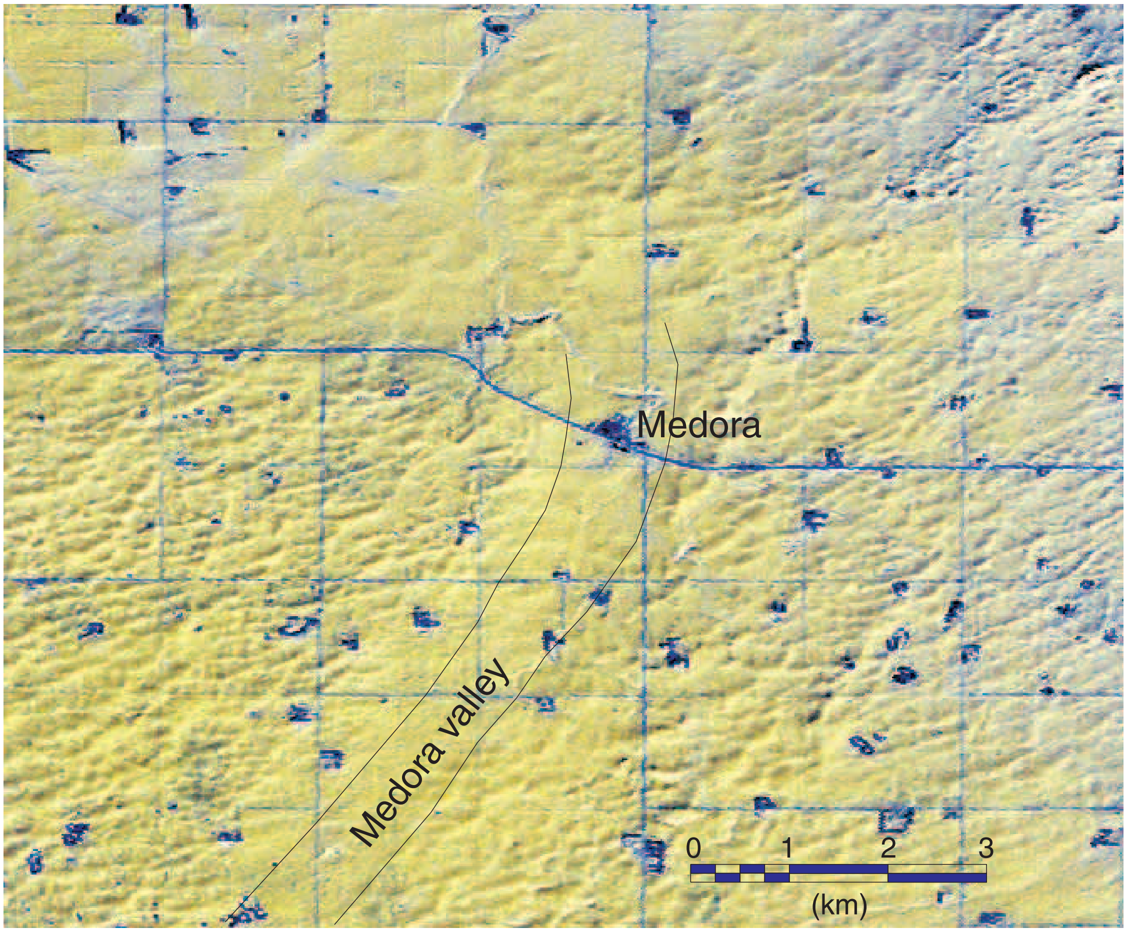


Figure 7. *LANDSAT image of the area near Medora where a variation in the till landforms appears to reflect the location of the 'Medora valley'. Low sun angle, winter scene with snow.*

diversions of earlier drainage systems, and the initiation of new channels by the consequent discharge of several glacial lakes and other meltwater. (It should be noted that in this discussion 'preglacial' valleys include all valleys that are incised in bedrock even though some may have developed at some time after the first glaciation of the area).

A major river system, interpreted to be the preglacial Missouri River valley by Meneley et al. (1957), Colton et al. (1963), and Christiansen (1965), entered the west side of the area near Carnduff, crossed southwestern Manitoba northeastward to the vicinity of Oak Lake, then swung east-northeastward to the Assiniboine River valley to enter the lowland to the east through the Assiniboine re-entrant in the Manitoba escarpment.

This major valley was joined by a tributary from the south in the south-central part of the Virden map area east of Pierson, (the preglacial Souris River system of North Dakota, according to Colton et al., (1963)). Klassen and Wyder (1970) called this, and the lower part of the preglacial Missouri valley, 'Pierson Valley'. They suggested the Missouri River valley was shallow and about 45 km wide in the southwest part of the Virden map area, becoming narrower near Brandon. The descent from the International Boundary (preglacial Souris River) to the point of departure from the Brandon map area is about 180 m in 225 km, an average gradient of 0.0008, which is less than most typical valleys within the area today.

Tributaries from the north side of this pre-glacial Missouri River valley, from west to east respectively, included a small tributary from the northwest that occupied the approximate position of present Pipestone Creek. A major trough-like valley trended south-southeast, passing east of Virden to join the preglacial Missouri River valley near Oak Lake (referred to by Klassen and Wyder (1970) as the 'Virden Valley'). It was parallel to the Assiniboine River valley in this vicinity and upstream it was part of it. It formed a connection to the pre- or inter-glacial Assiniboine and Qu'Appelle systems. The segment near Virden is now completely filled and concealed by drift. A short preglacial valley trends southeast and east from Kenton, ending in a broad part of the Assiniboine River valley west of Brandon. A much larger preglacial valley system rising on the back slopes of Riding Mountain (Klassen et al., 1970) extends southeast from the north edge of the Virden map area to join the Assiniboine River valley north of Kenmay. Part of this valley system follows the present-day Minnedosa River.

Tributaries from the south, from west to east, included an anomalous, narrow, deep channel referred to as the 'Medora valley' by Klassen and Wyder (1970). This channel trends generally northeast obliquely down the slope from the International Boundary south of Waskada to Brandon. It is filled by drift and lacks surface manifestations with the exception of an area west and north of Medora, where the till landforms appear to reflect a slightly lower area (Fig. 7). Probably it was formed along an as yet unknown glacier margin during a glacial recession previous to the last glaciation. This valley is joined at Souris by a smaller V-shaped valley that starts about the middle of Turtle Mountain and crosses the plain north of Whitewater Lake generally following Elgin Creek. This stream may have crossed the position of Medora valley and then swung east and northeast to Brandon prior to the inception of the Medora valley.

The basin now occupied by Assiniboine River 25 to 40 km west of Brandon represents the junction of another tributary from the northwest that connected with a major preglacial valley now represented by the present Assiniboine and Qu'Appelle River systems. It is likely that this is the Hatfield valley that has been recognized in Saskatchewan (Schreiner and Maathuis, unpub. rept., 1982).

There are three obvious discordances of existing major valleys with respect to the bedrock topography: these are the Assiniboine River valley in the vicinity of Virden, a section of the Pipestone valley near the northern edge of the map area, and a section of the Souris River valley south of Melita. In all three places, the present streams occupy valleys that were cut into bedrock after retreat of the last glaciers. Also in all three areas, the locations of older valleys that must have been occupied by these streams are not obvious.

Physiographic divisions

Turtle Mountain is a hilly upland that occupies the southeastern corner of the area and is underlain by hummocky moraine that overlies the early Tertiary Turtle Mountain Formation (*see* surficial geology map SE). Boissevain bench is a gently undulating, locally dissected, plain that extends outwards from Turtle Mountain and is underlain by till that mainly overlies sandstone of the uppermost Cretaceous Boissevain Formation sandstone. The Boissevain plain swings around the Boissevain bench, and is a very gently undulating plain underlain largely by till that overlies the Upper Cretaceous shale of the Pierre Formation (*see* surficial geology map SE). Oak Lake lowland lies between Boissevain bench on the south, Assiniboine spillway to the north, and Pipestone plain to the west. It is a flat to very gently undulating plain underlain largely by lake sediments that in places have been swept into dunes that overlie Upper Cretaceous shale of the Pierre Formation (*see* surficial geology map NE).

The Gainsborough, Pipestone Creek, and Elkhorn plains are underlain mainly by till (*see* surficial geology map SW and NW). In general the drift is thick (>50 m), but an area of near-surface rock (<10 m below surface) stretches across

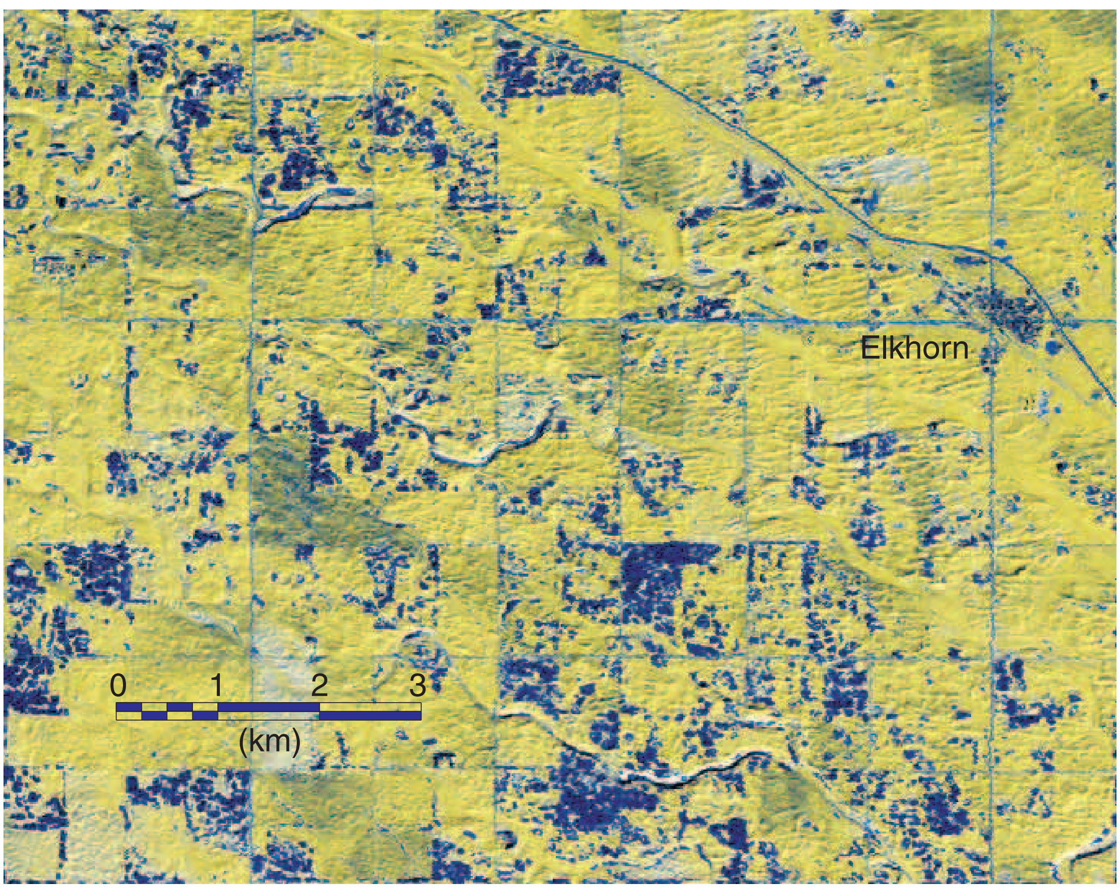


Figure 8. *LANDSAT image of an area west of Elkhorn that is underlain by a variety of ablation moraine forms. Low sun angle, winter scene with snow.*

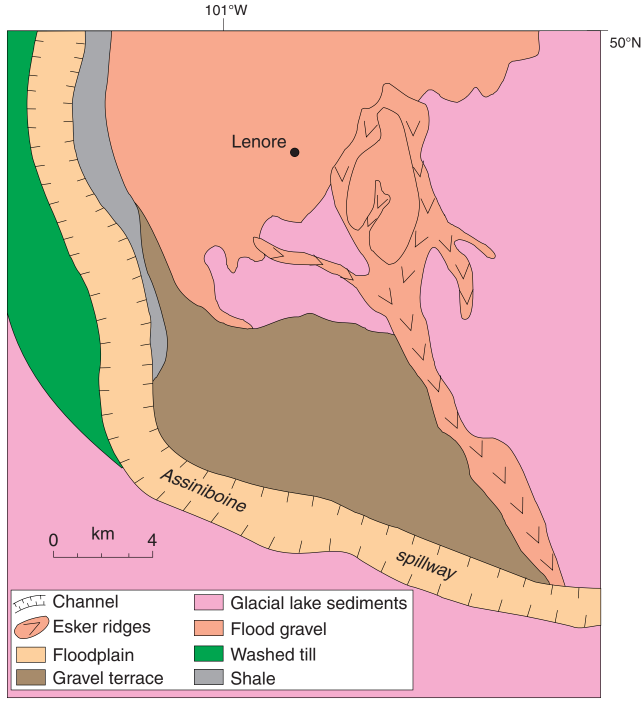


Figure 9. *Complex of glaciofluvial deposits that underlie the Arrow River plain, north of Virden.*

northern Pipestone Creek and Elkhorn plains. In many areas the till surface is marked by a variety of ablation landforms that include ridges, hummocks, and rim-ridged features (Fig. 8). The Antler River plain is underlain by till, but the till is overlain by a blanket of lake sediments adjacent to the Melita spillway and much of the rest of the area has a discontinuous cover of sand and gravel that was washed into the area by a meltwater flood from the west and by flow from meltwater channels originating in the Gainsborough plain (*see* surficial geology map SW).

The Arrow River plain is unique in that it is dominated by a large esker complex that is a part of the Arrow Hills moraine (Klassen, 1979) (*see* surficial geology map NE). This esker leads away from an area of kames and streamlined hills that are thought to have been formed by a subglacial meltwater flood (Fig. 9).

The Brandon Lakes plain is an area of glacial lake sediments (*see* surficial geology map NE). On the north side of the Assiniboine River these sediments are thick and deeply dissected by postglacial gullying. The part of this unit on the south side of the Assiniboine is contiguous with the lake deposits of the Oak Lake lowland, but, in general, is characterized by undulating topography that is a reflection of the morphology of the till that underlies the lake sediments.

The three main spillways (Assiniboine, Melita, and Pembina) are valleys cut by glacial meltwaters. The Pembina is relatively broad and shallow, the Assiniboine is the widest and has the highest valley walls, and the Melita is a well defined, broad, shallow valley with several steep-sided channels cut into bedrock. The Pembina spillway contains a few small gravel terraces, but is largely underlain by washed till. The Melita spillway includes an extensive fill of floodplain sediments near the present-day river and the modern and abandoned valleys contain a series of gravel terraces, areas of eroded bedrock and of washed till. The central part of the Assiniboine River valley contains a thick fill of postglacial alluvial sediments, locally the spillway contains thick gravels, and where the steep valley walls have been cut in shale, slope failures are a common feature (Fig. 10).

Only small parts of the Newdale plain, Upper Assiniboine delta, and Tiger Hills upland fall in the Virden map area. The Newdale plain is a gently undulating till plain, the Upper Assiniboine delta is a terraced area underlain by gravel and sand, the Tiger Hills upland is an area of hummocky moraine.

SURFICIAL GEOLOGY

Introduction

Surficial materials in the Virden area consist of deposits laid down during several glaciations that occurred during the Pleistocene Epoch (10 000 to 1 650 000 years ago) and deposits formed under conditions not too different from present during the Holocene Epoch (the past 10 000 years). The glacial deposits consist largely of till, a sandy, silty, clayey mixture that contains a few stones and scattered large boulders. This material is a mixture of the materials that were overridden by and incorporated within the glaciers, and then left behind as layers or as piles and ridges of unsorted debris when the ice melted. At present, these materials underlie gently undulating plains and some hummocky areas (such as Turtle Mountain). Sorted deposits of clay, silt, sand, and gravel were also left behind by the glaciers. These sediments result from glacial debris that was washed from the melting ice and deposited as stream and lake sediments. Clay, silt, and sand (glacial lake deposits) underlie nearly flat to very gently undulating plains; sand and gravel (glaciofluvial deposits) line the floors and occur at the mouths of glacial spillways, extend as terraces along spillway walls, or locally form ridges or hummocks. Holocene deposits are composed of the same types of material that are accumulating in the area today. They are the clay, silt, and sand that are being washed into low areas, deposited on floodplains, and carried into shallow lake basins; they are the debris that accumulates at the base of the steep walls of spillways; and they are the fans of debris, sand, and gravel that are spread out where streams exit gullies. In addition, the Holocene sediments consist of sand that has been built into sand dunes by the wind. Individual deposits are generally thin (a few metres thick at most), but over much of the area sediments from many episodes of deposition have accumulated, so at present the surficial materials may be more than 100 m thick (*see* Stratigraphy section).The general distribution of these deposits in the map area is shown on the maps that accompany this report (*see* surficial geology maps 62 F SE, 62 F NE, 62 F NW, and 62 F SW).

The glacial deposits near the surface were deposited by ice of two distinct episodes, an early glacier that moved southeast across the entire area, and a later one that moved southwest and west, pushing into the northeast corner of the

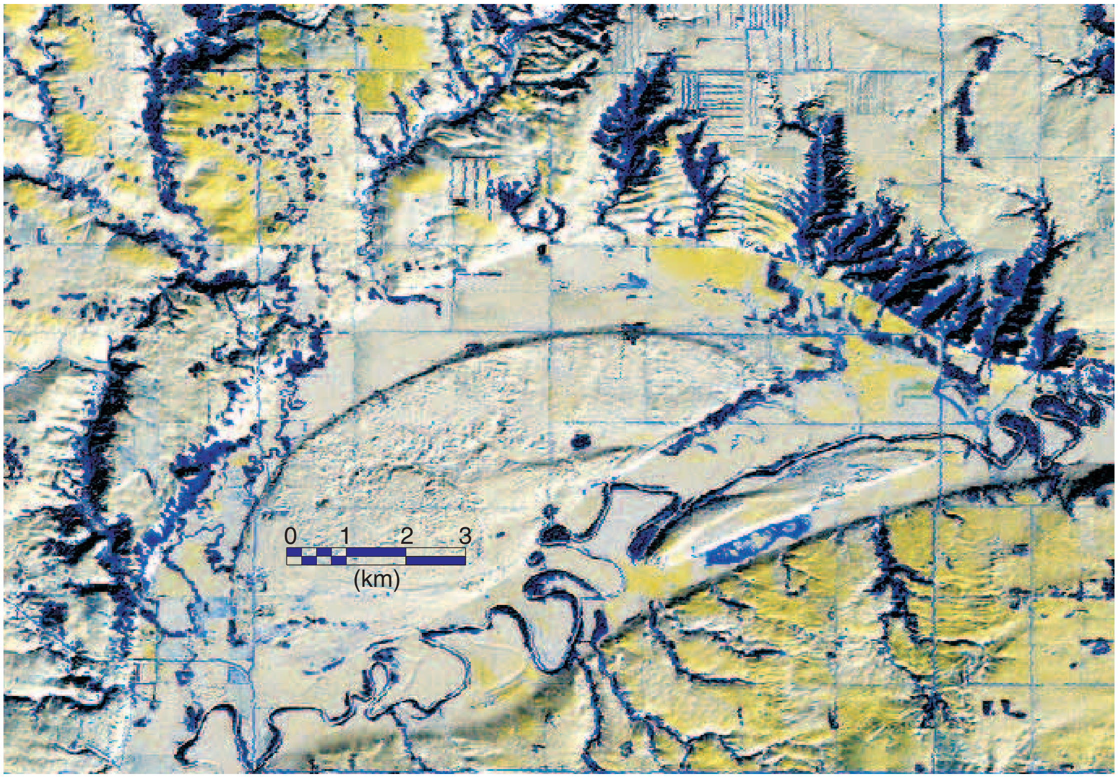


__Figure 10.__ LANDSAT image of a segment of the Assiniboine spillway at Assiniboine Flats. Note the series of scallops at the side of the valley that mark the sites of slope failure in shale. The crescent-shaped area in the lower part of the scene is a large bar consisting of gravel. Low sun angle, winter scene with snow.

area. The deposits of the two ice flows are similar lithologically, and they appear to have not been widely separated in time. Evidence that two different flows occurred is based on distribution and orientation of landforms, minor differences in carbonate content of tills, and the glacial history developed for the Brandon area to the east (Elson, 1956).

Evidence of earlier glaciations is not conclusive. Locally, a boulder pavement separates an upper, sandy brown till from a lower, dark grey, more compact, clayey till, but there is no associated weathered zone that might confirm a nonglacial interval. Boreholes drilled for water or other reasons penetrate as much as 100 m of Quaternary materials, but the information obtained from these is not easily interpreted and in many instances even the position of the contact between the drift and bedrock is difficult to determine. In some of the boreholes, stratified materials were encountered between till units, but in the absence of organic materials it could not be determined whether these were nonglacial in origin.

The following discussion covers the nature, form, and distribution of the materials at the surface (Surface Materials and Geomorphology), provides a brief description of the units and symbols used on the surficial geology map (Table 7), describes the stratigraphy and materials penetrated by boreholes (Table 8), and ends with a discussion of the geological events that have occurred in the area during the Quaternary (Quaternary History).

Surface materials and geomorphology

The surficial materials are described in order of approximate age, beginning with the oldest materials.

Quartzite pebble gravel (Souris gravel)

Gravel and sand in which the coarse clast content is dominantly quartzite are exposed in a pit 2 km east of the town of Souris. This gravel has been described and referred to as the 'Souris Gravel' by Klassen (1969). The gravel pebbles are well rounded. This deposit appears to include two rather poorly defined units. The lowest unit is about 2 m thick; however, the bottom was not seen (from boreholes in the area bedrock could be 2 to 90 m below the base of the pit). In addition to quartzite, the lowest unit includes chert, agate, petrified wood and bone, and ironstone concretions as common pebble types. The upper unit is about 2 m thick and includes all of the rock types seen in the lower one, but in addition includes minor granitic, gneissic, and dark, fine-grained pebbles (including scattered Omarolluk Formation clasts as described by Prest and Nielsen (1987) and Prest (1990)). The contact between the two units is indistinct, but the upper unit appears to be coarser and somewhat more poorly stratified.

The lower unit resembles the Saskatchewan gravel and sand units that are found at the base of Quaternary sediments in valleys in the southwestern Prairies (McConnell, 1886;

Rutherford, 1937; Stalker, 1968). Also, it is similar to the quartzitic gravel units of Eocene and younger ages that cap the Cypress Hills and similar highlands in Saskatchewan, Alberta, and Montana (Vonhof, 1965). The apparent lack of glacially derived materials in the lower unit suggests that it was deposited by a eastward-flowing river prior to the first Pleistocene glaciation of the area. The gravel has been suggested to be related to an early valley of the Missouri River (Elson, 1956; Klassen and Wyder, 1970). The upper unit, however, postdates the Pleistocene glaciation that carried the Omarolluk Formation clasts westward onto the central Prairies from the Belcher Islands more than 1500 km to the east (Prest, 1990). It may have resulted from a reworking of the early Missouri Valley materials during an interglacial interval.

The quartzite gravel at Souris occupies the side or summit of a bedrock high (inferred from well logs) and may have been preserved from erosion by its permeability and chemical stability. A major interval of erosion must have occurred after deposition of the gravel causing a local inversion of topography. The Souris gravel predates one and probably several glaciations, and yet is not overlain by glacial deposits. It is presumed that one of the several large meltwater floods that swept through the Souris River valley during retreat of the last ice sheet exhumed this earlier deposit.

Till

Till is a term "applied to sediments that have been transported by glacier ice and subsequently deposited with little or no sorting by water" (Dreimanis and Lundqvist, 1984; Klassen, 1989).

Till, in general, can be divided into lodgement till and ablation till based on compaction. A lodgement till is generally dense and compacted, deposited at the glacier base by lodging of debris from overlying, sliding ice (Shaw, 1982; Blatt et al., 1980). Stones in lodgement till may show preferred orientation parallel to the former ice-flow direction. In comparison, ablation till is less consolidated and contains less clay than lodgement till. Debris in ablation till was released or let-down from ice by the processes of melting and sublimation, and may have had some of its fines removed.

Till consists of material that was entrained at the base of the glacier. In the Virden area, the glacial deposits comprise varying proportions of comminuted bedrock of local origin (chiefly the hard siliceous Odanah Member), mixed with foreign detritus consisting of fairly uniform proportions of Precambrian and Paleozoic rocks. The proportion of foreign stones in the surface drift increases with the depth to bedrock. The foreign stones could have been derived in their present proportions by ice flowing across the Canadian Shield and the belt of Paleozoic rocks that separates it from the Mesozoic and Cenozoic rocks of the plains, either in a south-westward direction from northwestern Ontario and northwestern Manitoba, or in a south-southeastward direction from northern Saskatchewan. In addition to being picked up directly from outcrop, some of the foreign stones were reworked from deposits of earlier glaciations.

Table 7. Surficial geology map units.

EOLIAN DEPOSITS
Er
COLLUVIAL DEPOSITS
Cf - Colluvial fan sediments
Ch - Slope-failure deposits
Cx - Colluvial complex
Cx*- Colluvial complex including a stream floodplain that is 50–100 m wide
ALLUVIAL DEPOSITS
Ap - Modern floodplain sediments
gAp - Modern floodplain sediments, dominantly gravel
Al - Alluvial flats
At - Alluvial terrace sediments
Af - Alluvial fan sediments
gAf - Alluvial fan sediments, dominantly gravel
Af* - Alluvial fan sediments, deposition no longer active
gAf* - Alluvial fan sediments, deposition no longer active, dominantly gravel
LACUSTRINE AND GLACIAL LACUSTRINE DEPOSITS
Lr - Shoreline sediments
Ll - Lacustrine plain sediments, flat
Ll+c - Lacustrine plain sediments, flat with rim ridges
sLl - Lacustrine plain sediments, flat, dominantly sand
sLl,+r - Lacustrine plain sediments, flat dominantly sand, with ridges
c/Ll - Lacustrine plain sediments, flat with veneer of clay
c/sLl - Lacustrine plain sediments, flat, dominantly sand with veneer of clay
oLl - Lacustrine plain sediments, flat, organic-rich
Lp - Lacustrine plain sediments, gently undulating
sLp - Lacustrine plain sediments, gently undulating, dominantly sand
Lu - Lacustrine plain sediments, undulating
Lh - Lacustrine sediments, hummocky
Lv/T - Lacustrine sediments, veneer overlying till
GLACIOFLUVIAL DEPOSITS
Gt - Glaciofluvial terrace sediments
gGt - Glaciofluvial terrace sediments, dominantly gravel
g*Gt - Glaciofluvial terrace sediments, dominantly gravel, large clasts, predominantly shale
Gl - Glaciofluvial plain sediments, flat
gGl - Glaciofluvial plain sediments, dominantly gravel
g*Gl - Glaciofluvial plain sediments, dominantly gravel, shale-rich
Gp - Glaciofluvial plains sediments, gently undulating
gGp -Glaciofluvial plains sediments, gently undulating dominantly gravel
g*Gp - Glaciofluvial plains sediments, gently undulating dominantly gravel, shale-rich
gGu - Glaciofluvial plain sediments, rolling, dominantly gravel
gGr - Glaciofluvial deposits, ridged, dominantly gravel
g*Gr - Glaciofluvial deposits, ridged, dominantly gravel, shale-rich
Gh - Glaciofluvial hummocky and ridged gravels
Gv - Glaciofluvial sediments, veneer
Gv/T - Glaciofluvial sediments, veneer overlying till.
MORAINAL DEPOSITS
T-w - Till plain, eroded
Th - Hummocky moraine
Tl - Till plain, flat
Tl+c - Till plain, flat with rim ridges
Tl+r - Till plain, flat with ridges
Tp - Till plain, gently undulating
Tp+c - Till plain, gently undulating with rim ridges
Tp+r - Till plain, gently undulating with ridges
Tr - Till plain, ridged
Tr* - Till plain, ridged, complex thrust
Tu - Till plain, undulating
Tu+r - Till plain, undulating with ridges
Tv - Till veneer on bedrock
OLDER ALLUVIAL GRAVEL
gA*

Table 8. Surficial geology legend

SURFICIAL MATERIALS	
CENOZOIC	
Quaternary	
	Holocene
Er	EOLIAN DEPOSITS: sand and silty sand; occurring as ridges (dunes) with intervening swales; materials derived from sandy lake deposits and laid down by the action of the wind; 1–15 m thick.
COLLUVIAL DEPOSITS: silty to clayey diamicton occurring as slope and slump deposits derived largely from till, but in places from lacustrine deposits and shale.	
Cf	Colluvial fan sediments: silty diamicton with thin sand beds; fan-shaped deposits occurring at the mouths of gullies cut in steep slopes; formed largely as mud and debris flows;<5 m thick.
Ch	Slope-failure deposits: Silty to clayey diamicton and shale slabs and blocks; occurs as irregular hummocks, ridges and steps on slopes, and as ridges and hummocks within valleys; formed by slumping and slope failure; <10 m thick.
Cx	Colluvial complex: Silty to clayey diamicton; veneers, blankets, aprons, and fans of colluvial debris occurring on and at the base of steep slopes; complex of colluvial materials which can include areas of till, washed till, and locally may contain small inclusions of alluvial plains and terraces;
Cx* - colluvial complex including a stream floodplain that is 50–100 m wide; <5 m thick.	
ALLUVIAL DEPOSITS: clayey to sandy materials containing some gravel and organic-rich sediments; formed as stream deposits and now underlie modern floodplains, low terraces, or broad plains.	
Ap	Modern floodplain sediments: silt, clay, and sand with minor gravel and organic muck and organic-rich silt and clay; poorly sorted and stratified; occurs as gently undulating plains containing swales and abandoned stream channels; locally swampy; <5 m thick in most areas.
	gAp - Dominantly gravel.
Al	Alluvial flats: sandy silt, clayey silt, silty sand, sand, and minor organic-rich silt and clay; poorly stratified to massive; underlies broad, flat to gently undulating areas that are not directly associated with stream channels; consists of basin-fill deposits (delta and fan sediments) that were, in part, deposited in ephemeral water bodies; <5 m thick.
At	Alluvial terrace sediments: sand, silt, and clay with minor gravel; generally well sorted and stratified; occurs as low benches up to 5 m above present stream level; <5 m thick.
Af	Alluvial fan sediments: sand, pebbly sand, sandy gravel, bouldery gravel; content of shale and other friable lithologies generally moderate or low; generally well stratified, sorted, and washed; underlies triangular areas with flat to gently undulating surfaces and a low gradient from triangle apex towards base; locally contains abandoned channels and crossed by low escarpments; stream deposits formed where gradient decreased; <5 m thick.
	gAf - Dominantly gravel.
	Af* - Alluvial deposition no longer active.
	gAf* - Dominantly gravel, alluvial deposition no longer active.
Late Wisconsinan	
LACUSTRINE AND GLACIAL LACUSTRINE DEPOSITS: silt, sand, and clay; generally underlying flat to gently undulating plains with variable densities of small closed depressions (potholes); relief generally <2 m but locally up to 20 m; the surface metre of sandy lacustrine deposits has, in many places, been reworked by wind and locally is overlain by isolated dunes <20 m high; includes deposits of glacial Lake Hind and other temporary and existing lakes.	
Lr	Shoreline sediments: sand, pebbly sand, silty sand; well washed and sorted, moderately well stratified; occurs as single or series of low ridges; beach ridges formed at the margin of a lake; <2 m thick.

Table 8 (cont.)

Ll	Lacustrine plain sediments, flat: silt, sand, and clay with organic-rich muck at the surface in poorly drained areas; well to moderately well sorted, massive to laminated; nearly flat (level) surface, with some low rises and shallow hollows (relief <2 m); <50 m thick. **Ll+c** - Low rimming ridges present around some closed depressions. **sLl** - Sand dominant. **sLl+r** - sand dominant with short, low ridges (<2 m high) scattered throughout unit. **c/sLl** - Veneer of clayey lacustrine sediments overlying sand-dominated lacustrine sediments. **oLl** - Organic-rich clay (swamp and slough sediments).
Lp	Lacustrine plain sediments, gently undulating: clay, silt, and sand with organic muck at the surface in poorly drained areas; well to moderately well sorted, massive to laminated; gently undulating surface (relief 2–5 m), marked by either scattered sand dunes or erosional features such as scoured channels; in places relief may mimic underlying units; <50 m thick. **sLp** - Sand dominant.
Lu	Lacustrine Plain sediments, undulating: clay, silt, and sand; well to moderately well sorted, massive to laminated; broadly undulating to rolling with 4–10 m relief probably inherited from underlying units; <30 m thick.
Lh	Lacustrine sediments, hummocky: silt, sand, and clay; locally overlain by a veneer of pebbly silt (<1 m); well to moderately well sorted, massive to laminated; hummocky mounds, and hills with abundant closed depressions varying from small and shallow to large, irregularly shaped and relatively deep; relief >5 m due to slumping and collapse caused by melting of underlying and adjacent glacial ice; <15 m thick.
Lv	Lacustrine sediments, veneer: silt, clayey silt, and sandy silt; silt generally massive; thin to discontinuous layer of lacustrine materials overlying other units; flat to very gently undulating surface (depending on underlying unit) relief generally <2 m; underlying material assumed to be rock except where it is indicated; lacustrine component thickness <1.5 m thick. **Lv/T** - Thin lacustrine sediments deposited on till, mapped largely at margins of thick lacustrine sediments.
GLACIOFLUVIAL DEPOSITS: sand and gravel in ridges and hummocks, underlying benches well above present stream level, and underlying broad flat to undulating plains; coarse clast composition variable and in many places dominated by shale; deposited as glaciofluvial materials in contact with melting ice, as glacial outwash plains and deltas, as catastrophic flood deposits, and as terraces and flats in glacial lake outlet channels.	
Gt	Glaciofluvial terrace sediments: sand, gravel, and bouldery gravel; well washed and sorted; occurs as benches 5–40 m above modern valley floors; remnants of glaciofluvial outwash plains and terraces in glacial lake outlet channels; <5 m thick. **gGt -** Dominantly gravel. **g*Gt** - Dominantly gravel but with large predominantly shale clasts.
Gl	Glaciofluvial plain sediments, flat: sand, gravel, and bouldery gravel; well washed and sorted; nearly flat (level) to gently undulating with relief <2 m; coarse clast composition variable and generally high in shale; largely formed as deltaic deposits at the margin of glacial lakes; <10 m thick. **gGl -** dominantly gravel. **g*Gl** - Dominantly shale-rich gravel.
Gp	Glaciofluvial plains sediments, gently undulating: sand, gravel, and bouldery gravel; well washed and sorted; gently undulating plain marked by low ridges and abandoned scour channels with relief 2–5 m; coarse clast composition variable and generally high in shale; trains of outwash occupying meltwater channel bottoms and deltaic deposits formed at the margin of glacial lakes <10 m thick. **gGp -** Dominantly gravel. **g*Gp** - Dominantly shale-rich gravel (locally >99%)

Table 8 (cont.)

gGu	Glaciofluvial plain sediments, rolling: gravel, bouldery gravel, and sandy gravel; moderately well sorted and well stratified; occurs as area of closely spaced mounds and hummocks (relief 4–10 m); interpreted as catastrophic flood deposit; <20 m thick.
gGr	Glaciofluvial deposits, ridged: sand, gravel, and bouldery gravel; well washed and sorted; occurs as a complex series of ridges ; <5 m thick.
	g*Gr - Dominantly shale gravel (locally >99%).
Gh	Glaciofluvial hummocky and ridged gravels: gravel, and gravelly diamicton with minor sand and silt; poorly sorted; in most places the coarse clasts are dominantly shale; occurs as mounds, hummocks, and ridges with 2–20 m relief and deep relief potholes and lakes; formed as ice-contact glaciofluvial deposits; <15 m thick.
Gv	Glaciofluvial sediments, veneer: sand and bouldery gravel; thin to discontinuous layer of glaciofluvial materials overlying rock; glaciofluvial component thickness <1.5 m.
	Gv/T - glaciofluvial veneer overlying till.
MORAINAL DEPOSITS: till (diamicton), in many areas overlain by a surface layer (~1 m) of massive, sparsely pebbly, clayey silt; in places includes variable amounts of sorted glacial deposits, and minor veneers of postglacial alluvial and eolian silt and sand, and organic-rich silt and clay; till generally is a sandy, clayey, silt diamicton having a minor content of boulders; morainal deposits are the direct deposits of glacial ice; till layers of different ages commonly underlie the surface, but stratigraphy and thickness can be assessed only by drilling; a discontinuous layer of large (>1.5 m diameter) faceted boulders lies at the base of the surface till layer in many places; thickness varies from as little as 1 m where a single till sheet overlies bedrock, to 120 m in buried valleys and where multiple till units are present.	
T-w	Till plain, eroded: till, gravel, boulders, sand silt, sand, and muck; consists of till, in many places with an overlying discontinuous lag deposit of gravel, sand, and boulders; includes muck and silty sediments in poorly drained valley-floor locations; occurs as flat plains, on benches, in valley bottoms, and on slopes at the margins of meltwater channels; patchy gravel and sand occurring as part of this unit is in places <2 m thick.
Th	Hummocky moraine: till, silt, gravel and sand; sorted sediments occur interstratified with till and as areas of surface sediments not differentiated from till areas; surface is marked by sharp ridges, hummocky mounds, and hills with abundant closed depressions varying from small and shallow to large, irregularly shaped, and relatively deep; relief >5 m.
Tl	Till plain, flat: till and minor sorted sediments, in many places overlain by massive clayey silt up to1.5 m thick; nearly flat (level) to very gently undulating with relief <2 m in the form of low rises and shallow depressions; locally includes low mounds which generally consist of massive, pebbly, silty sand or sandy gravel;
	Tl+c - flat till plain including rim ridges (arcuate ridges in part outlining shallow depressions).
	Tl+r - flat till plain including scattered low ridges 100 m to 5 km in length, generally consisting of massive, pebbly, silty sand.
Tp	Till plain, gently undulating: till and minor sorted sediments; gently undulating areas of low rises and shallow depression (relief 2–5 m), locally includes low mounds which generally consist of massive, pebbly, silty sand or sandy gravel.
	Tp+c - gently undulating till plain including rim ridges (arcuate ridges in part outlining shallow depressions).
	Tp+r - gently undulating till plain including scattered low ridges 100 to 1000 m in length, generally consisting of massive, pebbly, silty sand or sandy gravel.
Tr	Till plain, ridged: till with variable inclusions of sorted sediment; generally occurs as broad (50–175 m), moderate relief (2–10 m), ridges which are 500 m to 2 km long and spaced at intervals from 0.5 to 2 km; ridges developed by ice thrusting and various ablation-related processes during melting of the glacier.
	Tr* - complex of closely spaced ridges and hummocks, relief <30 m (thrust moraine).
Tu	Till plain, undulating: till and minor sorted sediment; undulating areas made up of rises and depressions (relief 4–10 m), locally includes low mounds which generally consist of massive, pebbly, silty sand or sandy gravel.
	Tu+r - undulating till plain including scattered ridges, which generally consist of massive, pebbly, silty sand or sandy gravel.

Table 8 (cont.)

Tm	Till plain, rolling: till and minor sorted sediments; broadly rolling to hilly surface form with broad rises and shallow depressions (relief >10 m), locally includes mounds which generally consist of massive, pebbly, silty sand or sandy gravel.
Tv	Till, veneer: sand, clayey, silt diamicton; thin to discontinuous layer of till overlying other units; underlying material assumed to be rock unless it is indicated otherwise; till thickness <1.5 m .
Pre-Late Wisconsinan	
gA*	Older alluvial gravels: sand and gravel; well stratified, sorted and washed; shale and other friable lithology content low, quartzite a common component and may contain agate, chert, jasper, petrified wood, and bone; variable cover of till and other sediments but mapped only where cover >2 m thick; gravels which were deposited before advance of the last ice sheet; <5 m thick.
BEDROCK	
Tertiary	
	Paleocene
R	Rock, Turtle Mountain Formation: shale and sandstone, largely unconsolidated, in places containing lignite; confined to area underlying Turtle Mountain, outcrops locally but is not shown as a unit on the map.
Mesozoic	
	Cretaceous
R	Rock, Boissevain Formation: sandstone containing minor clay and siltstone, largely poorly consolidated; confined to area adjacent to Turtle Mountain, outcrops locally but is not shown as a unit on the map.
R	Rock, Pierre Formation: shale, soft greenish brown bentonitic, hard grey siliceous, and buff silty; outcrops locally in roadcuts and valley walls; locally present in scoured floors of meltwater channels in many places difficult to recognize because it quickly weathers to a clay that is difficult to distinguishable from Quaternary sediments.

The grain-size distribution of sampled tills of the Virden map area is illustrated in Figure 11. Material coarser than sand (>2 mm) generally makes up less than 5% of the till and is not included in the ternary diagram. The data on which the ternary diagram is based are included in the GEOCHEM (TILL ANALYSES) table of the FIELDAT database. Distribution of the 660 till samples that were analyzed clusters tightly between 35 and 50% sand, 30 and 40% silt, and 15 and 20% clay. This is a little sandier than the norm for tills in the Prairie region generally described as being approximately equal parts sand, silt, and clay (Klassen, 1989), but is not too different from what Christiansen (1960) found in the Qu'Appelle area of Saskatchewan, northwest of the Virden area (40 to 50% sand, 25 to 30% silt, and 20 to 30% clay). A possible explanation of the higher sand content is that the Saskatchewan Research Council, who did the mechanical analyses, uses 0.05 mm rather than the conventional, geological 0.0625 mm as the sand-silt break. This smaller lower limit for sand size would increase the apparent sand content, particularly if a high proportion of the grains fell in the fine sand-coarse silt interval. The average engineering properties of the tills (Atterberg limits) run 22–45 for liquid limit, 14–22 for plastic limit, and 10–25 for plasticity index.

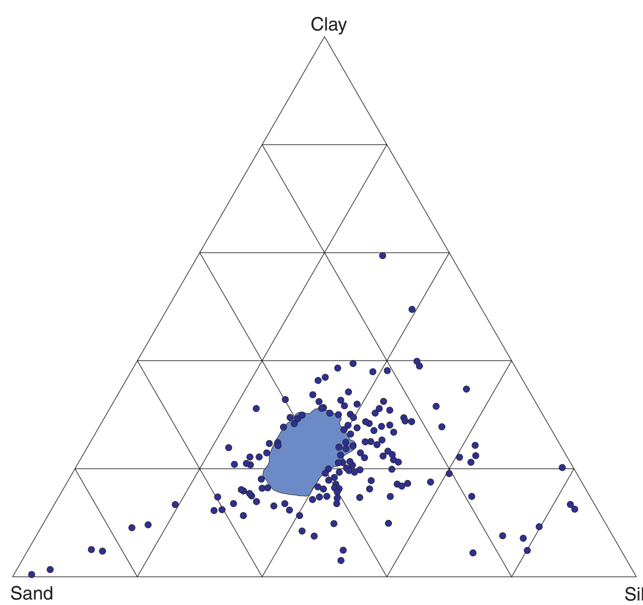


Figure 11. Till textures from Virden area samples plotted on a ternary diagram. A total of 661 analyses were obtained. The concentration of data was such that individual points could not be distinguished in the solid area.

Most areas of till in the Virden area are mapped as till plains. Surface relief was used as the criteria to subdivide till plains. The subdivisions were referred to as flat, gently undulating, undulating, and rolling. A flat till plain is nearly level to very gently undulating with <2 m of relief in the form of low rises and shallow depressions. A gently undulating till plain has a relief of 2 to 5 m, with gently undulating areas of low rises and shallow depressions. An undulating till plain is similar to the gently undulating till plain, but with a relief between 3 and 10 m. A rolling till plain has long slopes and 5 to 30 m of relief. All till plains include potholes (closed depressions) that are generally shallow and 50 to 400 m in diameter.

Several areas are mapped as hummocky moraine and others as ridged moraine. Hummocky areas have abundant high hummocks and closed depressions with a relief of 5 to 30 m. Potholes are more abundant, variable in size, and generally deeper in hummocky moraine areas than in till plain areas. Ridged moraine consists of closely spaced, roughly parallel ridges with local relief of 2 to 20 m.

Glaciofluvial deposits

Glaciofluvial deposits consist of sand and gravel that is much better sorted than the parent till. Glaciofluvial deposits are usually subdivided into ice-contact deposits and proglacial deposits. Ice-contact deposits are fluvial sediments deposited on the surface of, within, or underneath ice. Proglacial sediments are materials deposited by meltwater streams flowing away from the ice margin. The Virden map area includes a wide variety of glaciofluvial features and materials that range from hummocks of shale boulders deposited by subglacial floods (*see* glacial Lake Hind and Arrow Hills Flood in Quaternary History section), to terraces of well sorted sand and gravel laid down in glacial lake outlet channels.

Spillways and meltwater channels

Most channels in the study area are believed to have been excavated by meltwaters during the last deglaciation. In a number of places the meltwaters followed or excavated a valley that existed before the last glaciation, and in almost every place these channels have been modified by postglacial exploitation. Meltwater channels generally have four common characteristics. 1) They are relatively straight: this is because the stream path was controlled by the ice margin, hydrostatic pressure within the glacier, or a steep hydraulic gradient, rather than by local topography as is the case for normal streams. 2) They are underfit: the postglacial runoff that now occupies the channels is only a small fraction of the discharge derived from the melting glaciers that cut the channels. 3) Valley or channel walls are uncharacteristically steep: meltwater channels were cut quickly by large discharges. In most places there was insufficient time for lateral planation or gradation of valley slopes. 4) They have few tributaries, and, where they are present they are generally restricted to one side of the trunk channel. This is because the meltwater that carved the channels generally came from point sources and only from the side nearest to the retreating glacier. Despite these common characteristics, meltwater cut channels in the study area can be subdivided into subglacial channels, ice-marginal channels, spillways, and worm-shaped channels. A channel may evolve from a subglacial or superglacial channel to a proglacial channel or a spillway. Thus, the boundaries between these channels are arbitrary.

Glacial lake deposits

Lacustrine deposits are general flat with less than 2 m relief. They consist of gently rolling terrain devoid of distinctive features and warrant no special discussion. In places however, the morphology of underlying deposits can be seen through a cover of glacial lake deposits. Landforms that are reflections of the morphology of underlying deposits are referred to as palimpsest features. These are discussed in a separate section. Sand dunes are the other features that punctuate areas of glacial lake deposits in places. The dunes consist of lake-deposited sand, but the morphology resulted from wind action and so these are discussed under eolian deposits.

Eolian deposits

Eolian (wind) deposits are widespread in the glacial Lake Hind basin and locally occur in other parts of the Virden area. Patches of sand dunes occur between Oak Lake and the Souris River to the south and the Assiniboine River to the north (*see* surficial materials map NE). These sand dunes form a zone that is about 6 to 10 km wide and curves around Oak Lake and Plum Lake. Dunes are dominated by longitudinal forms that are up to 2 km long and 200 to 400 m wide, and are oriented southeast-northwest. Individual dunes ranges from 5 to 15 m high, with an average height of about 8 m. Average grain size in the dunes ranges from very fine sand to fine sand. Dunes are absent from areas where either surface sediments are coarser than medium sand, or the groundwater table is high. Sheet sand that overlies finer lacustrine sediment in many areas may also be of eolian origin, but for the sake of convenience in mapping has been lumped with the lacustrine sediments.

Palimpsest landforms

Palimpsest landforms result when young sediments drape the morphology of older sediments or rock. The relief and surface form of the young sediments is inherited from the buried topography, with a degree of modification dependent on the thickness of the young sediments. Examples are a bedrock escarpment that is covered, but not buried, by lake sediments and an old valley that is not completely filled by later sediments.

Glacial lake sediments draped over till landforms

The landforms seen in areas covered by glacial lake sediments are in many instances a reflection of the landforms of the underlying till. In areas such as the east side of the Souris River valley, west of Coulter, the till surface is flat and consequently the morphology of the lake sediments also is flat (*see* surficial geology map SE). In the area near Alexandria, on the other hand, the underlying till has a broadly rolling to hilly expression and consequently the lake sediments in that area appear as large hills (*see* surficial geology map NE). It is surprising that till landforms are reflected through a lacustrine sediment cover to such a large degree. In the area south of Alexander, mounds, potholes, and even doughnuts make up an area that is underlain by 2 or more metres of silt. In the area lying at the edge of the glacial Lake Hind basin south of the Souris River, subparallel, closely spaced grooves occur in a generally flat surface (*see* surficial geology map SE). Individual grooves range from 400 m to 5 km long, and from 50 to 150 m wide. The surface sediments consist of 1.2+ m of lacustrine silt that is underlain by till. These features are similar in spacing, orientation, and size to the till ridges that occur in the area to the south between the margin of glacial Lake Hind and Whitewater Lake. It seems likely that the grooves in the lake sediments are an upward reflection of buried till ridges.

Till drapes

The eastern and central parts of Turtle Mountain can be viewed as palimpsest landforms because in these areas the upland consists of a bedrock high draped with glacial sediments (*see* surficial geology map SE). Similarly, the escarpment in Boissevain Formation sandstone that skirts Turtle Mountain is a palimpsest scarp because it is a bedrock feature that is reflected through a cover of thin till. Near Medora, a broad (3 km wide) linear depression cuts through an area of till ridges (Fig. 7). This feature extends northward through the subtle bedrock escarpment that marks the southern edge of the glacial Lake Hind basin and fades out in the flat till plain area north of Wascada. Borehole records have been used to identify a buried valley that crosses this area (Klassen and Wyder, 1970)(Fig. 47, 49). Hence, the subtle depression that can be seen in the surface deposits is a reflection of a valley that was cut and partly filled at sometime prior to the last ice advance.

More subtle and difficult to identify palimpsest features occur in till plains that make up the western part of the area. Eilers (1982), by means of a detailed shallow drilling program in the west-central part of the Virden map area, showed that the surface till is only a few metres thick and that the main landforms are a reflection of the surface of the underlying till. A few kilometres west of Virden, a series of broad (30–60 m wide) low (2–5 m) ridges nose eastward into an area of flat till plain. The ridges are crosscut by, and lie perpendicular to, the pattern of disintegration ridges that occur in this area. Several cuts expose a compact, dark grey, joined till underlying 1–2 m of relatively loose, brown surface till and a pavement of large faceted boulders can be seen 2–4 m below the surface in deeper road cuts and many dugouts. These factors further prove the conclusions reached by Eilers (1982) that the large scale geomorphic features seen in this area are not products of the last glaciation, but were formed during a previous glaciation and draped with a thin layer of till and surficial ice-disintegration features during the last glaciation. Klassen (1979) arrived at a similar conclusion for parts of the Riding Mountain area lying to the north.

Surficial geology map units

Table 7 shows the general structure of the surficial geology legend, and gives the letter designators used on the surficial geology map and the name used for that unit. Descriptions of each unit are included in Table 8.

Feature and symbol descriptions

Geological boundary - This is the line which delineates the limits of a map unit. A solid line delineates a well defined limit (estimated that boundary is accurate within 50 m). Examples are alluvial fans (Af), floodplains (Ap) or other units that can be clearly defined and traced.

A dashed line delineates an approximately defined unit (estimated that boundary is accurate within 250 m). Here there is certainty that the boundary lies within a narrow zone, but the exact position within the zone is uncertain. An example would be where lacustrine plain sediments (Ll) lapped onto a gently undulating till plain (Tp).

Dotted lines are used to delineate an assumed boundary (estimated accurate within 500 m). Here the contact is assumed to lie in a broader zone that is difficult to define accurately. Examples would be sandy lacustrine sediments (sLl) grading into silty ones (Ll), and silty lacustrine deposits (Ll) abutting against a level till plain underlain by sparsely stony till (Tl).

Stabilized sand dunes - low ridges, hummocks, or mounds of loose sand material that has been deposited by wind and subsequently overgrown with vegetation so that wind can no longer move the sand.

Escarpment in unconsolidated materials- A steep slope that is usually of great lateral extent compared to its height, an example is the steep edge of river terraces.

Table 9. Features and symbols

Symbols this map	Standard Symbols	Name
		Geological boundary (defined, approximate, assumed)
		Escarpment in unconsolidated material
		Abandoned channel (large, small)
		Streamlined features developed by glaciofluvial flow
>>>>, <><><>	>>>>, <><><>	Esker (>>>> direction known, <><><> direction unknown)
•	⊗	Conical gravel hill
•	↑	Ice flow direction from striations on boulder pavement
		Moraine ridges (major, minor)
•	×	Bedrock outcrop
• •	⚒⚒	Gravel pit (active, abandoned)
•	f	Fossil locality
•	▼	Radiocarbon age
•	•	Ground observation
⊡	⊡	Till analysis site
•	¤ ¤	Borehole log site (locality, analyses available)

Landslide scar - The part of a slope exposed or visibly modified by detachment and downslope movement of a landslide; usually lies upslope from a deposit of material transported by the landslide.

Abandoned channel - A channel or a valley that is no longer occupied by a stream or one that contains a much smaller stream than the one which cut the channel. In this area most abandoned channels were cut by glacial meltwater, catastrophic floods, or water draining from a former lake. Large channels are generally wider than 200 m; small channels are generally narrower than 200 m.

Abandoned channels are important because they may contain local deposits of aggregate that are not shown as map units. The larger channels may also include important, diverse ecological niches.

Streamlined features developed by glaciofluvial flow - These include smoothly rounded, oval, elongate mounds and smooth, shallow, curving valleys. The general idea is that series of these features were formed by the overland flood of large flows of water.

Areas of these features might contain local deposits of aggregate that are shown as map units.

Esker - A sinuous ridge or complex of ridges of sand and gravel resulting from deposition by meltwater in a tunnel beneath or within a glacier. The ridges generally trend at right angles to a glacier margin, and the sand and gravel may be covered by till or glacial lake sediments.

These features can provide an excellent, easily worked source of aggregate, but in most places in this area they include high contents of shale and/or fines. This high content of deleterious material is common in many glaciofluvial deposits in this area.

Conical gravel hill - Irregular or cone-shaped hill composed chiefly of silty and pebbly sand, and locally of gravel. These features are thought to have formed by deposition of meltwater-transported sediments in contact with glacier ice.

Conical gravel hills or kames can serve as a source of aggregate, but in this area most include an excess of fines and are deficient in material coarser than sand.

Ice flow direction from striations on boulder pavement - The approximate direction of movement of the last glacier as determined from striations on a pavement of boulders. This is one of the few indicators of the direction of ice movement in this area. The ice-flow data is in the FLOWLOG file which is part of the FIELDAT database.

Moraine ridges - Ridges that consist of till, and locally include stratified sediment. The ridges are variable in size and can be as broad as 175 m, or as narrow as a 10 m; in many areas their relief is <2 m but can be as much as 10 m. They can be closely packed so that it is difficult to separate one ridge from the next or spaced at intervals up to 200 m apart. Ridges are generally smoothly curved and subparallel, but can occur in converging and overlapping sets, and locally as crisscrossing sets. High-relief ridges and those containing layers of faulted and folded stratified sediment probably developed by ice thrusting; lower relief crisscrossing patterned ridges probably developed through various glacier ablation processes.

Major ridges are relatively narrow belts of ridges. These belts probably mark the position of a significant advance limit or glacier stillstand.

Minor ridges are small features whose individual extent might be limited, but that collectively form broad fields that extend over in excess of 100 km^2. Rim ridges are a special type of minor moraine ridge that can be almost circular in outline.

Bedrock outcrop - An exposure of bedrock. Bedrock in this area is poorly consolidated and consequently does not form prominent exposures. Most outcrops are located in the walls of meltwater channels, in recently cut valleys, in stream-cut banks, and in excavations such as roadcuts. Because the soft bedrock readily disintegrates, exposed bedrock is soon covered by a mantle of clay or sand.

Gravel pit - A site where gravel or sand has been extracted. The symbol does not indicate the size of the deposit, but does indicate whether extraction was occurring when the pit was visited. In general, gravel pits in glaciofluvial deposits are large, those in alluvial deposits may be extensive, but aggregate units generally are thin, and those within morainal deposits are small and contain poor quality aggregate. This report includes a separate chapter on Aggregate Resources.

Fossil locality - Site where traces of plant or animal remains have been found in surficial materials.

Radiocarbon age - Site where the content of ^{14}C in organic material has been used to provide a geological age.

Ground observation - Site where a field observation has been made. The information collected at this site can be viewed by clicking on the site symbol and using the viewer. The data have been assembled in the FIELDAT database.

Till analysis site - Ground observation site where till was collected and analyzed. The analytical data are included in the GEOCHEM file of the FIELDAT database. It can be viewed by clicking on the site symbol.

Borehole log site - Site of a water well or other boring or excavation that has provided information on the nature of materials underlying the surface. Borehole locations are stored in a separate file from the other symbols (*see* Borehole Locations) The borehole data are stored in the BORDAT database. Most of this information came from the GWDrill files of the Manitoba Water Resources Branch and from Saskatchewan Water Corporation. Exact borehole locations were not available so the symbols were plotted at the centres of the enclosing quarter sections.

A locality symbol enclosed in a box indicates that special deposit analyses are available for that site. This, and other information, can be accessed by clicking on the site and using the borehole viewer.

Surficial deposit stratigraphy

Introduction

This part of the plains area is relatively flat and there are few natural exposures. Consequently, most stratigraphic data are derived from boreholes and a few excavations. The prime data sources are records for about 9000 water wells and test holes that have been compiled in the file referred to as BORDAT (display borehole data). Observations from surface exposures are included in a file referred to as FIELDAT (display field data); however, few of these observations extend below a depth of 1 m.

The information in BORDAT came primarily from the Manitoba Water Resources Branch 'GWDrill (ND)' database (for further information on 'GWDrill', contact Manitoba Water Resources Branch, 1577 Dublin Ave., Winnipeg, R3E 3J5, (204) 945-7403). Information for the Saskatchewan part of the area is from Saskatchewan Water Corporation (Saskatchewan Water Corporation, 111 Fairford St., Moose Jaw, Saskatchewan, S6H 7X9, (306) 694-3900) and Saskatchewan Research Council (Saskatchewan Research Council, Resource Technology Division, 15 Innovation Blvd., Saskatoon, Saskatchewan, S7N 2X8, (306) 933-5400). The data was extracted from ASCII formatted files and edited into a dBASE® format file by L. Murray of Environmental Earth Sciences Associates, Calgary. Elevations were obtained by means of a digital elevation model run in ArcInfo℠.

Several important items concerning the BORDAT information must be kept in mind.

Location accuracy - in the original databases, the borehole sites are located in terms of section, township, and range (most to the nearest quarter section). The UTM locations in BORDAT refer to the centroid of the nearest quarter section. This means that the location given could be as much as 285 m in error. Also it means that all boreholes that fall within a quarter section are shown as occurring at the same point. The 'comments' entry for some boreholes contains more precise information on borehole location. In order to direct the user to what we consider to be the best log of a group plotted at the same point, we have designated certain records as 'Display wells' (indicated by Y in the DSP_WELL field of the database). Criteria used in selecting display wells were: rated log quality (*see* below), whether hole reached bedrock, and total depth. The total number of holes that are used as display wells is 4392.

Elevation accuracy - Borehole elevations were determined using a digital elevation model based on 1:50 000 scale digital databases. This probably means that the accuracy in determining point elevations is about one quarter of a contour interval (10 m). Given the borehole location accuracy (*see* above), however, ±5 m is probably a more realistic estimate of elevation accuracy. The error will, however, be greater in areas of higher relief than in areas of lower relief.

Geological quality - The quality of the BORDAT records varies and each record has been given a qualitative 'Relative Rank' (1 to 5). The highest rank, 1, is given to records that were collected by a geologist and are backed by compositional analyses and geophysical logs. The lowest rank, 5, is given to records where little is known of the driller or the person who logged the hole.

Unit descriptive information - This is based on drillers' logs that were recorded by many different workers with a wide range of backgrounds and experience. The user is warned that the materials information comes directly from a driller's log and has not been verified. In addition, in order to plot and manipulate the data, we have converted the original driller's description to standard simplified terminology. Examples of the types of conversions made are 'stoney clay' and 'hardpan' were changed to 'till', and 'sand and gravel' was changed to 'dominantly sand with some gravel'. The original driller's description however, has been retained in the database, and in the CD-ROM viewing application is referred to as 'Driller's Description'.

Drift thickness and bedrock surface

The drift thickness and bedrock surface contour maps were developed from the BORDAT database, locations of outcrops indicated on the bedrock geology map (*see* bedrock geology map), and FIELDAT records of bedrock exposure. In total, about 1666 data points were used in drawing the maps.

Elevation data for the top of bedrock was interpolated at the nodes of a 400 m grid. Drift thickness was generated by subtracting the bedrock surface grid from a grid of the topographic surface. Drift thickness in the Virden map area varies from about 0 to 120 m with an average of about 15 m. It tends to be uniformly thickest in the southwest, west-central, central, and the northeastern and southeastern corners of the area. The drift is uniformly thin in several areas: 1) a patchy belt that extends from the northwestern corner of the area, 2) a northeast-southwest-trending belt that lies on the south side of the Souris River, 3) a belt that largely coincides with the Assiniboine River valley, and 4) a narrow belt flanking Turtle Mountain that coincides largely with subcrop of the Boissevain Formation (Bamburak, 1978).

As mentioned above, the bedrock surface was outlined by modelling a grid from bedrock intercepts of boreholes. Because it was interpolated by automated techniques, the resulting contour map is relatively coarse and does not contain obvious recognizable features such as buried valleys. These features are much better shown on the hand contoured maps of Klassen and Wyder (1970) and Betcher (1983). In a general way the bedrock surface mimics the present land surface with the highest bedrock underlying Turtle Mountain and the lowest occurring in the northeast corner of the map area. A pronounced broad, depression in the bedrock surface extends from the southwest corner to the northeast corner of the area. This extends under the Oak Lake lowland (Fig 6). Klassen and Wyder (1970) refer to this broad feature as the 'preglacial Missouri Valley'. An inner valley (within the broad depression) that extends north from the International Boundary to Pierson and from Pierson northeast towards Oak Lake, has been referred to as the 'Pierson Valley' by Klassen and Wyder (1970). On the east side of the Souris River valley, a chain of anomalously low areas suggests the presence of a narrow buried valley. Klassen and Wyder (1970) and Betcher (1983) include this feature on their maps. It has been referred to as the 'Medora Valley'. Two of the cross-sections that accompany this report include this feature (*see* Fig. 47, 49). A buried valley that probably is related to an earlier path of the Assiniboine River, lies to the west of, and parallels, the present-day Assiniboine River at the northern edge of the area. The extent of this feature is uncertain, with Klassen and Wyder (1970) showing it as extending into the Oak Lake lowland and Betcher (1983) showing it as joining the present-day Assiniboine River valley north of Virden. This buried valley has been referred to as the 'Virden Valley' (Klassen and Wyder, 1970).

Regional stratigraphy

The surficial deposits in the Virden map area consist dominantly of till with minor stratified sediments (gravel, sand, silt, and clay). The till was deposited during several glaciations, but deposits related to all of the glaciations which affected the area are not present in all parts of the area. In addition, most till in the area is uniform, calcareous, silty, sandy, grey, and hard, and does not include delimiting intertill units or distinctive characteristics that would make it easy to trace units related to particular ice advances. The Saskatchewan Research Council has used carbonate content, geochemical analyses, and geophysical logs to correlate borehole records of many of the quality 1 holes that are included in BORDAT with the standard Quaternary stratigraphic scheme that is used in Saskatchewan (Schreiner and Millard, 1995; Schreiner, 1990; Christiansen, 1992). Table 10 lists the Quaternary stratigraphic units used in this study and describes the dominant characteristics of each unit. The initial quality 1 hole correlations were extended to adjacent quality 2 holes. This second level of correlation was based on similarities in unit succession and in drillers unit descriptions. The results of these correlations are shown in a series of cross-sections that are part of this report (Fig.12 to 51).

The units described in Table 10 were used in constructing a three-dimensional model of the surficial geology of the area. This was done by J.D Hughes and W.J. McDougall of the Geological Survey of Canada, Calgary using an 'Expert System' developed to model coalfields (Hughes, 1993). This system employs a sophisticated multiple-surface logic to identify the positions of missing layers and to automatically determine pinch-outs, and other reasons for nonpenetration of layers. The surfaces were then interpolated to the nodes of a 400 m grid. Once the model has been created, unit isopach maps can be drawn, cross-sections can be generated at any position, and predictions can be made of the stratigraphic succession that would be penetrated if a hole was drilled at any location. Two types of models were created using this system. The first utilized elevation data for the boundaries of till and other stratigraphic units (SSD, Battleford, Floral, Warman, Suther_B, and Suther_A units) to define the geometry and thickness of each stratigraphic unit (*see* surficial stratigraphic unit isopach maps, SSD, Battleford, Floral, Warman, Suther_B, and Suther_A units). The second mapped the distribution of aquifer materials within depth slices without regard to stratigraphic units.

Information on distribution and thickness of each unit derived from these maps is incorporated into the unit description that are given below.

Till units exposed at surface

Multiple till units were recognized in very few surface exposures. Where present, these generally consisted of the upper two tills. In exposure the surface till is a dark brown, relatively loose, sandy diamicton, that locally contains lenses of stratified sediments. This unit is considered as correlative with the Lennard Formation of the Riding Mountain area to the north (Klassen, 1979). The Lennard Formation has been correlated with the Battleford Formation of Saskatchewan (Christiansen, 1992). A pavement of boulders, ranging in size from 10–100 cm, lies near the contact of the surface and the underlying till in many places (Fig. 52, 53). In some places it may lie slightly below and in others slightly above the contact. The most distinctive of the boulders are tabular, tan-coloured carbonate rocks that lie with their largest surfaces in the plane of the pavement, but there are also many rounded and bullet-shaped boulders that consist of a variety of metamorphic and granitic rock types. Some of the boulders within the pavement are marked by roughly parallel striations that indicate the general direction of flow of the last ice sheet to occupy this area. Measurements of these striations are recorded in the 'Ice Flow Data' table (for viewing *see* display field data). An excellent description of boulder pavements and discussion of their origin is given in Elson (1956). The main areas where this pavement can be seen are on the Boissevain bench, the northern edge of the Boissevain plain, and the Pipestone Creek plain (Fig. 6)

The second till below the surface as seen in exposures is generally a compact, very dark grey, silt diamicton that has fractures that die out downwards. Material within the fractures is oxidized and the fractures in many places have manganese oxide coatings. This till is here referred to as the Minnedosa Formation (Klassen, 1979). The Minnedosa Formation has been correlated with the upper part of the Floral Formation of Saskatchewan (Christiansen, 1992). Two tills can be most often seen where the surface till is thin (Boissevain bench, the northern edge of the Boissevain plain, and the Pipestone Creek plain Fig. 6).

An extensive comparison of the two surface tills was done in the west-central part of the area by Eilers (1982). In this study, samples of the two tills were collected in about 150 four- to five-metre cores. The surface till (referred to as Battleford)

Table 10. Prime characteristics of surficial stratigraphic units of the Virden area.

Unit name[1]	Letter on cross-sections	Prime characteristics
Saskatoon Group: surficial stratified drift (SSD)	G	Gravel, sand, silt, and clay that lie at the surface (overlie till or bedrock). The main continuous area of SSD is in the former basin of glacial Lake Hind in the northeast quarter of the area, with a continuous area extending southward into the area formerly occupied by glacial Lake Souris (*see* SSD isopach map).
Saskatoon Group: Battleford unit	F	Till that is at the surface or overlain by stratified sediments. It is oxidized in most places, sandy, and soft. Because of oxidation and leaching, its geochemical values are variable. This unit is present tthroughout the area and is generally thin (<10 m) but exceeds 40 m in the northeastern and southeastern parts of the area (*see* Battleford isopach map).
Saskatoon Group: Floral unit	E	Hard silty grey tills that are generally overlain by soft sandy Saskatoon Group: Battleford till. Tills of this unit are generally highly calcareous, and upper parts in many places contain oxidized till that extends down fractures. Contents of vanadium are moderately low and those of zinc medium low. This unit is present throughout most of the map area, is thickest in a belt running north-south through the centre of the area, is absent or thin in a north-south belt in the east-central part of the area, and generally ranges in thickness between 5 and 20 m. (*see* Floral isopach map)
Sutherland Group: Warman unit	D	Tills of this unit are hard, silty, grey, and calcareous. Carbonate content is generally lower than in the Saskatoon Group: Floral unit, the vanadium content higher, and the zinc content about the same. This unit is limited largely to the western part of the area and generally is <50 m in thickness. (*see* Warman isopach map)
Sutherland Group: Suther_B[2] unit	C	Tills of this unit are hard, silty, grey, and calcareous. Their carbonate content is slightly higher than the overlying Sutherland Group: Warman unit, but lower than the Saskatoon Group: Floral unit. Vanadium content is lower and zinc content higher than in Sutherland Group: Warman unit; vanadium values are higher and zinc values higher than Sutherland Group: Suther_A unit. It occurs largely in the southwestern part of the area with a thick east-west-trending tongue in the north central part of the area. (*see* Suther_B isopach map)
Sutherland: Suther_A[2] unit	B	Tills of this unit are hard, silty, grey, and calcareous. They generally have a higher carbonate content than all units other than Saskatoon Group: Floral unit and vanadium and zinc contents are higher than in the other units. This unit appears to occupy the general depression that extends southwest to southeast through the central part of the area with a north-south belt in the western part of the area. In most places it lies on bedrock, but locally it lies on Empress Group deposits. (*see* Suther_A isopach map)
Empress Group	A	The deposits included in this unit generally consist of sand, silt, and clay with minor gravel. This unit is overlain by till and overlies bedrock. It has been identified in the bottom of some of the buried valleys. Unfortunately, because of its restricted and discontinuous nature, it did not lend itself well to automated contouring techniques.

[1] The unit names used in this table are in most cases similar to those used in the standard stratigraphic succession at Saskatoon (Christiansen, 1992).

[2] In the Saskatoon succession, the two lowest tills are referred to as the Dundurn and Mennon formations. There is some uncertainty over whether units correlative with these formations are present in this area and consequently the lowest two till units in the boreholes are labelled ‘Suther A’ and ‘Suther B’.

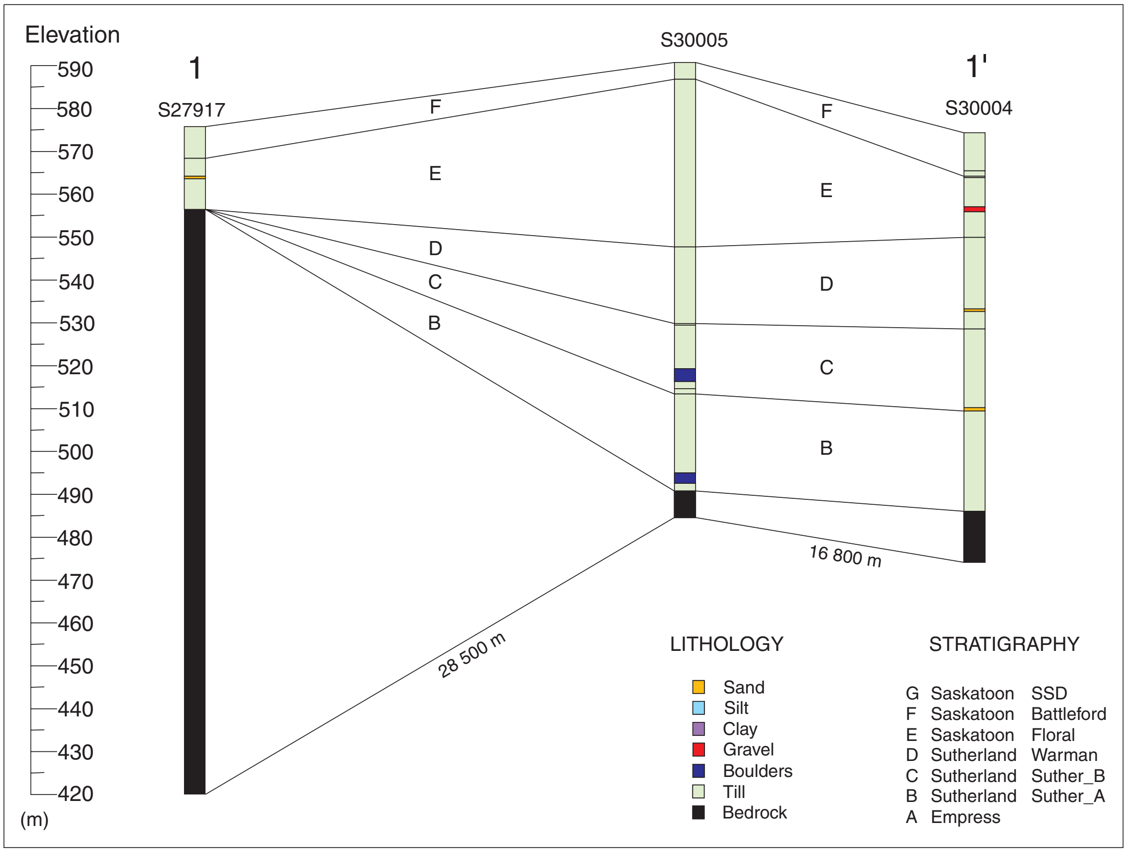


***Figure 12.** Cross-section 1–1 .*

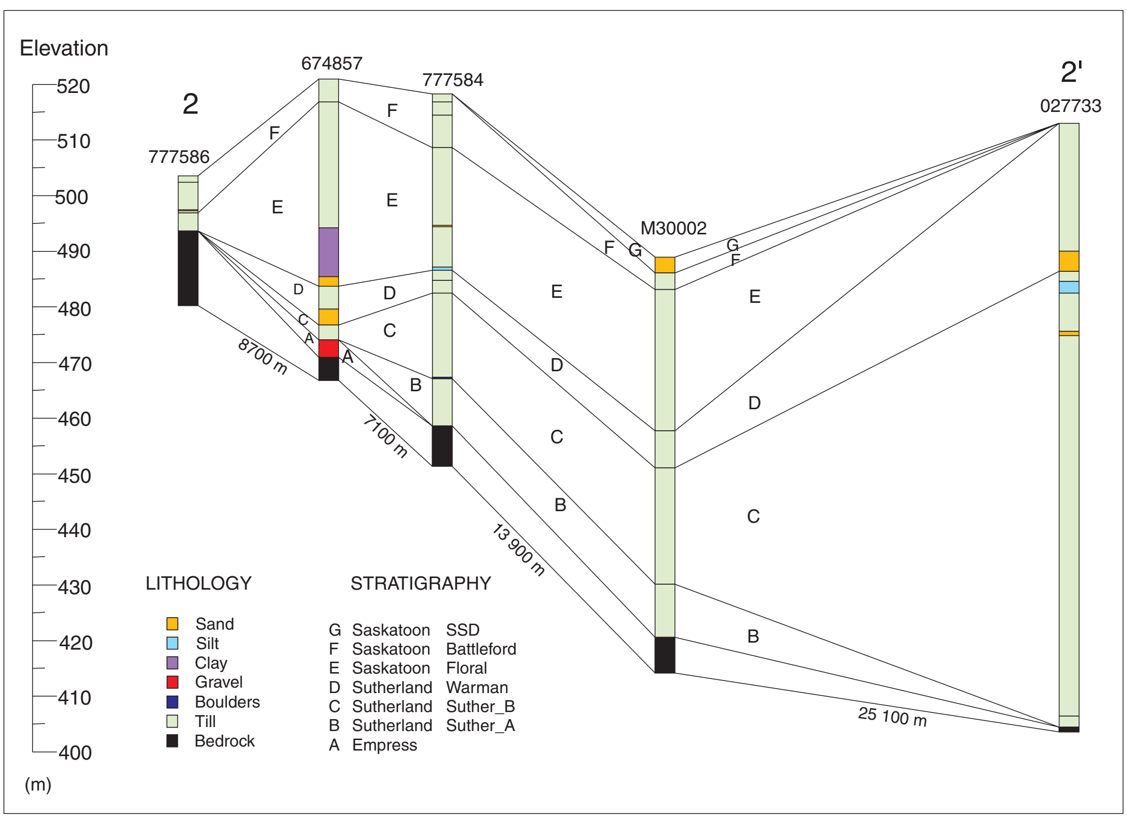


***Figure 13.** Cross-section 2–2 .*

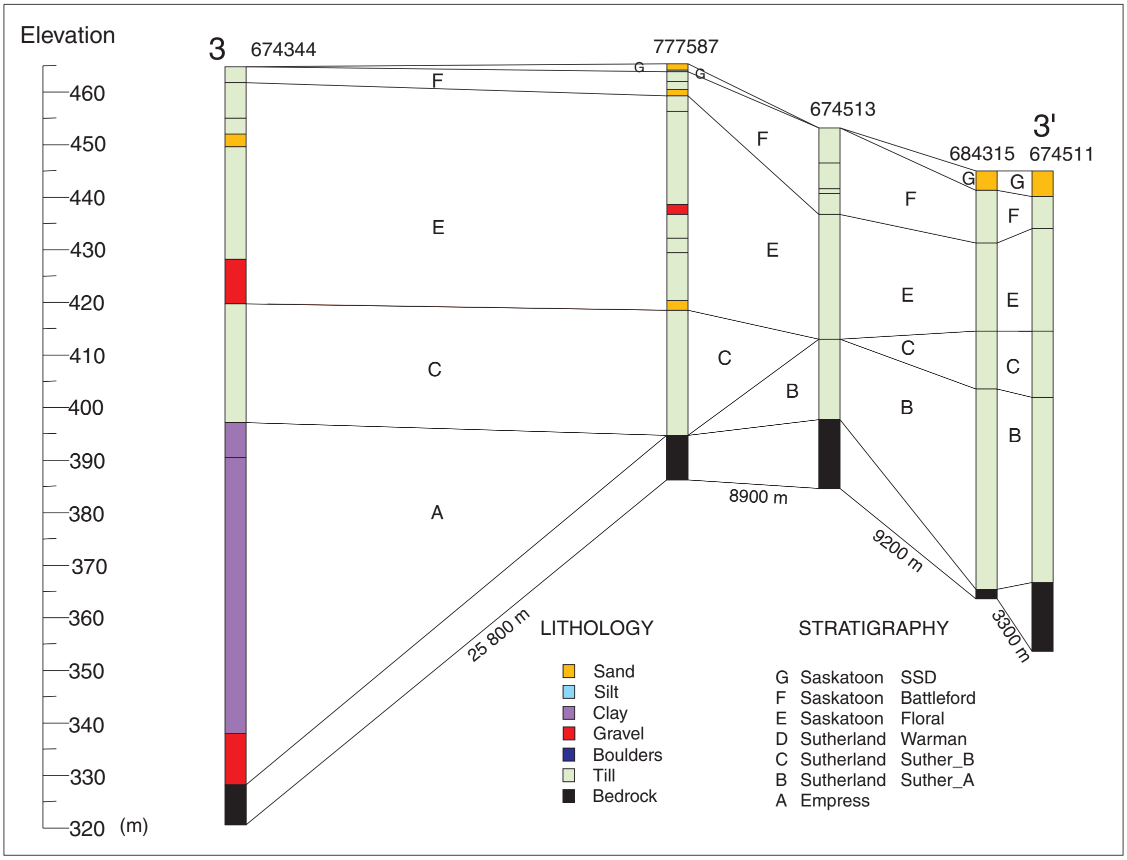


Figure 14. *Cross-section 3–3 .*

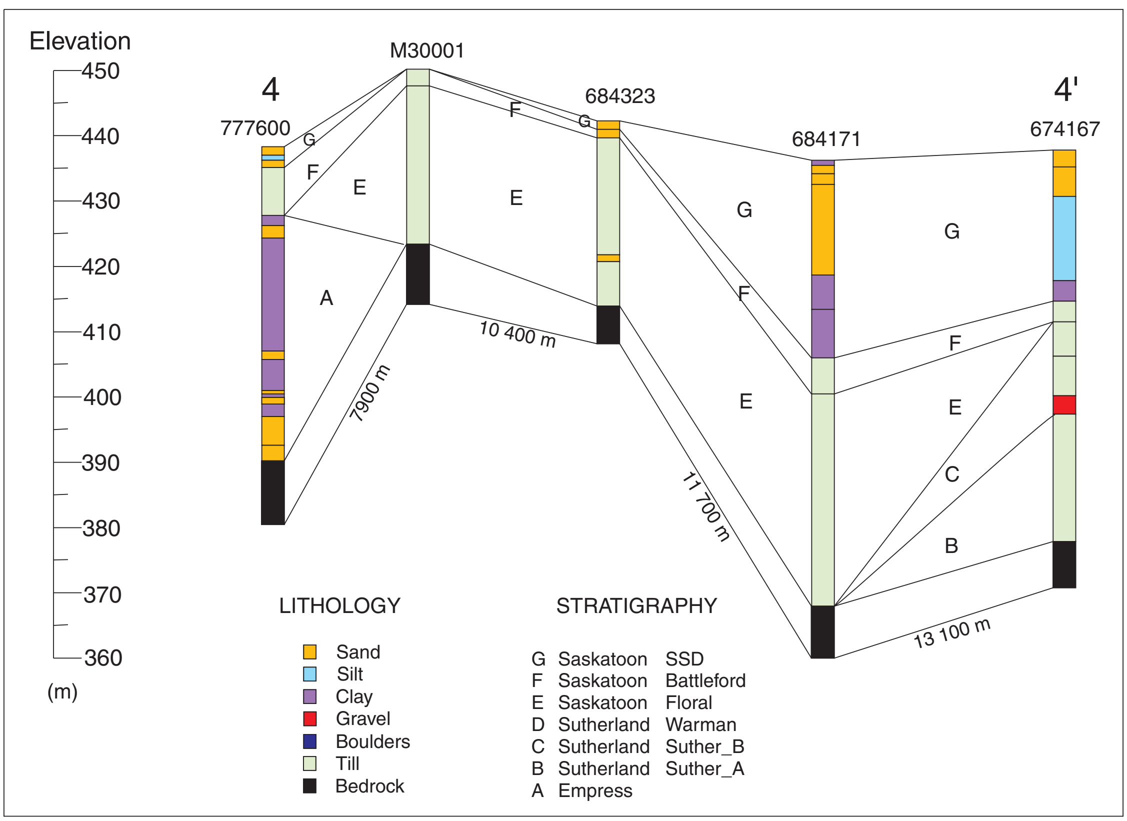


Figure 15. *Cross-section 4–4 .*

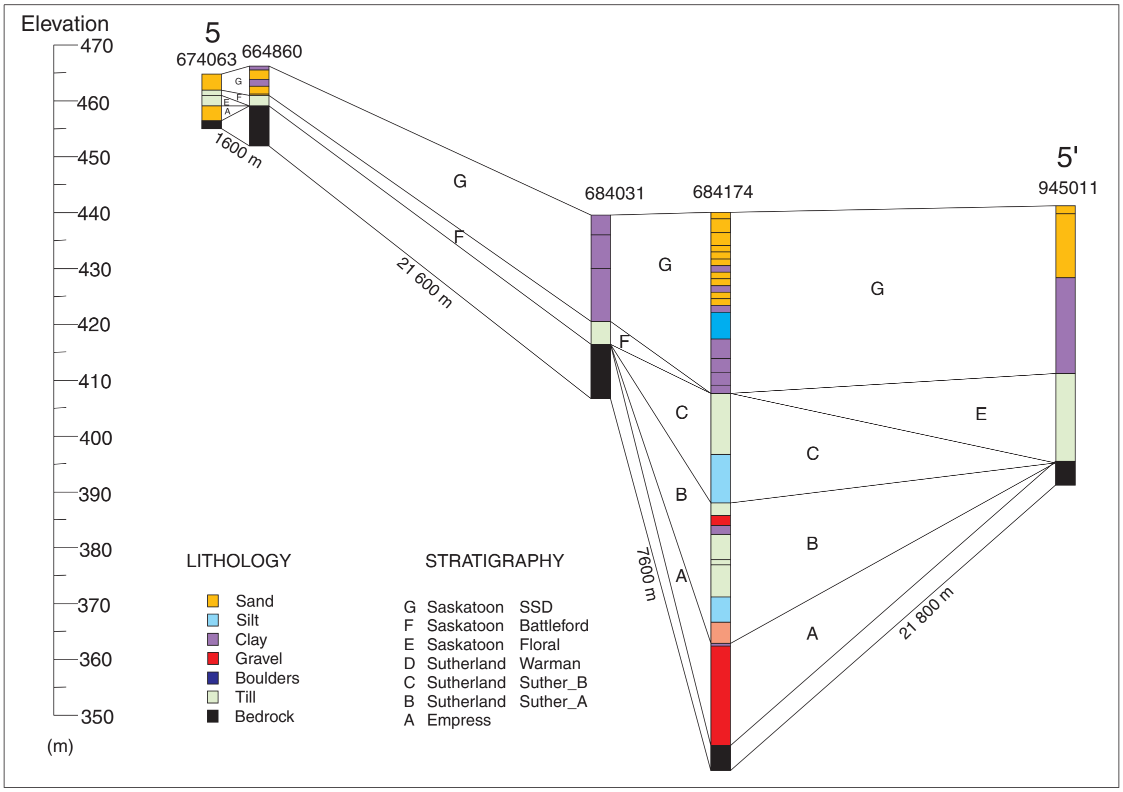


Figure 16. *Cross-section 5–5 .*

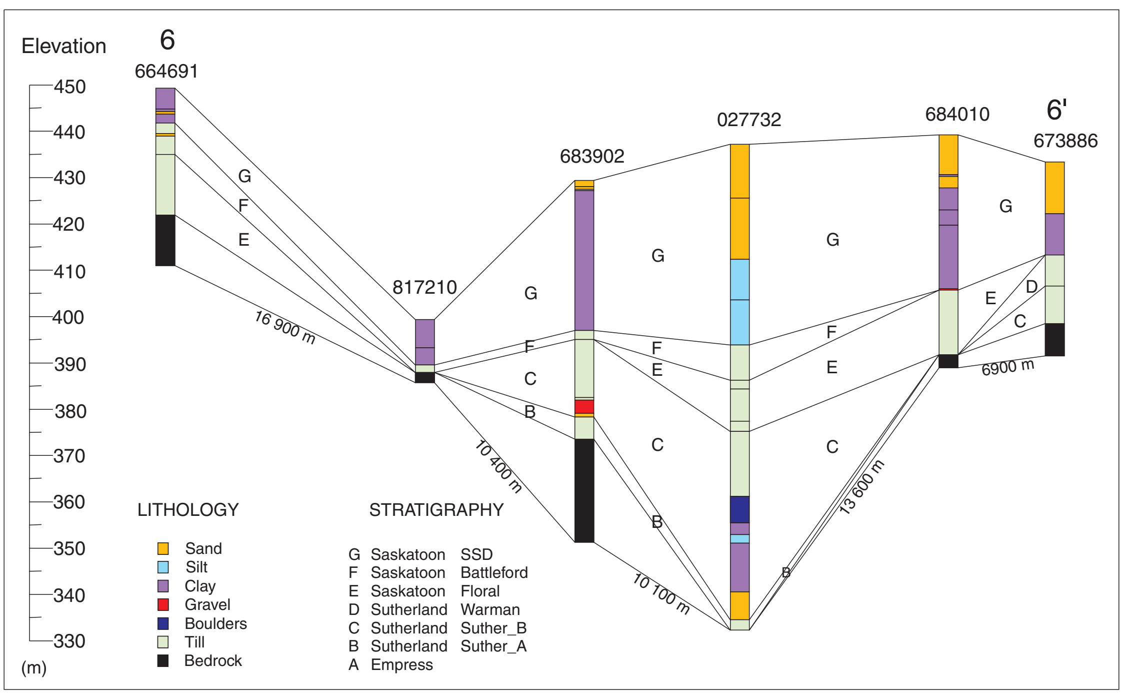


Figure 17. *Cross-section 6–6 .*

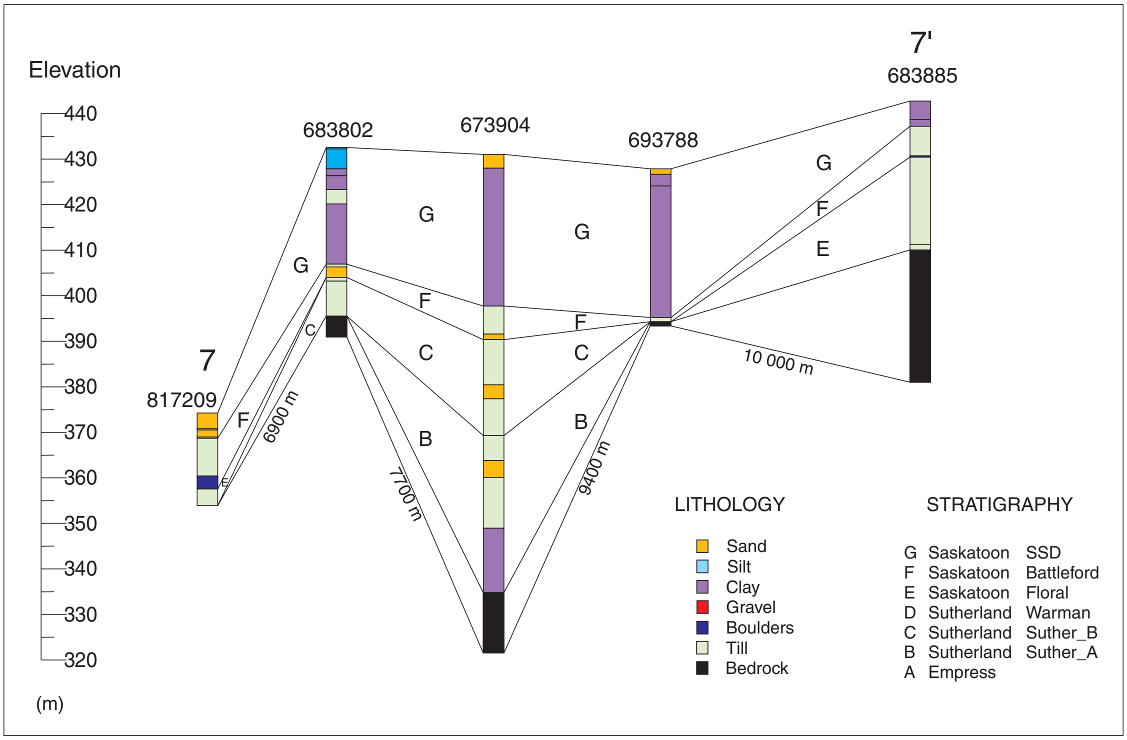
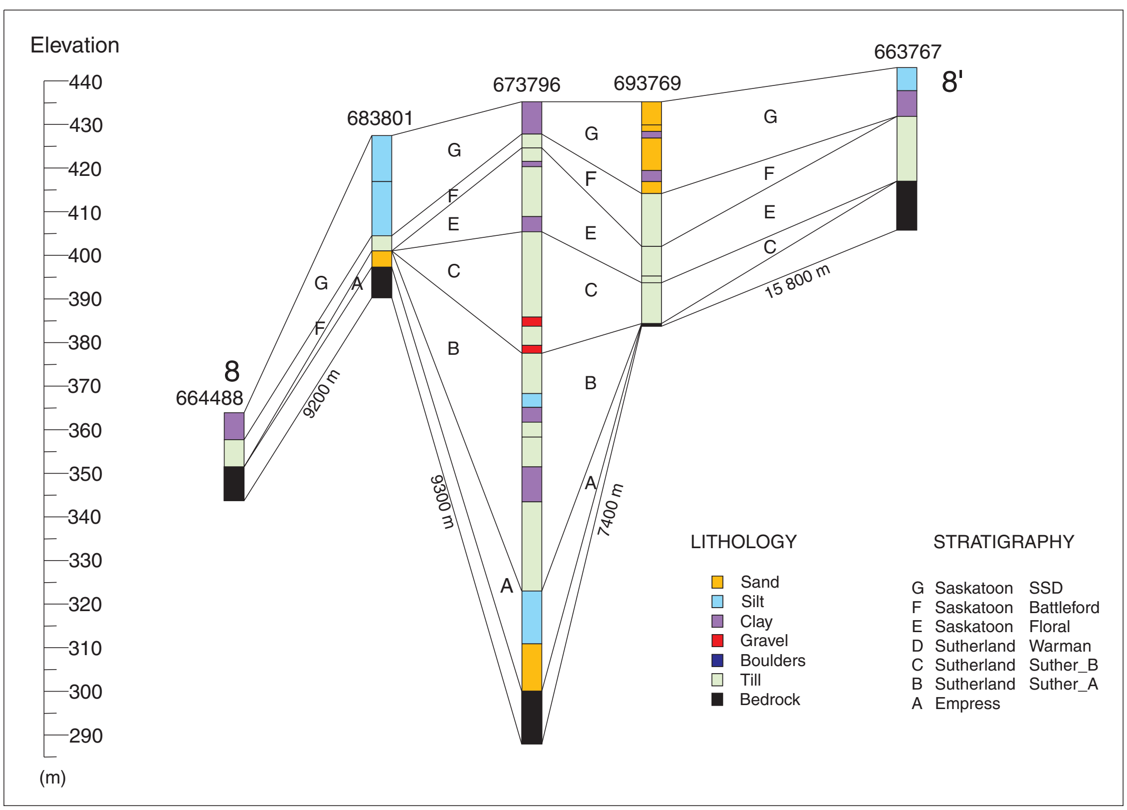


Figure 18. *Cross-section 7–7 .*



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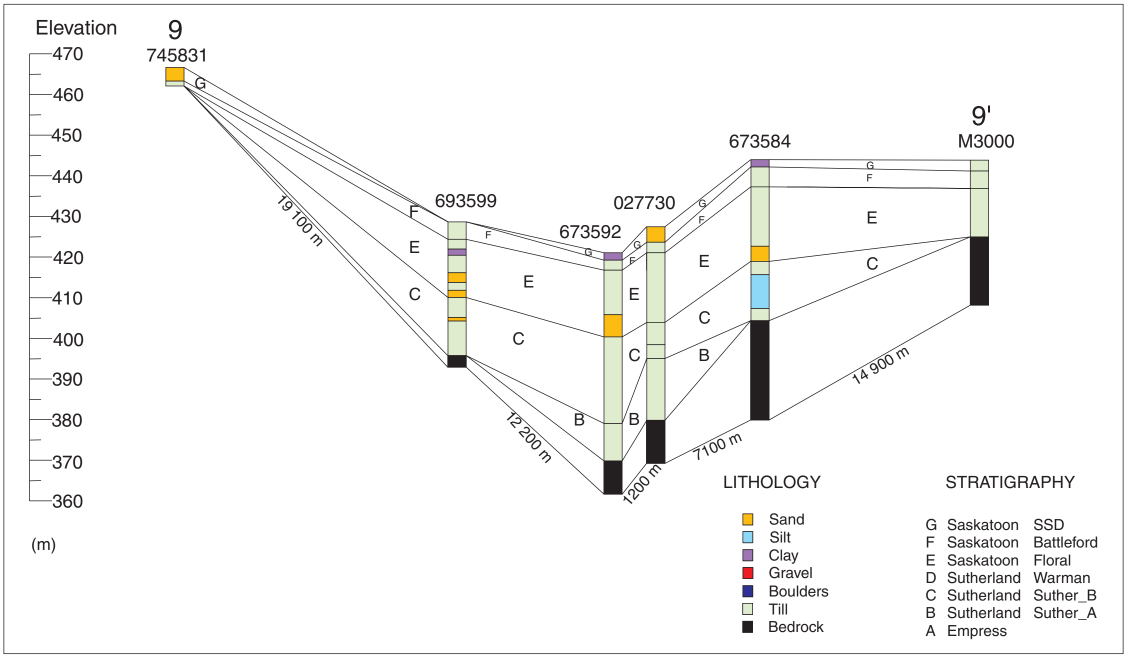

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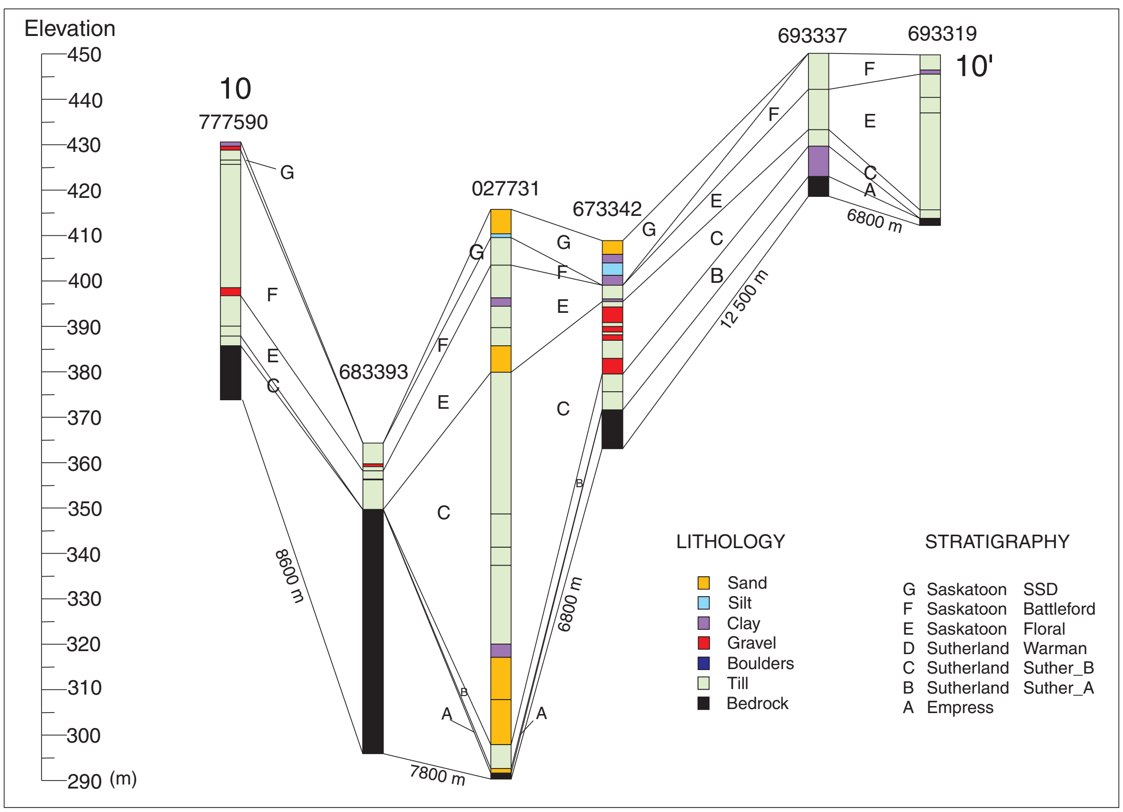

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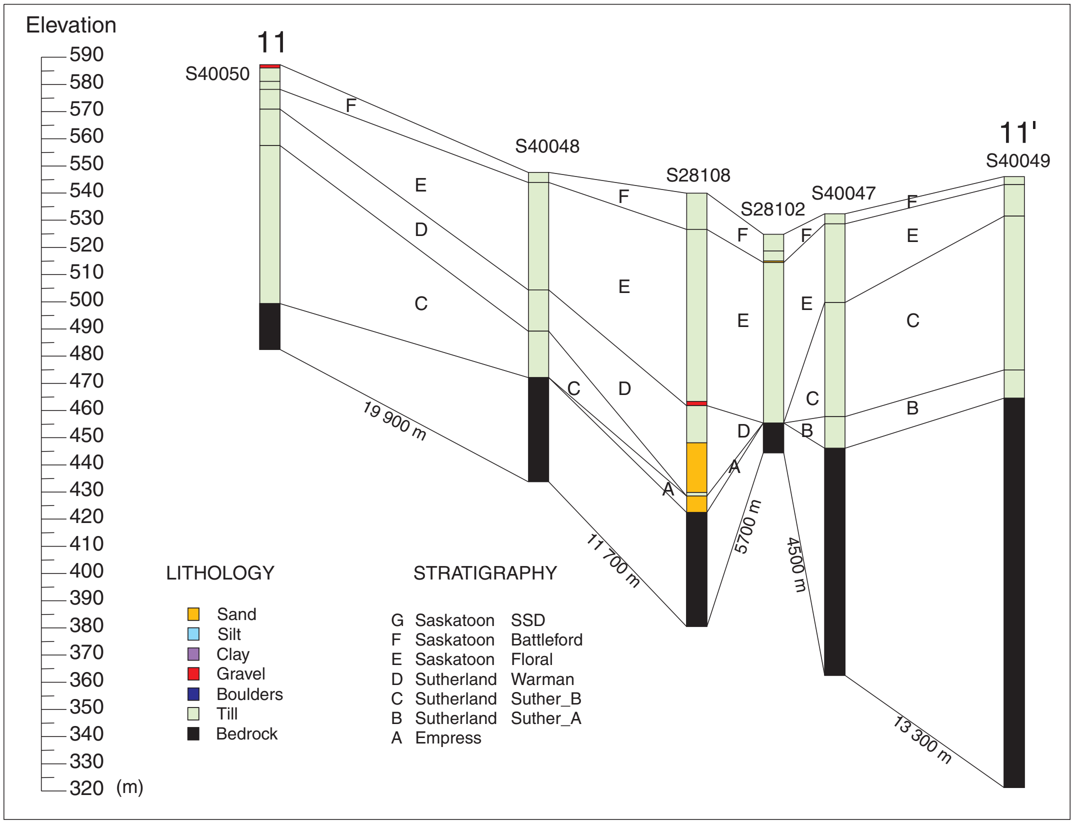

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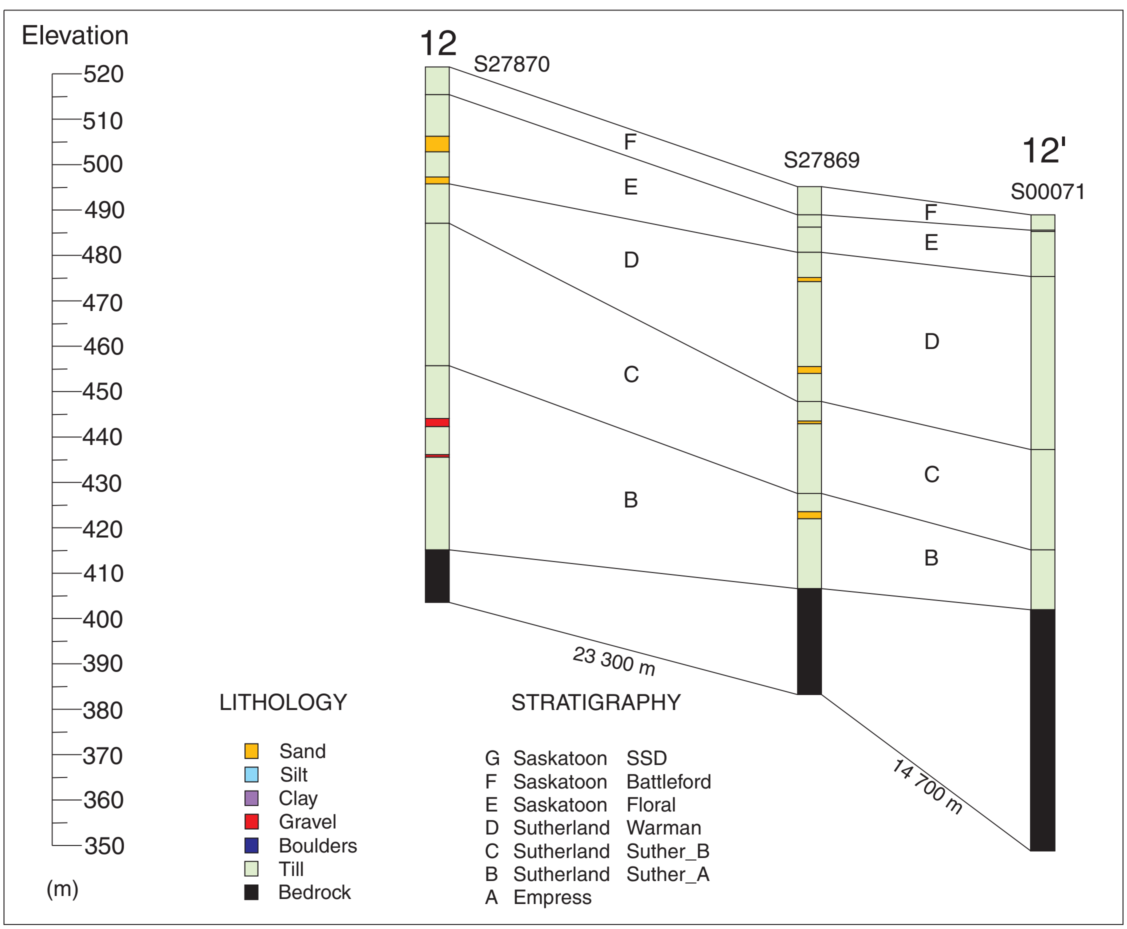

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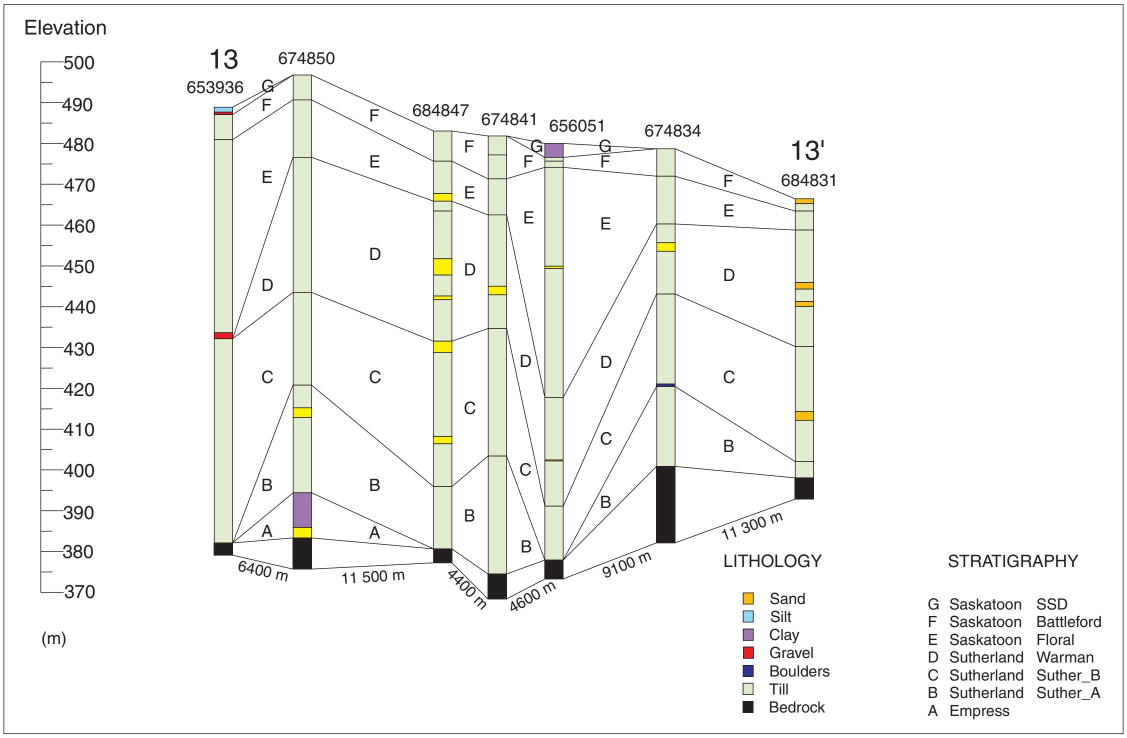

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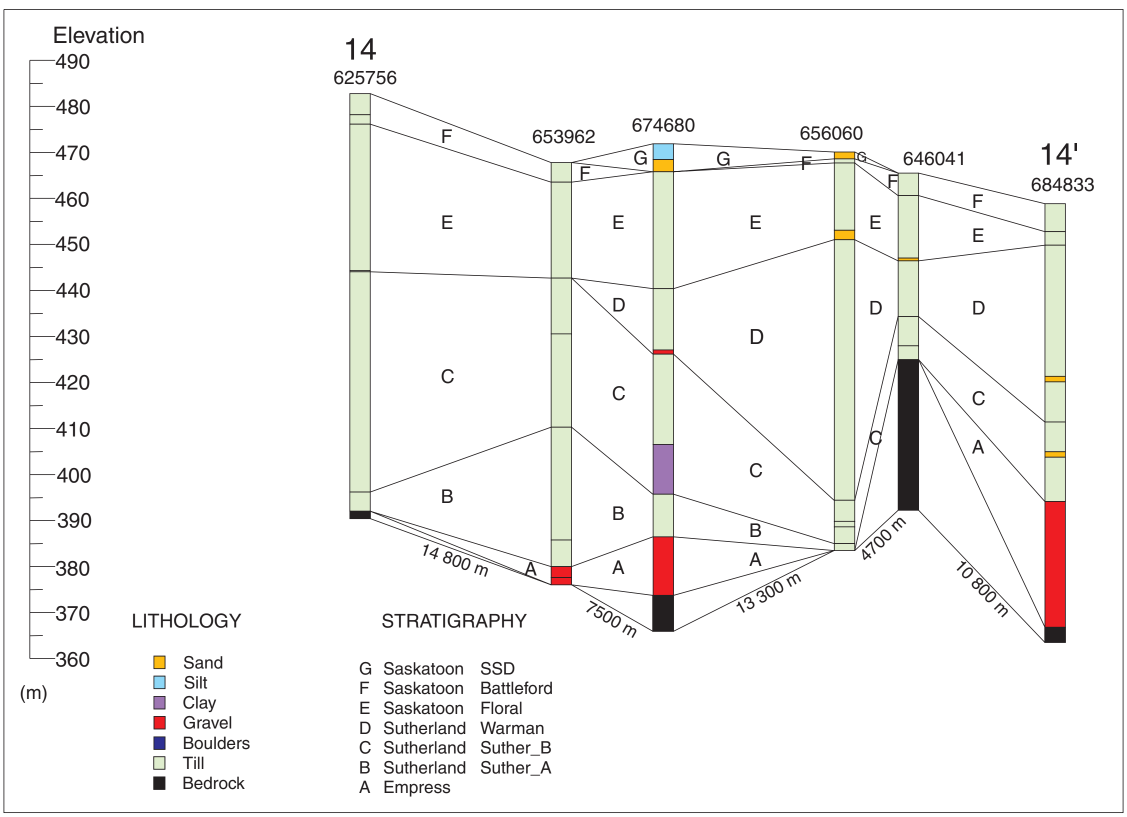

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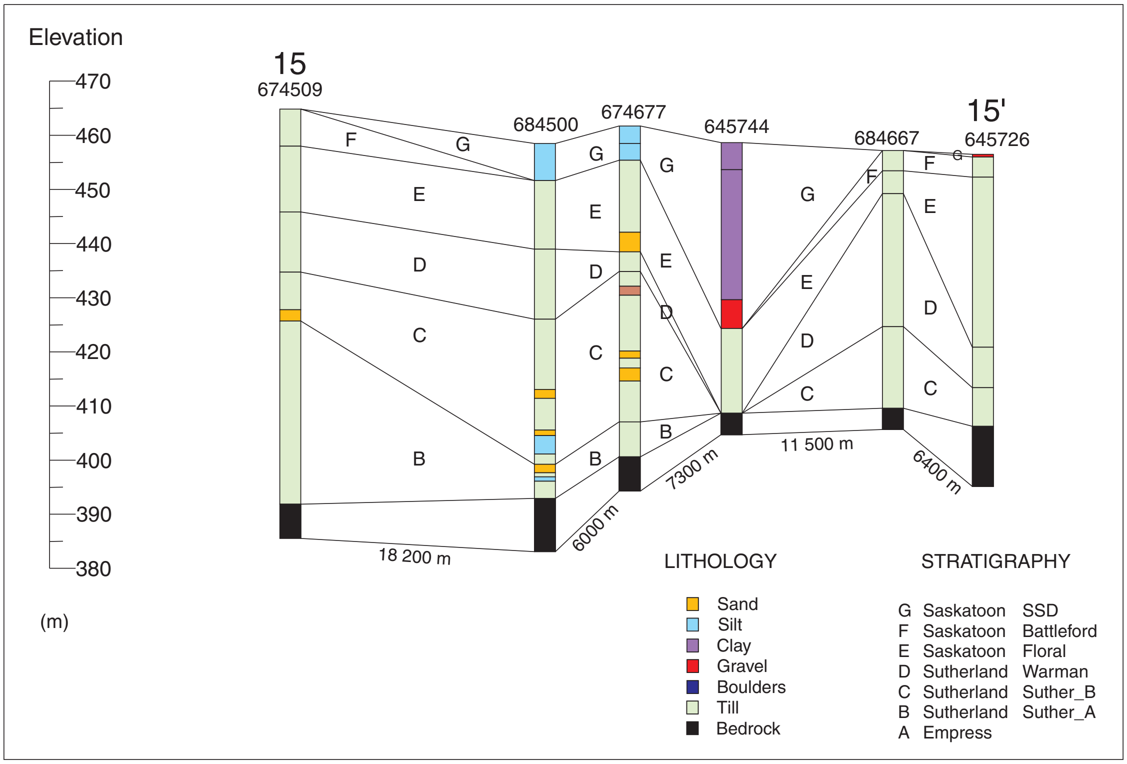

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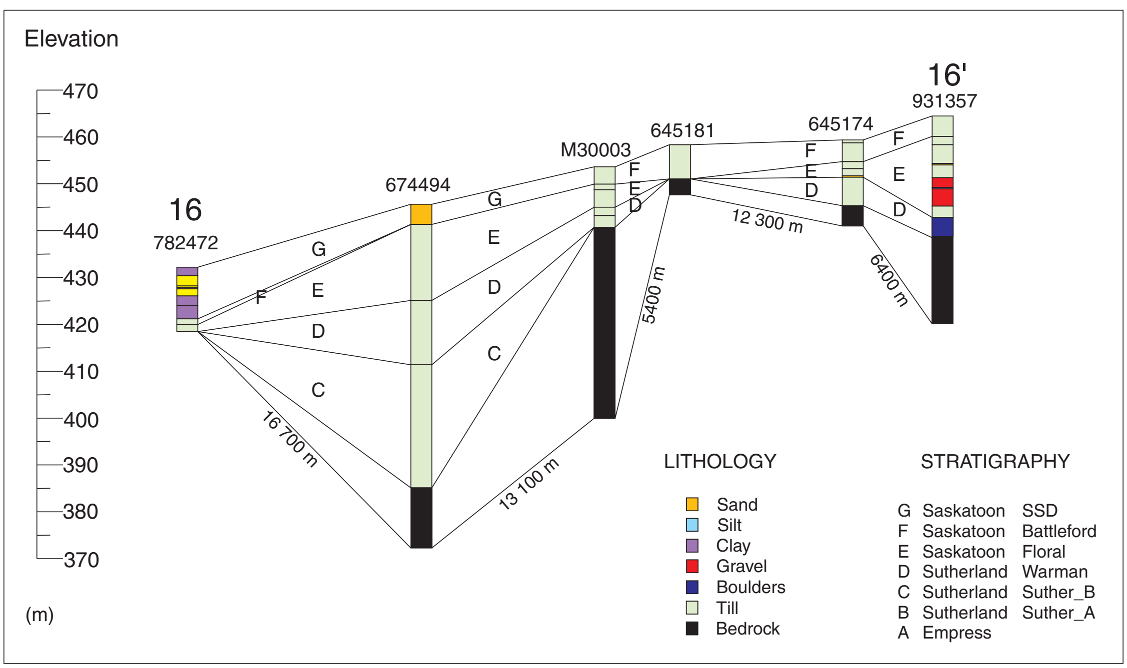

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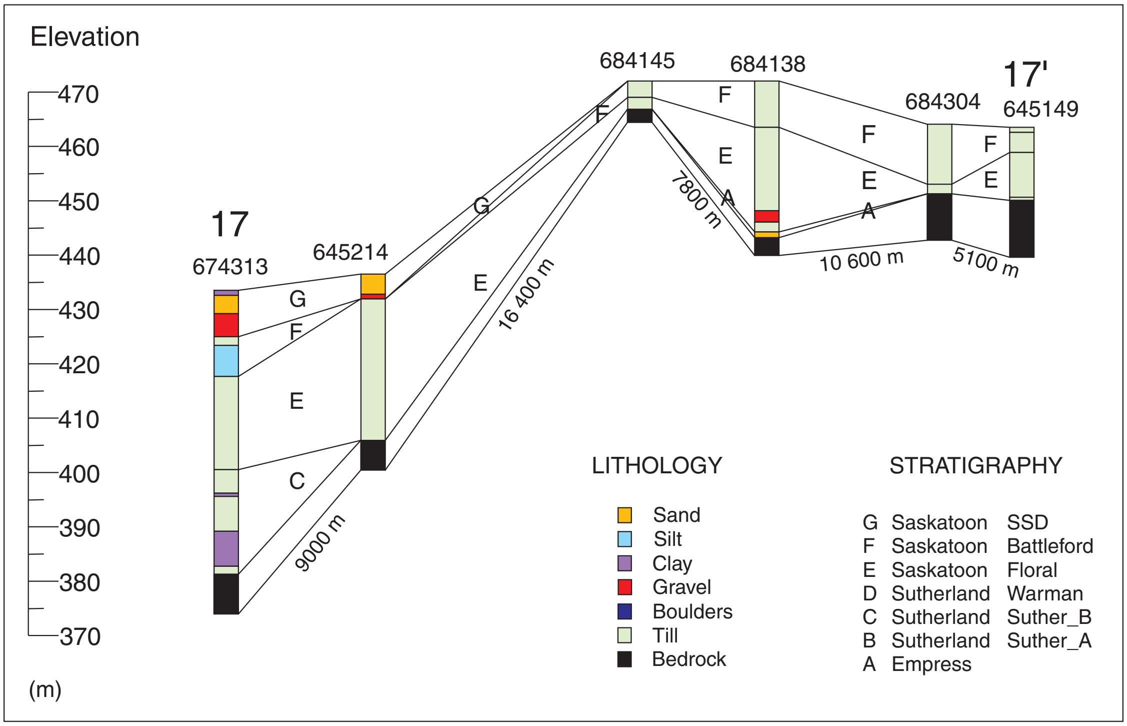

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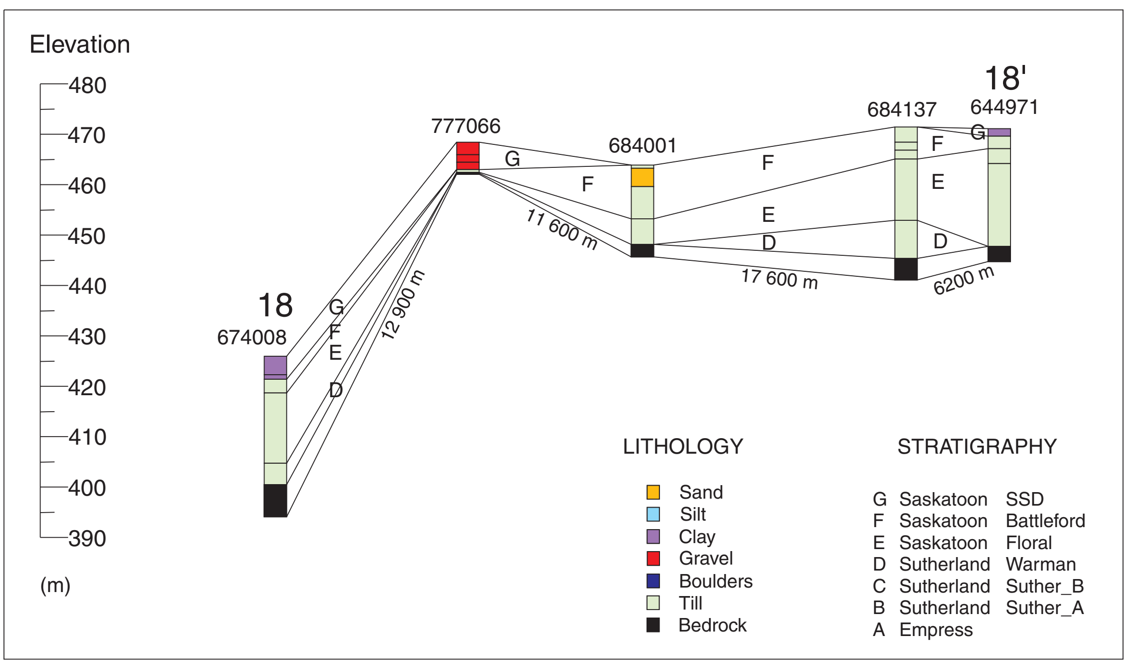

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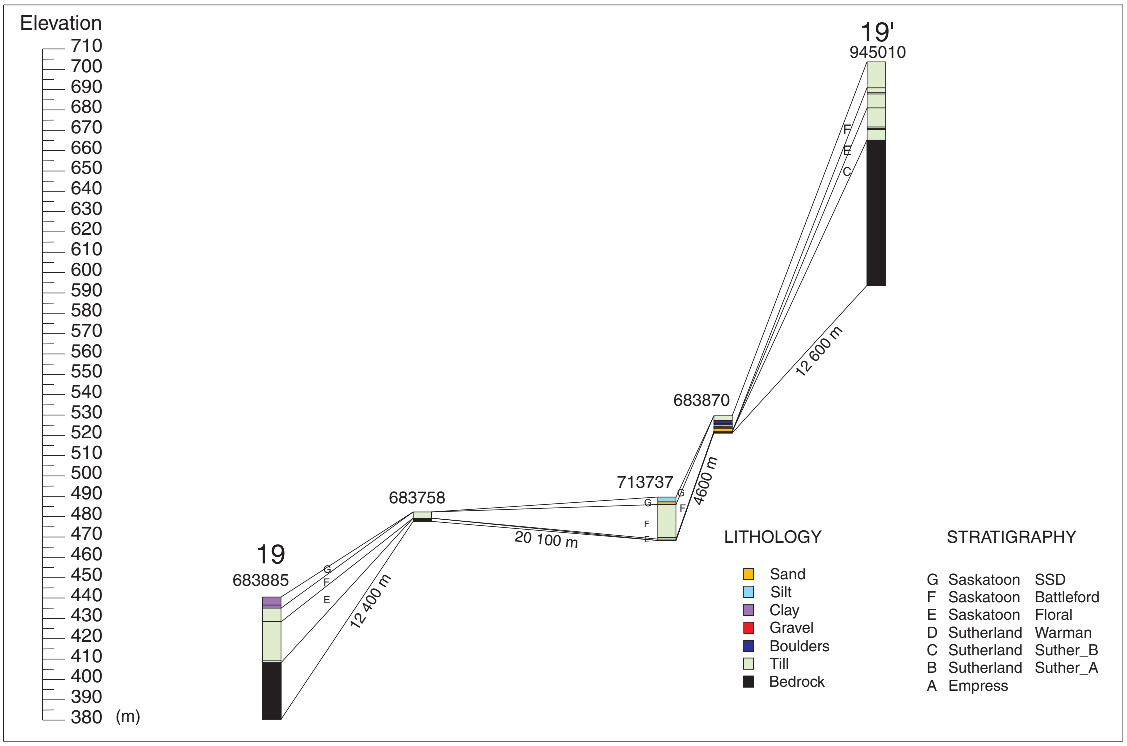

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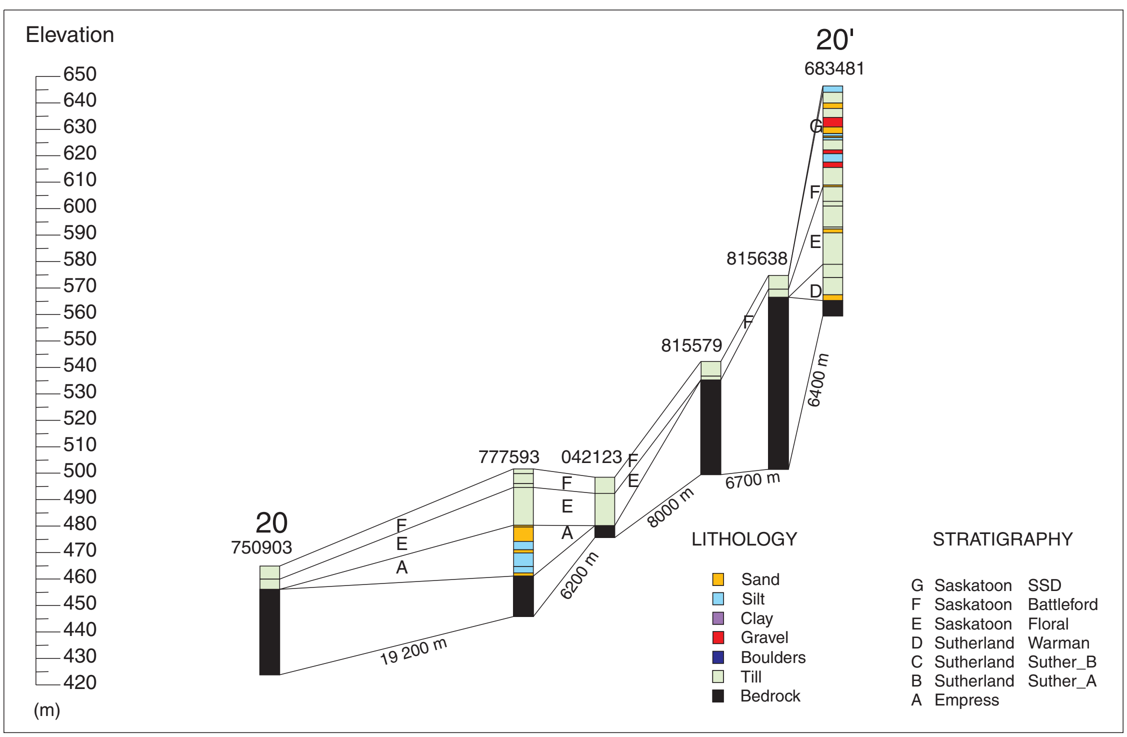

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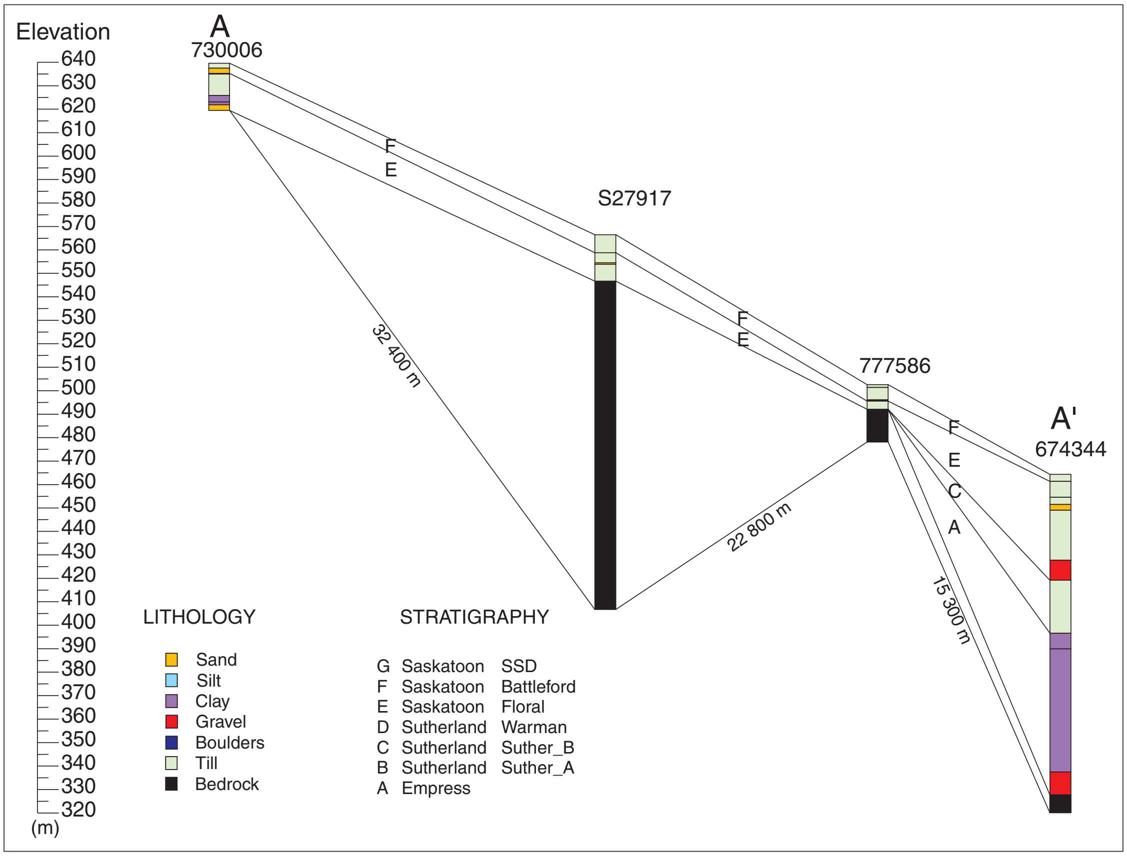


***Figure 32.** Cross-section A–A .*

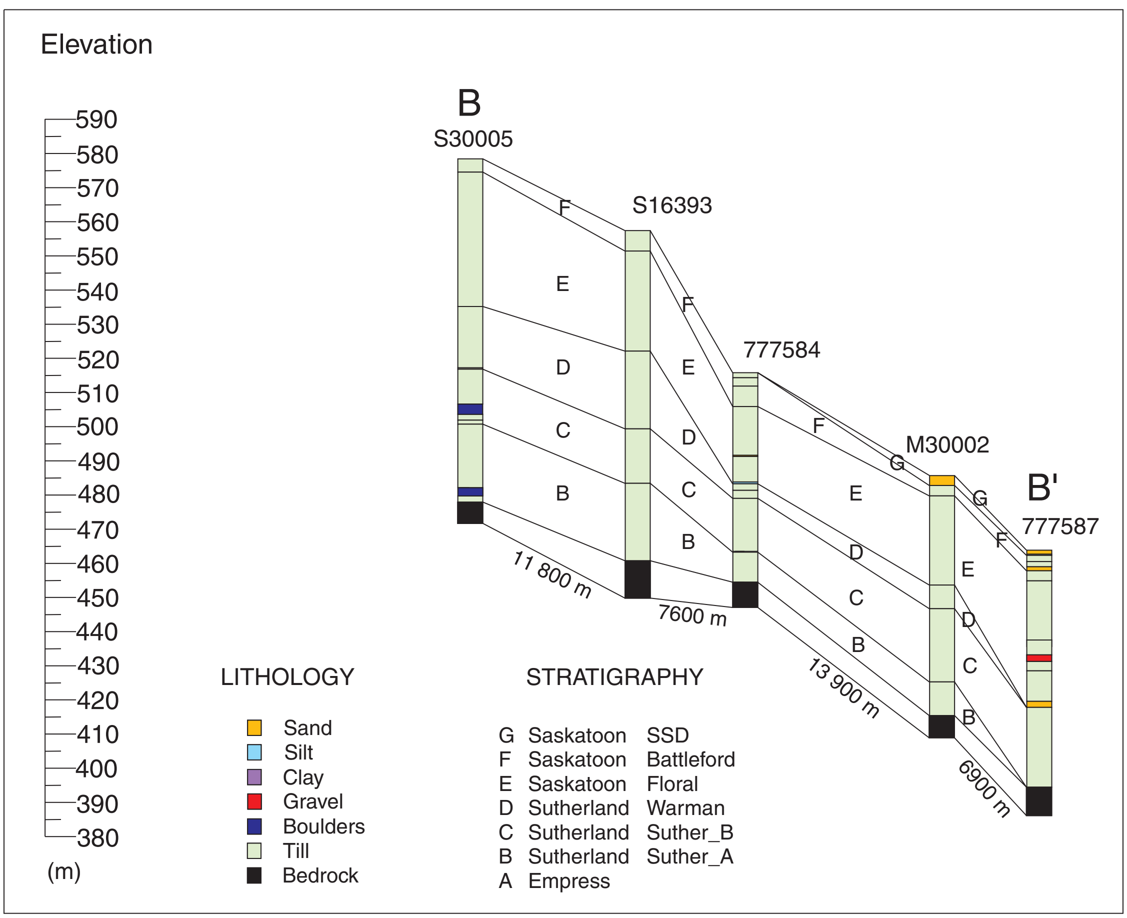


***Figure 33.** Cross-section B–B .*

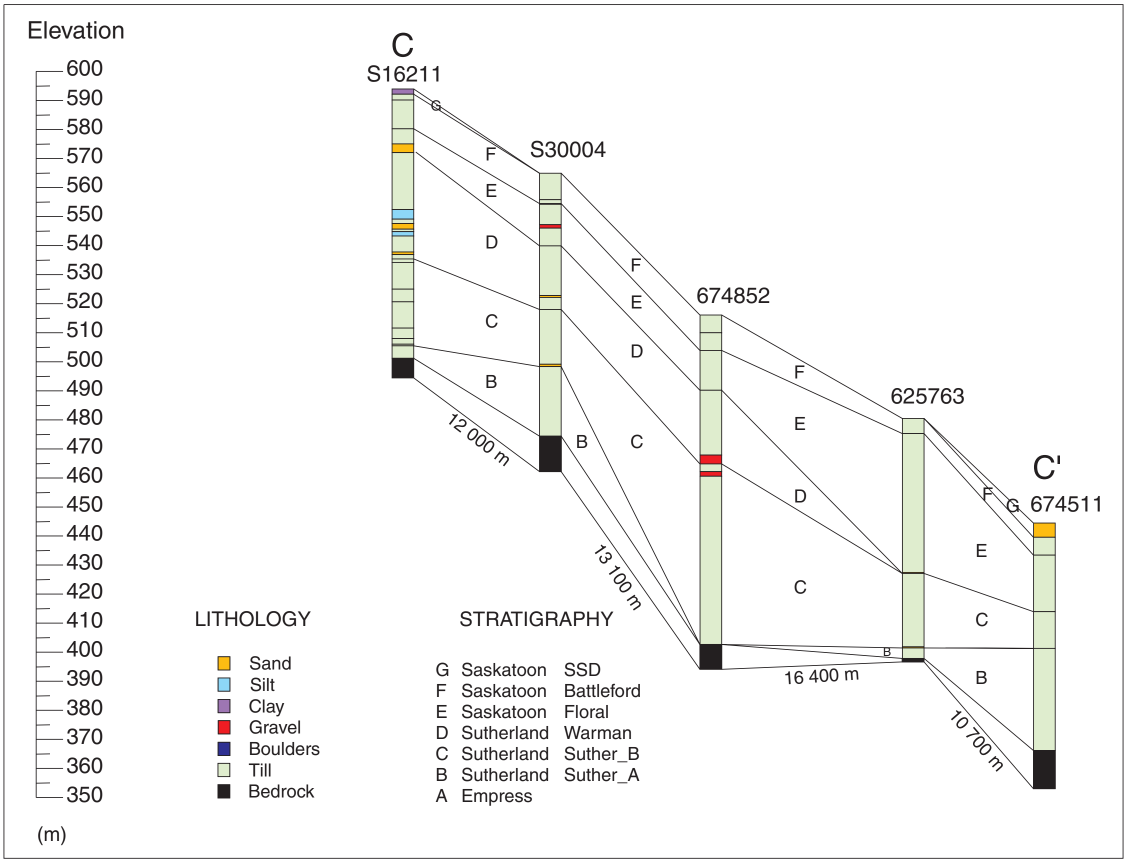


Figure 34. *Cross-section C–C .*

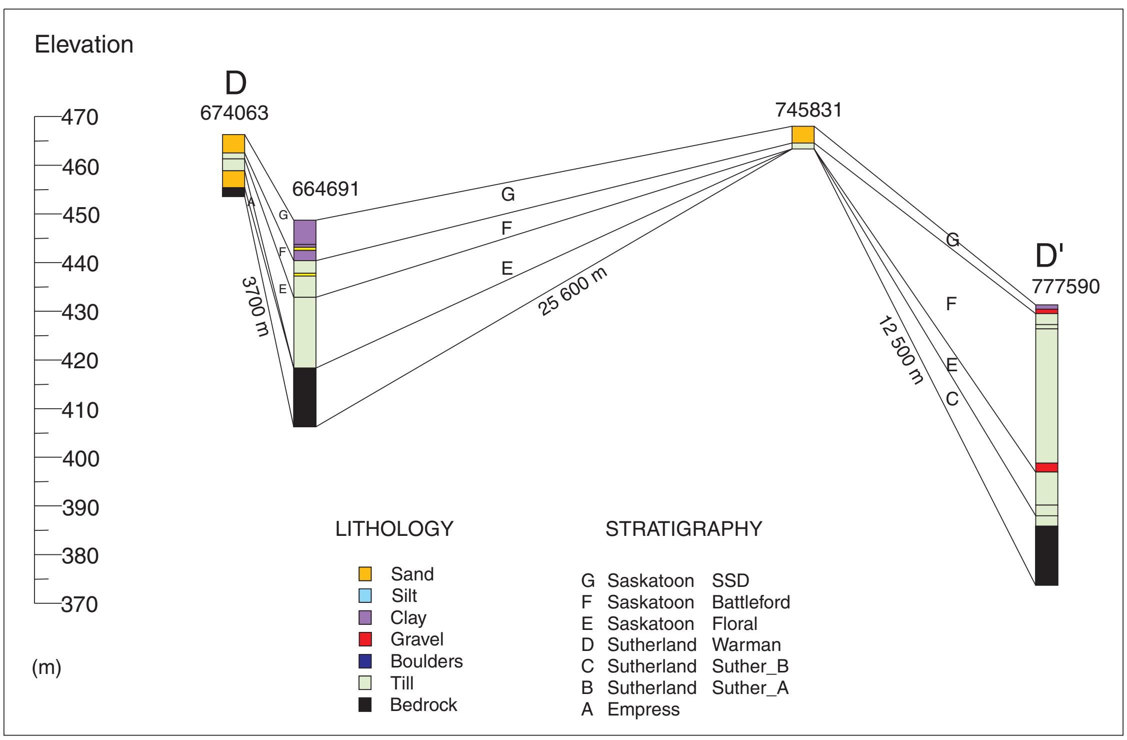


Figure 35. *Cross-section D–D .*

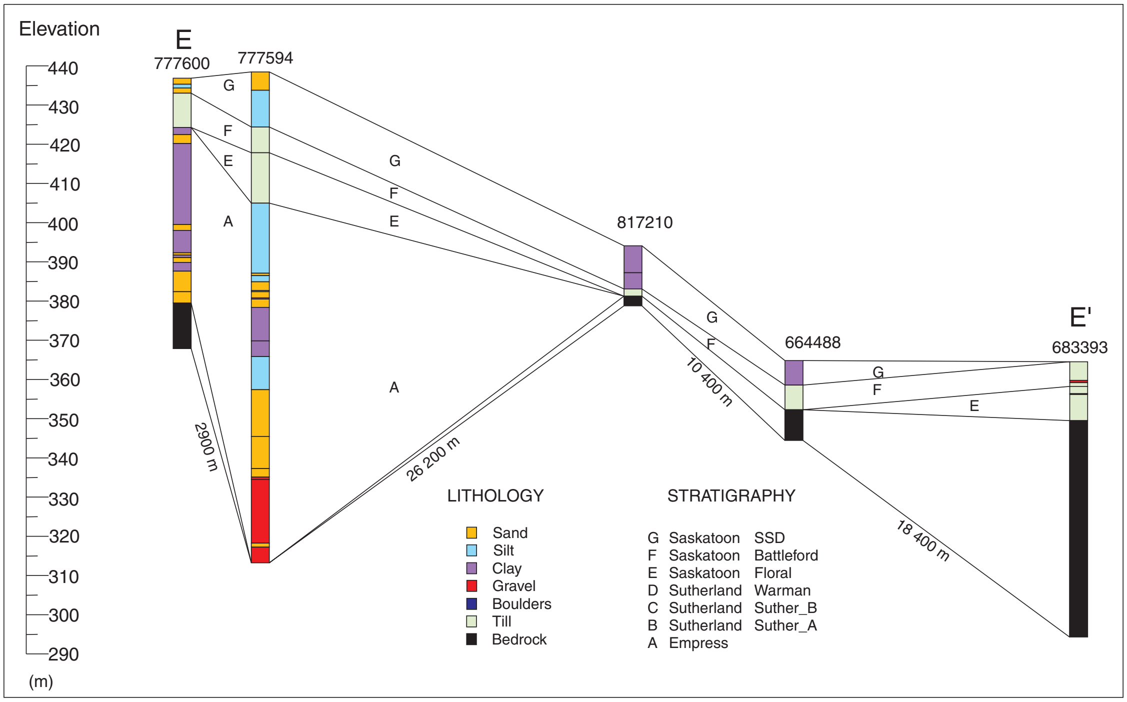


Figure 36. *Cross-section E–E .*

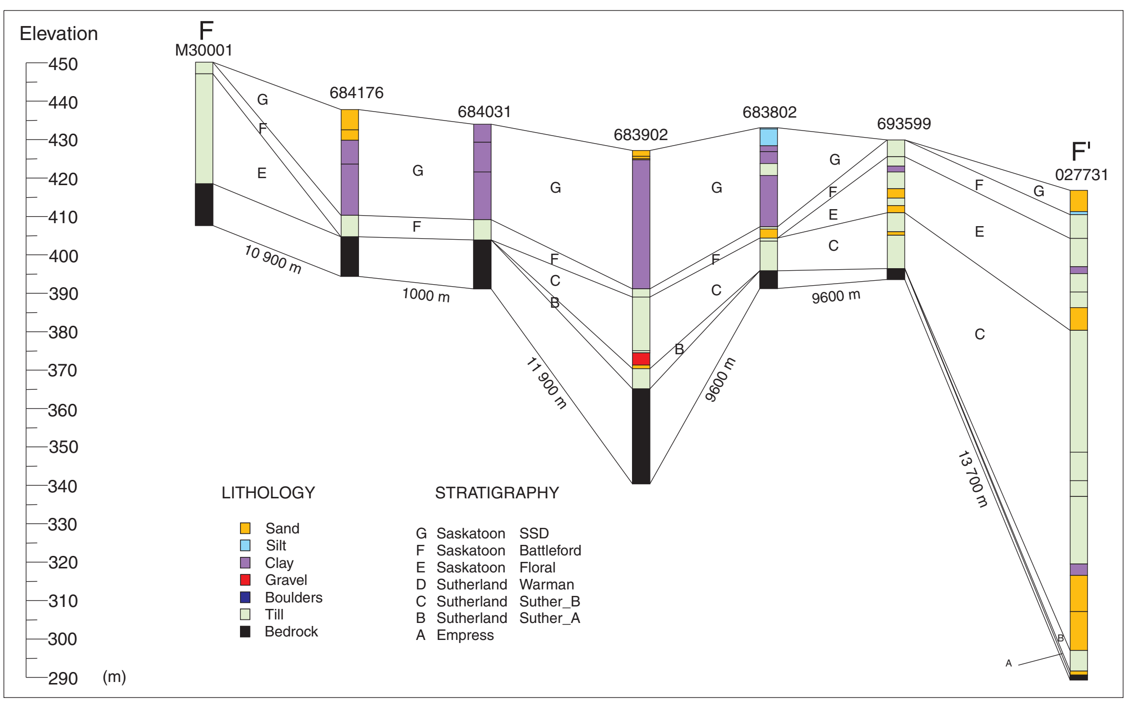


Figure 37. *Cross-section F–F .*

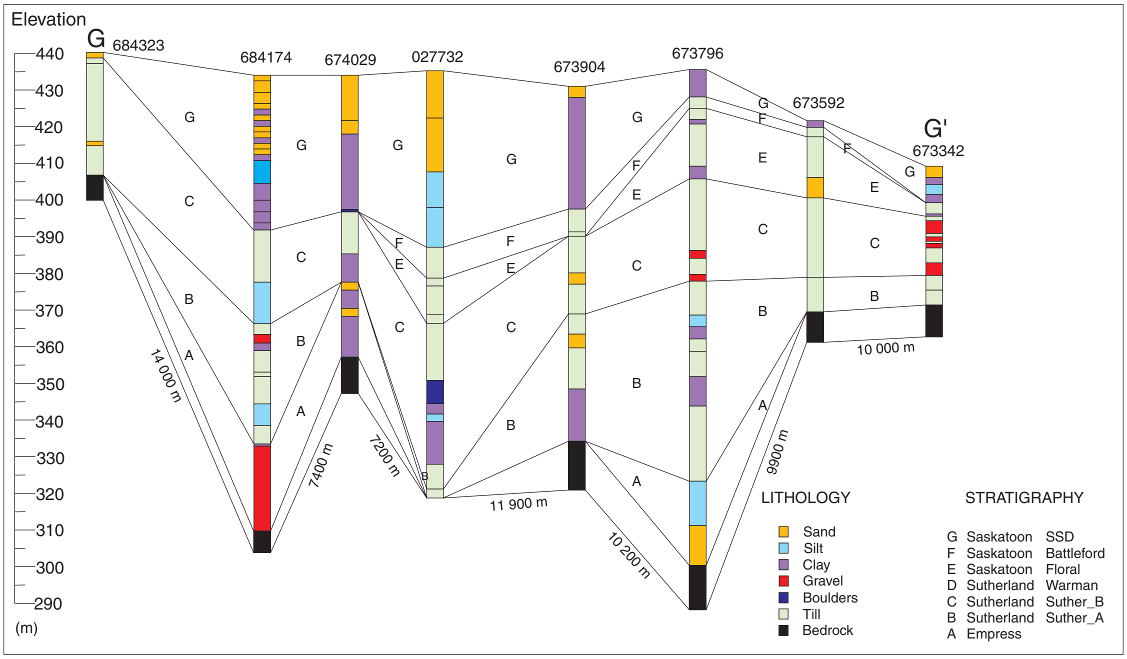
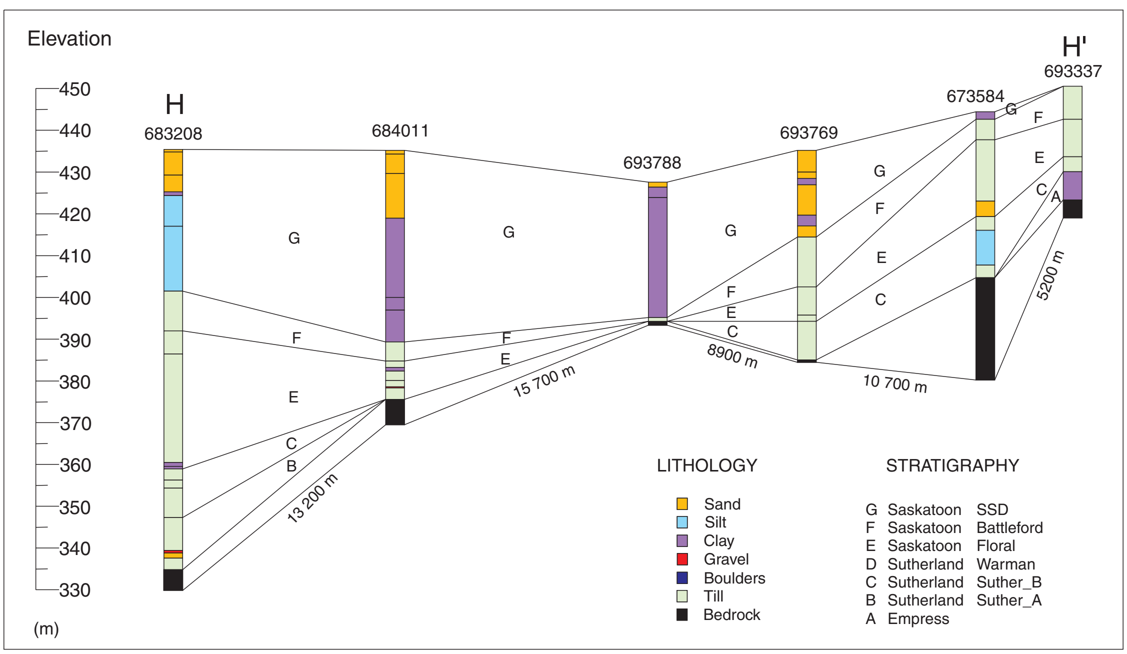


Figure 38. *Cross-section G–G .*



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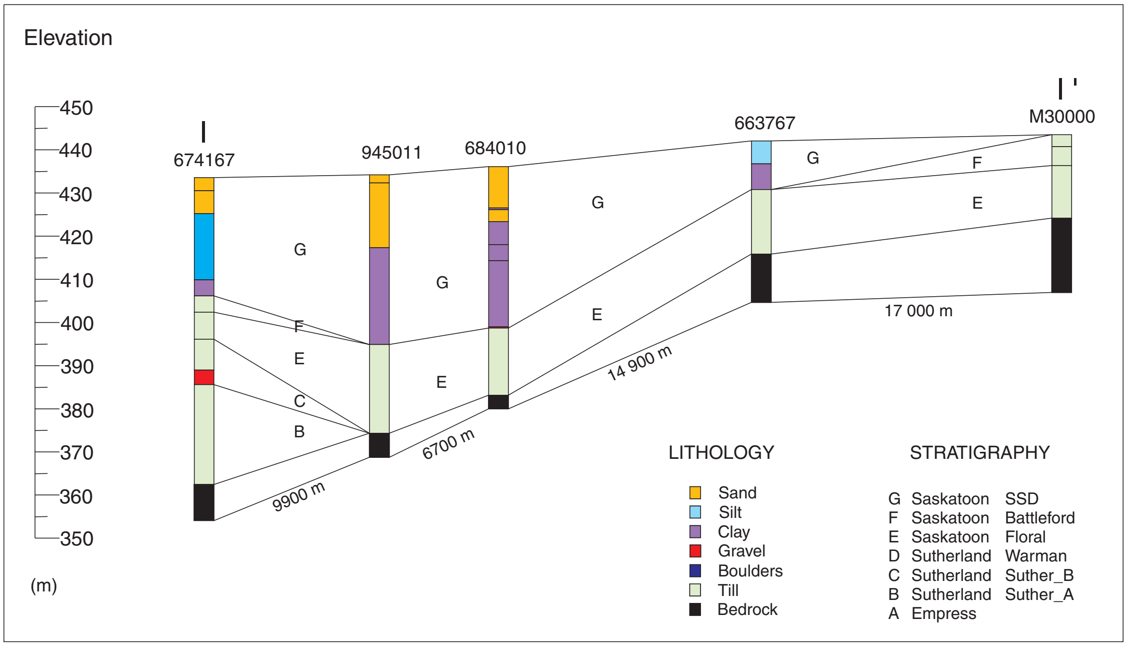


Figure 40. *Cross-section I–I .*

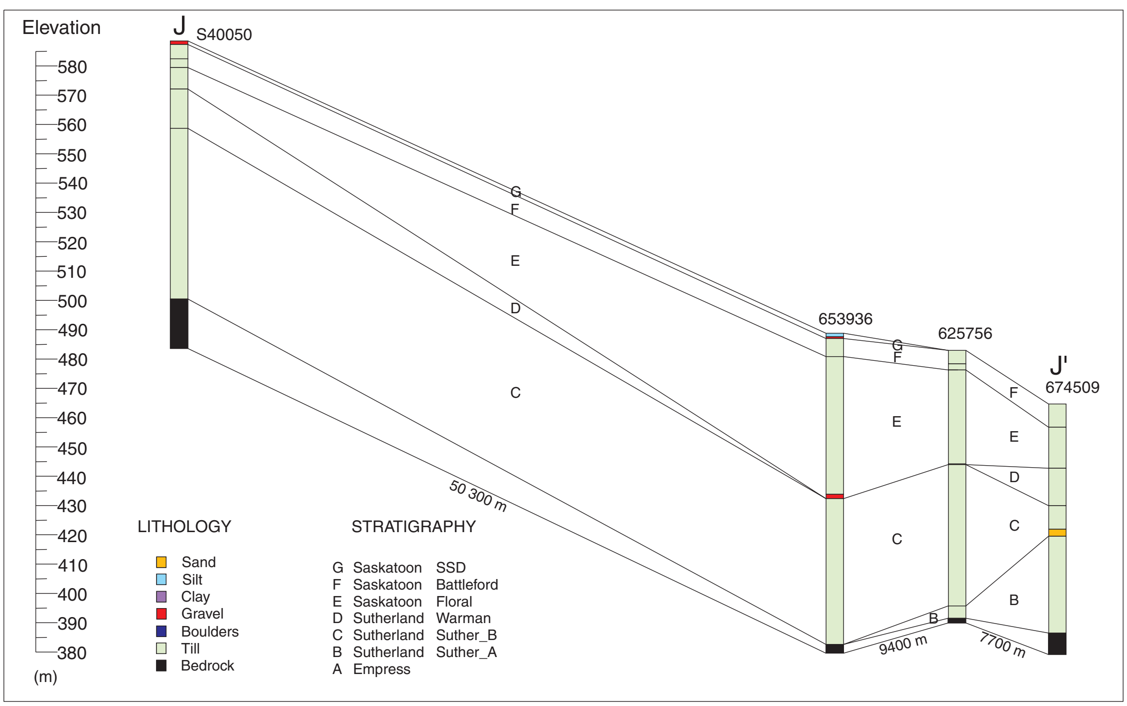
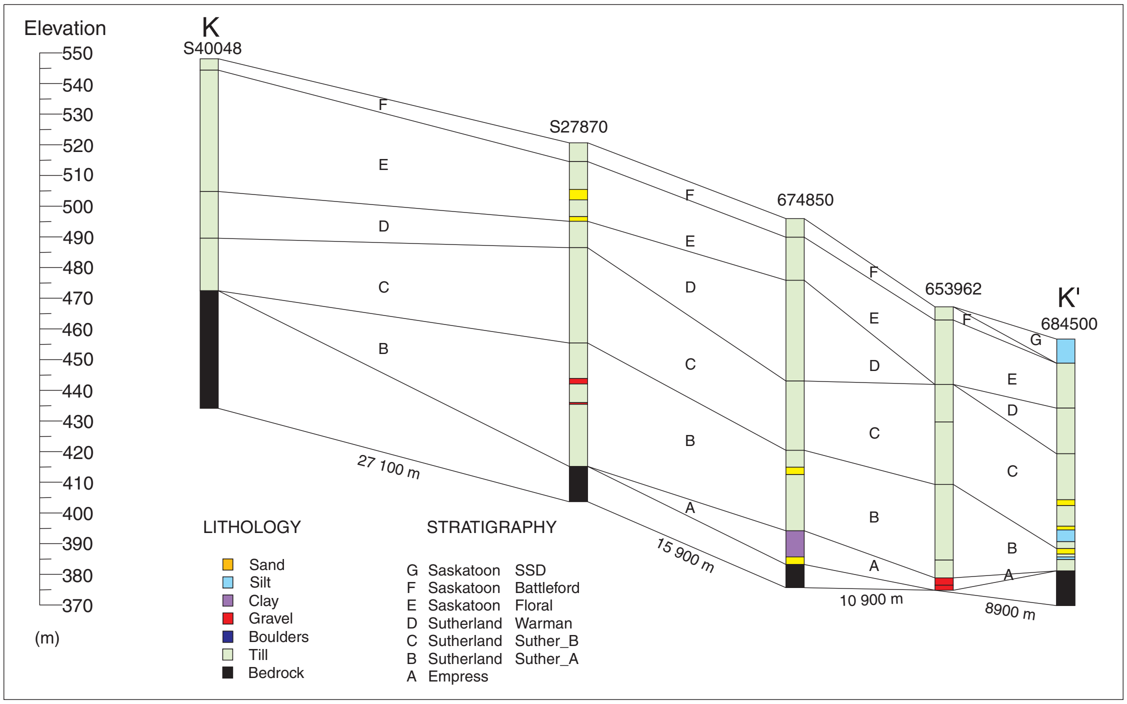


Figure 41. *Cross-section J–J .*



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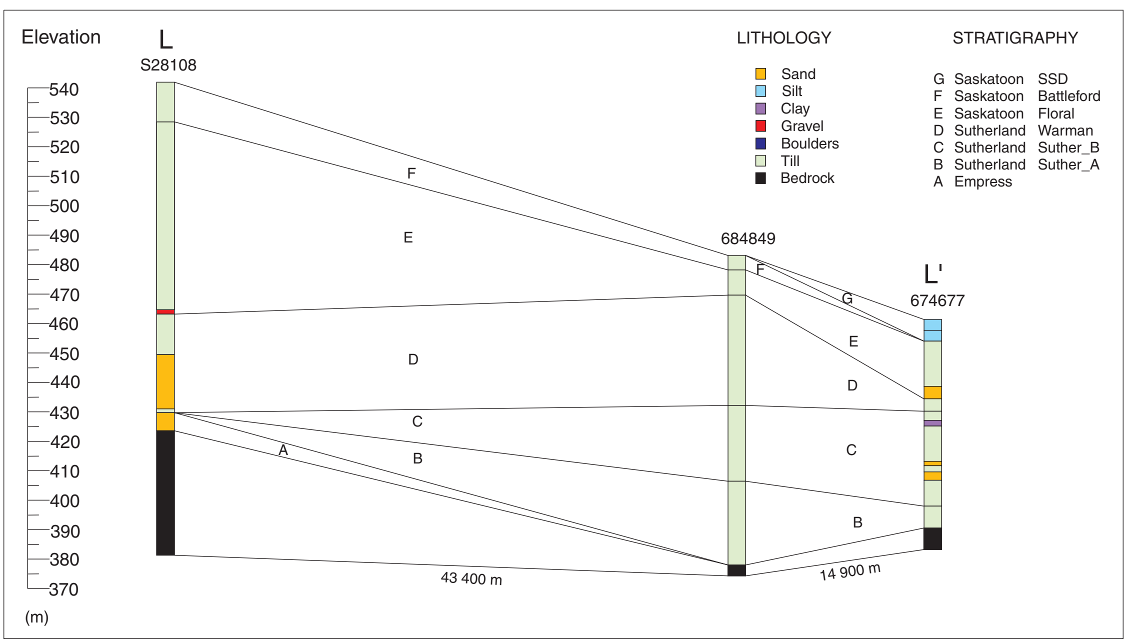

Figure 43. *Cross-section L–L .*

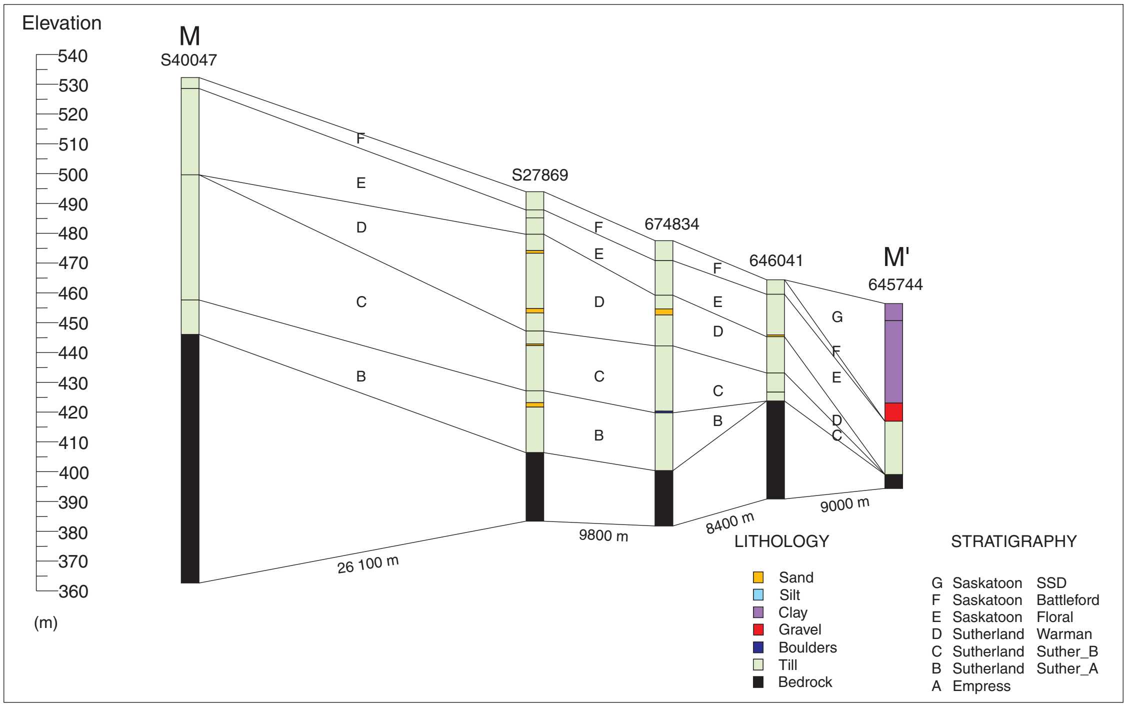

Figure 44. *Cross-section M–M .*

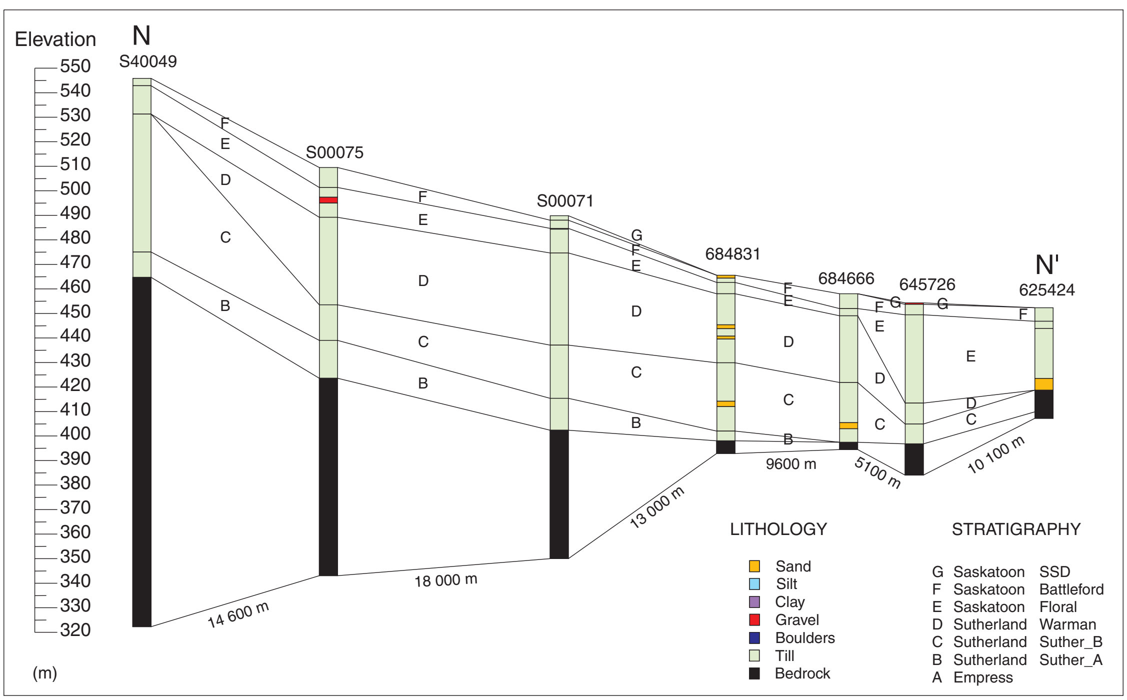

Figure 45. *Cross-section N–N .*

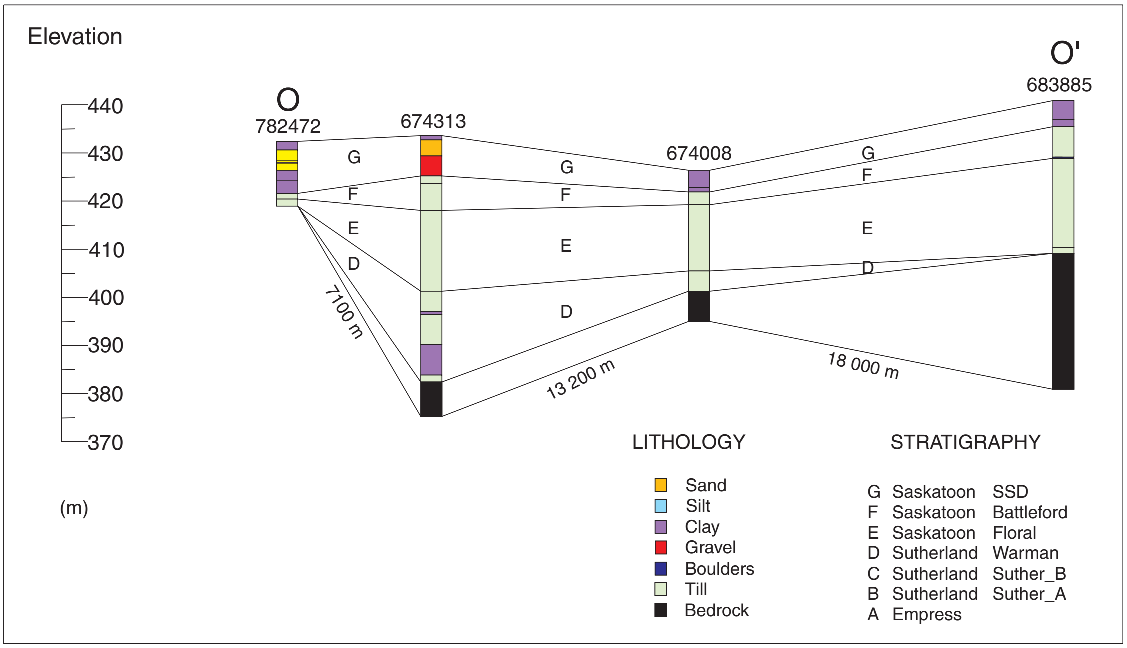

Figure 46. *Cross-section O–O .*

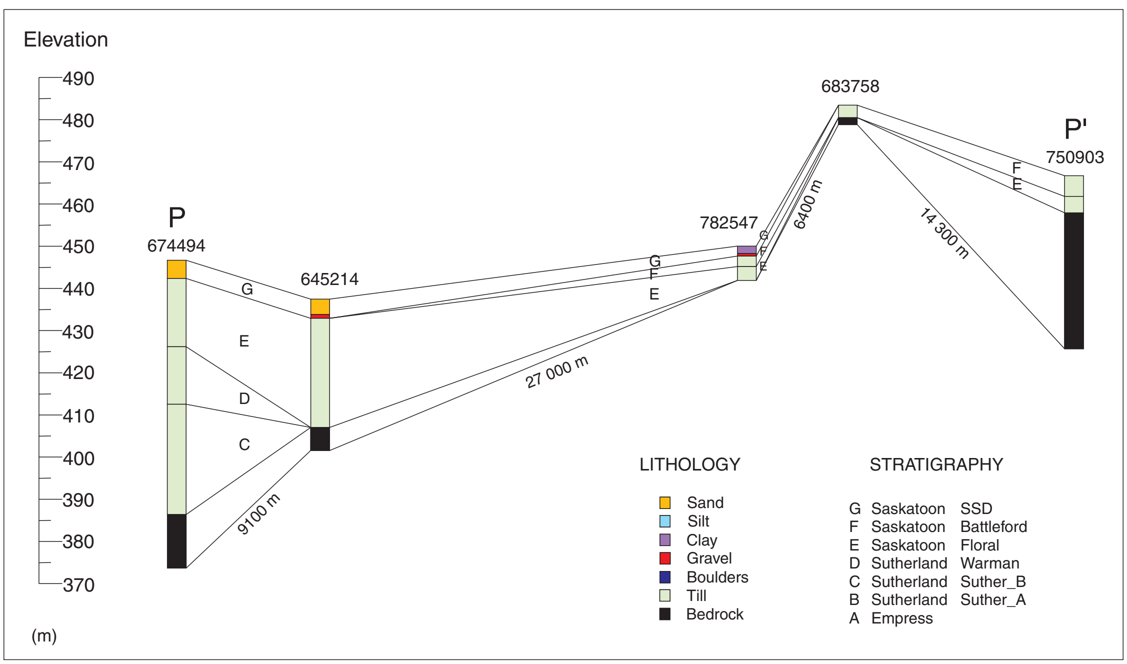

Figure 47. *Cross-section P–P .*

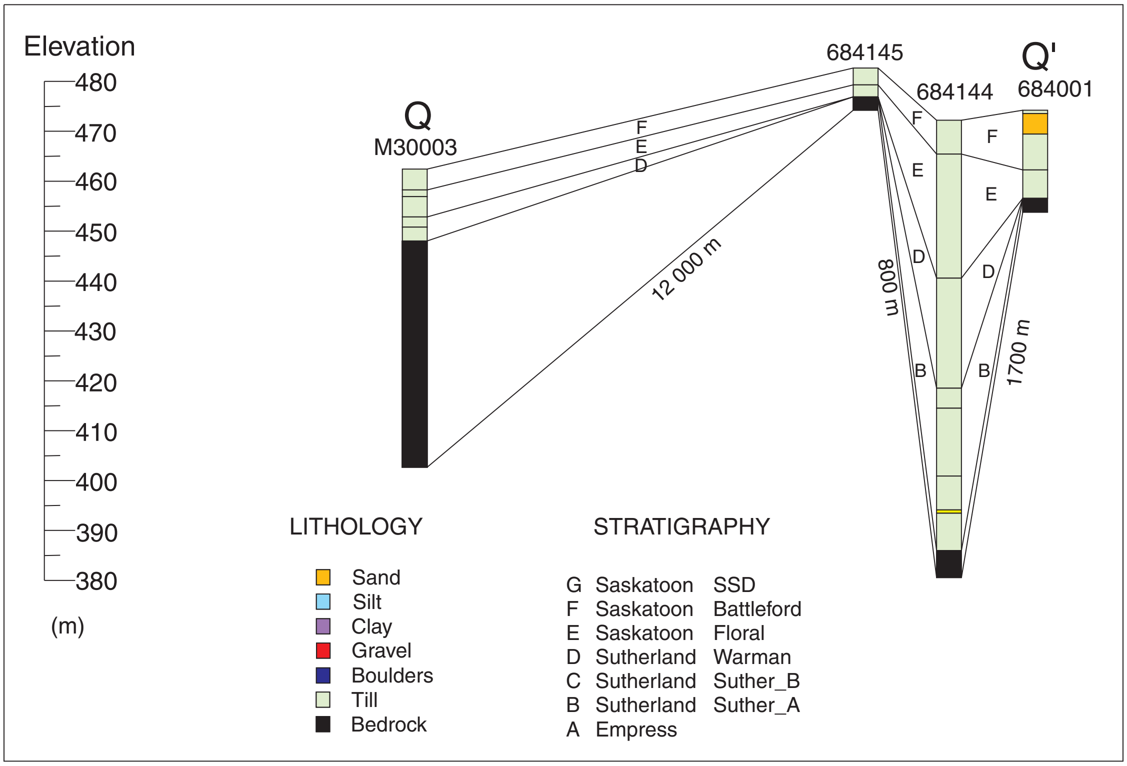

Figure 48. *Cross-section Q–Q .*

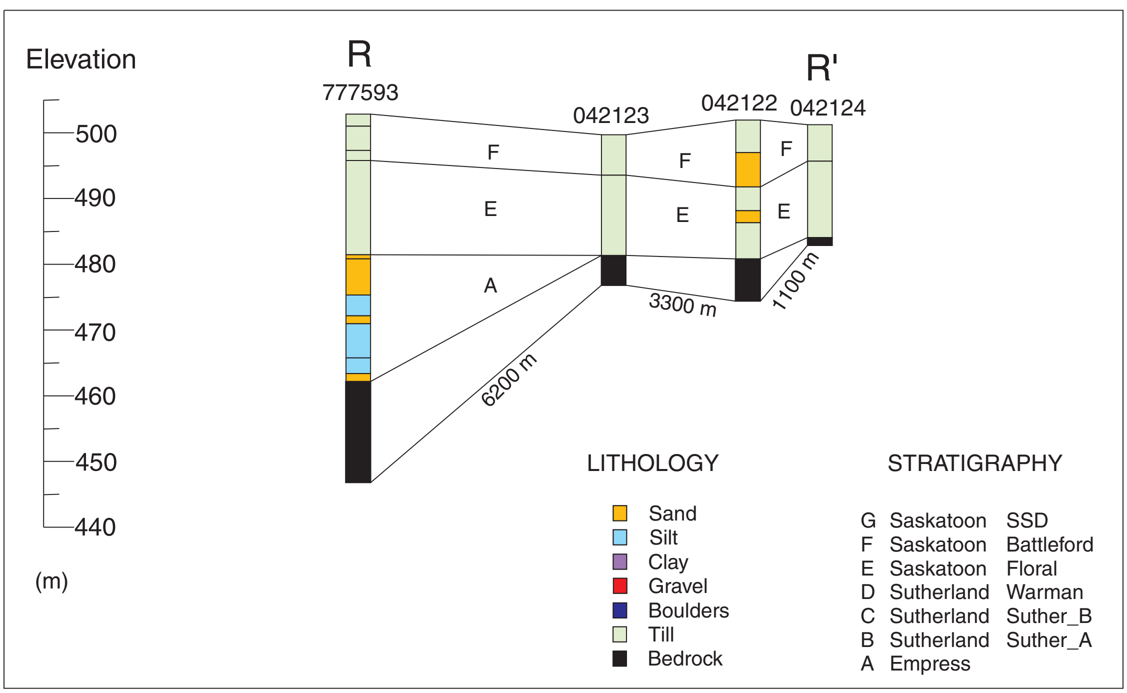

Figure 49. *Cross-section R–R .*

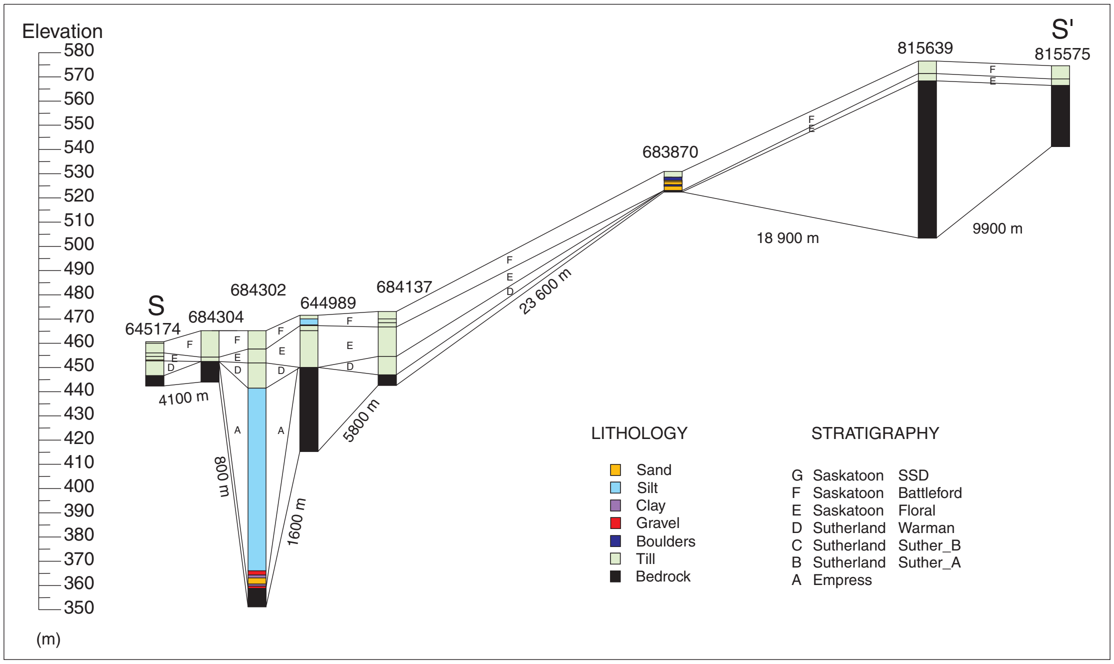

Figure 50. *Cross-section S–S .*

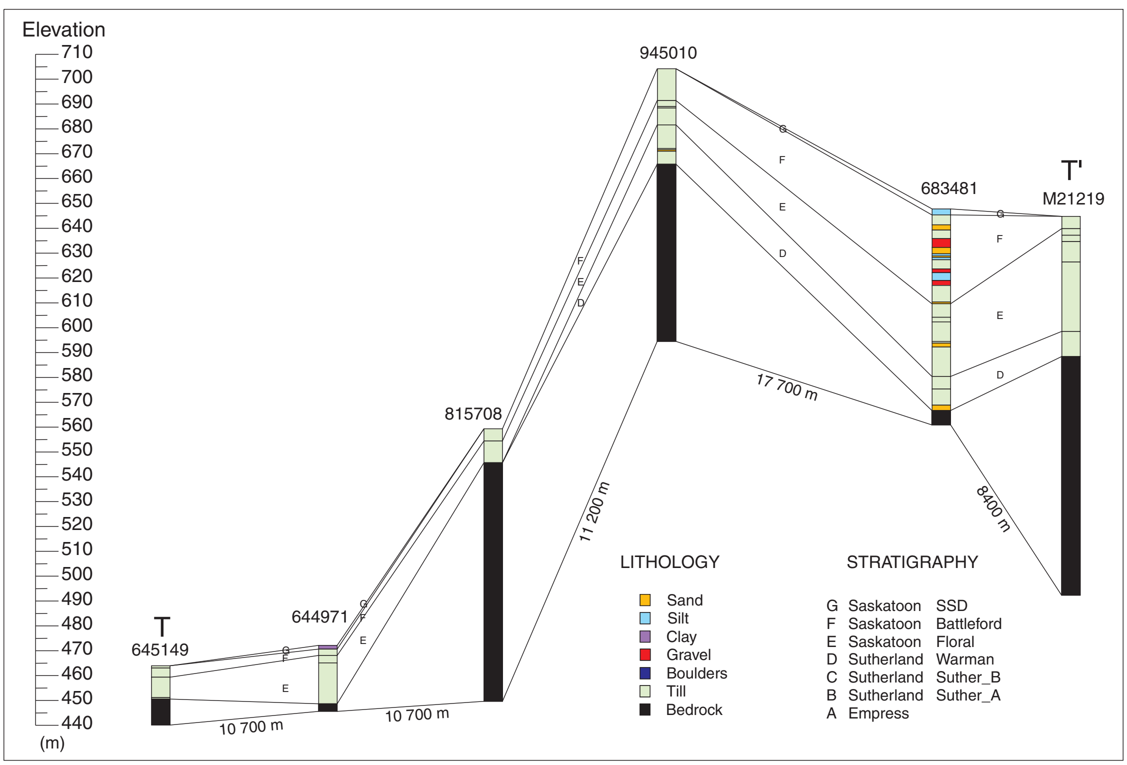

Figure 51. *Cross-section T–T .*

Figure 52.

Boulders making up a pavement that separates surface Lennard Till from underlying Minnedosa Till. GSC 2002-574

Figure 53.

A limestone boulder that is part of a pavement that separates surface Lennard Till from underlying Minnedosa Till. GSC 2002-575

was seen to differ from the next till below (referred to as Floral) in structure with the Floral till being recognized by its strong jointing and prominent iron and manganese oxide staining. A thin transition unit that lay between the two was interpreted as Battleford lodgement till that consisted mainly of sheared Floral till. The upper part of the surface till was considered to be 'flow till' and 'melt-out till'. The transition till had the same texture as the Floral till, which was a little finer grained than the surface layer. The Battleford till formed a relatively uniform layer 2–4 m thick that overlays the undulating surface of the underlying Floral till. It was concluded that much of the surface relief was a reflection of the surface of the Floral till.

Stratified sediments can be seen locally within the lower part of, and beneath, the surface till. In general it appears that this material was deposited as the last ice sheet pushed into the area. This stratified material generally occurs as lenses, blocks, and balls incorporated into the surface till (Fig. 54). At one point (site FI940037 of FIELDAT; Fig. 55), there is evidence that the stratified sediment underlying the surface till might be of earlier, nonglacial origin (Fulton, 1995).

At one or two localities what was thought to be older tills were seen below the Minnedosa Formation. These were generally more in tan colour than the overlying Minnedosa Formation, but exposures were too poor to clearly establish that older units were indeed present in surface exposures (e.g. sites FI940137).

Quaternary history

A general lack of exposures means little is known of the Quaternary history of the area prior to the last glaciation. Multiple tills and nonglacial deposits of interglacial origin indicate that the area was subject to several glaciations and interglaciations, but the number is unknown. Information on the Quaternary history of adjacent areas can be found in Elson (1956, 1958), Klassen (1979), and Bluemle (1985, 1989) Additional Quaternary history information on the Virden map area is included in Klassen (1969, 1972), Fulton (1995), Sun (1996), and Sun and Teller (1997).

Figure 54. Section showing inclusion of gravel near the base of surface till. GSC 2002-576

Quaternary history previous to last glaciation

A series of tills has been encountered in boreholes in the area (Table 10). These have been correlated with the succession described for the Saskatoon area by Christiansen (1992); however, this is a tenuous correlation (*see* Surficial Deposit Stratigraphy section). There is no indication of deposit age in the Virden map area.

Definitive interglacial deposits are not present in the area, but several buried valleys cut into these tills may date back to earlier nonglacial intervals (Klassen and Wyder, 1970; *see* Hydrogeology section). Gravels in pits at Souris (*see* description of quartzite pebble gravels in the Geomorphology and Surface Materials section) appear to be made up of two units, a lower unit devoid of glacial erratics and an upper unit containing some pebbles of granitic and fine, dark-coloured lithologies (including Omarolluk Formation pebbles). The lower unit is interpreted as material predating the first Quaternary glaciation, while the upper was deposited during a later interglaciation (Klassen, 1969).

The only Quaternary organic material known to have been collected from below till is a piece of tusk that came from a gravel pit (Fig. 55) on the northern flanks of Turtle Mountain (Fulton, 1995). The tusk segment was taken from a truckload of gravel, so the exact context of the find is not known. The pit is, however, in subtill gravel and the tusk has provided an AMS radiocarbon age of 33 860 ± 3300 a (TO-4639). It is not known whether nonglacial sediment was exposed in the pit or whether glacial meltwater eroded the tusk from a nonglacial deposit.

Last glaciation

Virtually no information is available on the advance of the last ice into the area. The only information pertinent to the timing of the last advance is the tusk segment mentioned above. This indicates that the last advance did not occur until after about 33 500 years ago. The only information available on the direction of ice movement is the striations present on boulders in pavements that are locally present at the base of the surface till (*see* ice-flow feature symbols on Surficial Materials Map SE, NE, and NW). These indicate that the ice was generally moving towards the southeast. The trend of groups of minor till ridges suggest that over the Boissevain and Pipestone plains, the ice front had a general southwest-northeast orientation during ice retreat (*see* pattern of minor moraine feature symbols on Surficial Materials Map SE and NW).

Figure 55. Section showing till overlying gravels from which a tusk was collected (Fulton, 1995). GSC 2002-577

Little information pertinent to timing of ice retreat is available in the Virden map area. Klassen (1972) reported a radiocarbon age of 11 600 ± 430 a (GSC-1081) for plant detritus 18 m below surface in alluvium in the Assiniboine River valley near Virden, and a radiocarbon age of 10 000 ± 280 a (GSC-1428) for wood 9 m below the surface in the same material north of Alexander. From this evidence it could be argued that ice had retreated from the area and deposition of postglacial alluvium had commenced by 11 600 years ago. Clayton and Moran (1982) argued that radiocarbon ages on materials other than wood are not reliable and that the chronology of Klassen (1972) is probably 3000 to 4000 years too old. According to their chronology, the ice did not begin to retreat from the area until after 12 000 BP, and the area was free of ice by between 10 500 and 10 000 years ago.

Ice retreat

Turtle Mountain was the first part of the area to be free of ice. During retreat most of the area was covered by a lobe of ice that retreated in a northwesterly direction but the northeastern corner of the area was occupied by a northeasterly retreating lobe. Glacial lakes formed along parts of the retreating lobes and periodic floods carved deep spillways.

Turtle Mountain ice retreat phase

Early during glacier retreat, ice stagnated on the top of Turtle Mountain, subsequently developing hummocky moraine. There is no absolute data on the timing of deglaciation of the top of Turtle Mountain, but from regional considerations it probably occurred between 12 000 and 13 000 years ago. Flow continued to move around the highland and a glacial lake developed in the shadow of Turtle Mountain (Fig. 56). This lake was referred to as glacial Lake Souris (Upham, 1895). Clayton et al. (1980) indicated that the earliest incarnation of glacial Lake Souris was completely overridden during a readvance. This readvance probably had little impact on surficial materials in the Virden area, but possibly was responsible for the area of moraine ridges on the northern slopes of Turtle Mountain and the thrust area at the western end of this feature (*see* Surficial Materials Map SE). Details on the pattern of ice retreat south of Turtle Mountain can be found in Bluemle (1985).

Glacial Lake Boissevain phase

With further retreat a glacial lake, referred to as glacial Lake Boissevain, began to form on the northeastern flank of Turtle Mountain (Elson, 1956). This lake drained eastward via the course of the present Pembina River to glacial Lake Agassiz in the Red River valley. Glacial Lake Boissevain expanded to the west as the ice retreated (Fig. 57).

Glacial Lake Goodlands phase

With continued retreat, glacial Lake Souris entered the area on the west side of Turtle Mountain from the south (Fig. 58). Eventually, drainage from glacial Lake Boissevain was able to escape westward into glacial Lake Souris. This heralded development of a new lake, glacial Lake Goodlands, on the north side of Turtle Mountain (Fig. 58; Elson, 1956). At about this same time, the suture between southeasterly flowing Assiniboine Lobe ice and the southwesterly flowing Red River Lobe entered the east-central part of the area. An interlobate lake that was a precursor of glacial Lake Hind occupied this suture.

Dand Channel phase

Continued northwestward ice-front retreat led to drainage of glacial Lake Goodlands and opened an ice-marginal channel connecting glacial Lake Souris to the in-part interlobate glacial Lake Hind (Fig. 59). This drainage way has been referred to as the Dand Channel (Sun, 1996). Deltas deposited at the mouth of the Dand Channel have been used in defining the various levels of glacial lakes in the area (Sun and Teller, 1997).

Antler By-Pass Flood phase

A complex of shallow channels, streamlined forms, and thin discontinuous gravels occupies the shallow topographic saddle that extends from the Souris spillway to the west of the area to the basin of glacial Lake Souris. (*see* Surficial Materials Map SW). These features are interpreted as resulting from a subaerial catastrophic flood that occurred when glacial Lake Souris stood near its maximum level. A string of small ice-contact features that lie along the northern edge of

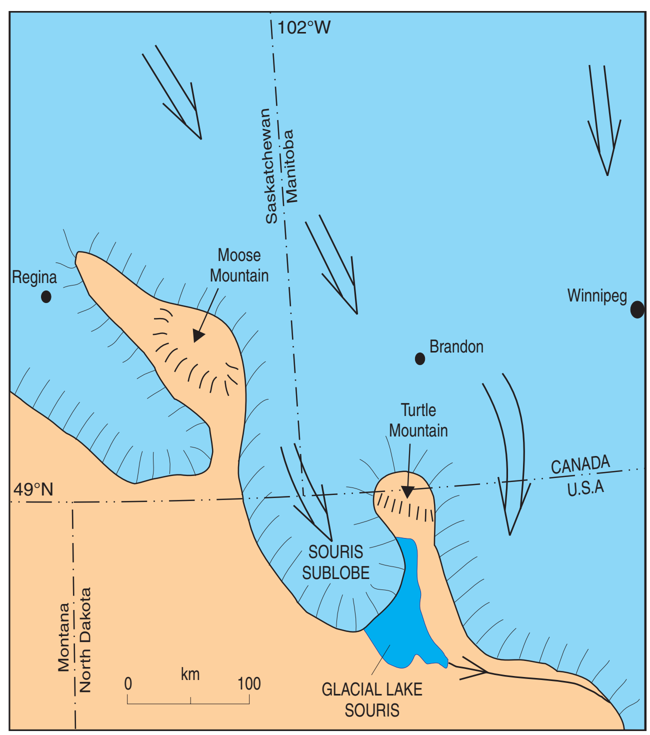

Figure 56. *Turtle Mountain ice retreat phase: Turtle Mountain split the Souris sublobe from the main southeastward-flowing Assiniboine Ice Lobe. Eastward-draining glacial Lake Souris formed at this time.*

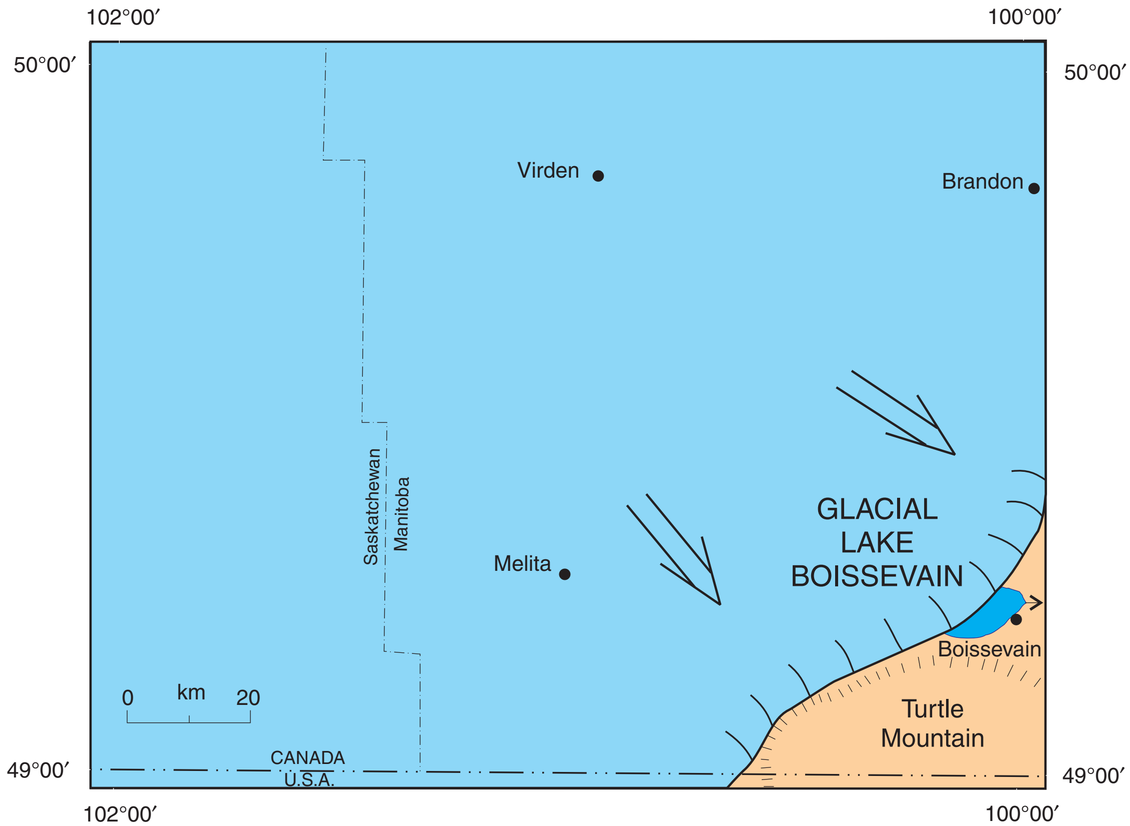

Figure 57. *Glacial Lake Boissevain Phase: retreat from the east side of Turtle Mountain resulted in development of eastward-draining glacial Lake Boissevain.*

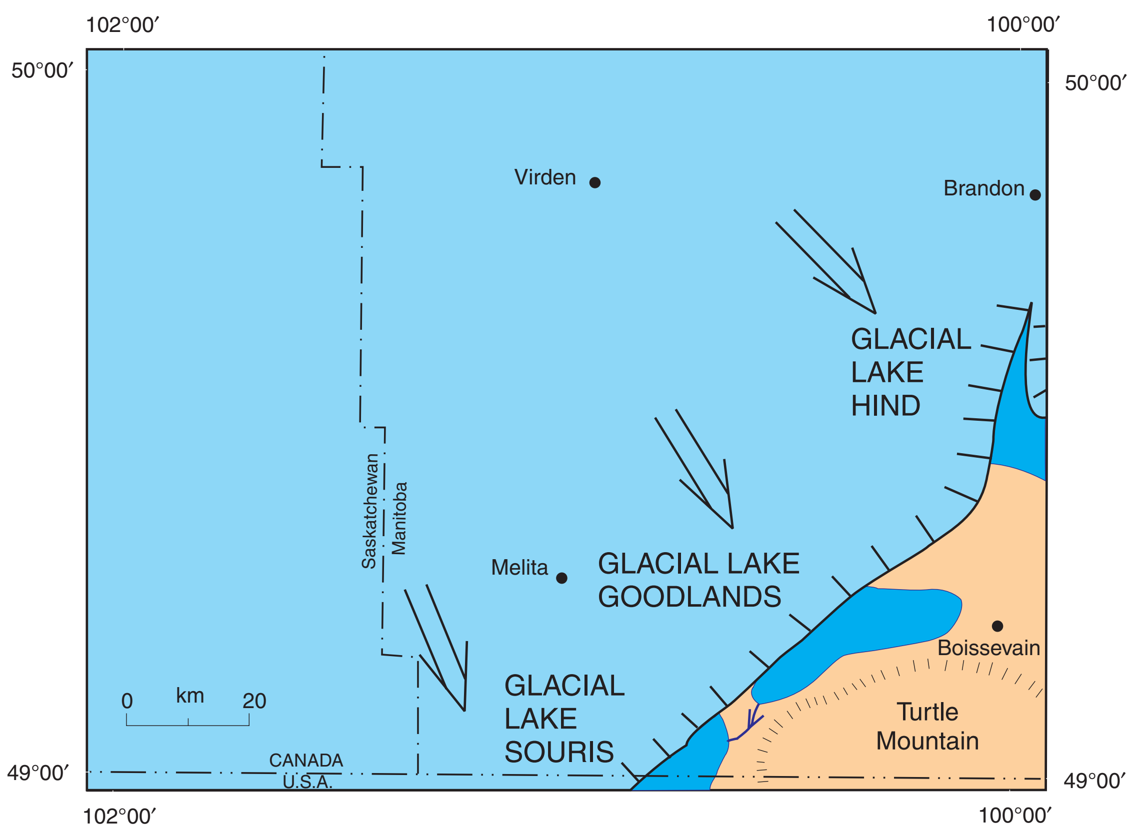

Figure 58. *Glacial Lake Goodlands phase: when glacial retreat from the northwest corner of Turtle Mountain permitted southwestward drainage, glacial Lake Goodlands came into being. At about this same time, eastward-draining glacial Lake Hind began to form in the east-central part of the area, and glacial Lake Souris extended into the area from the south.*

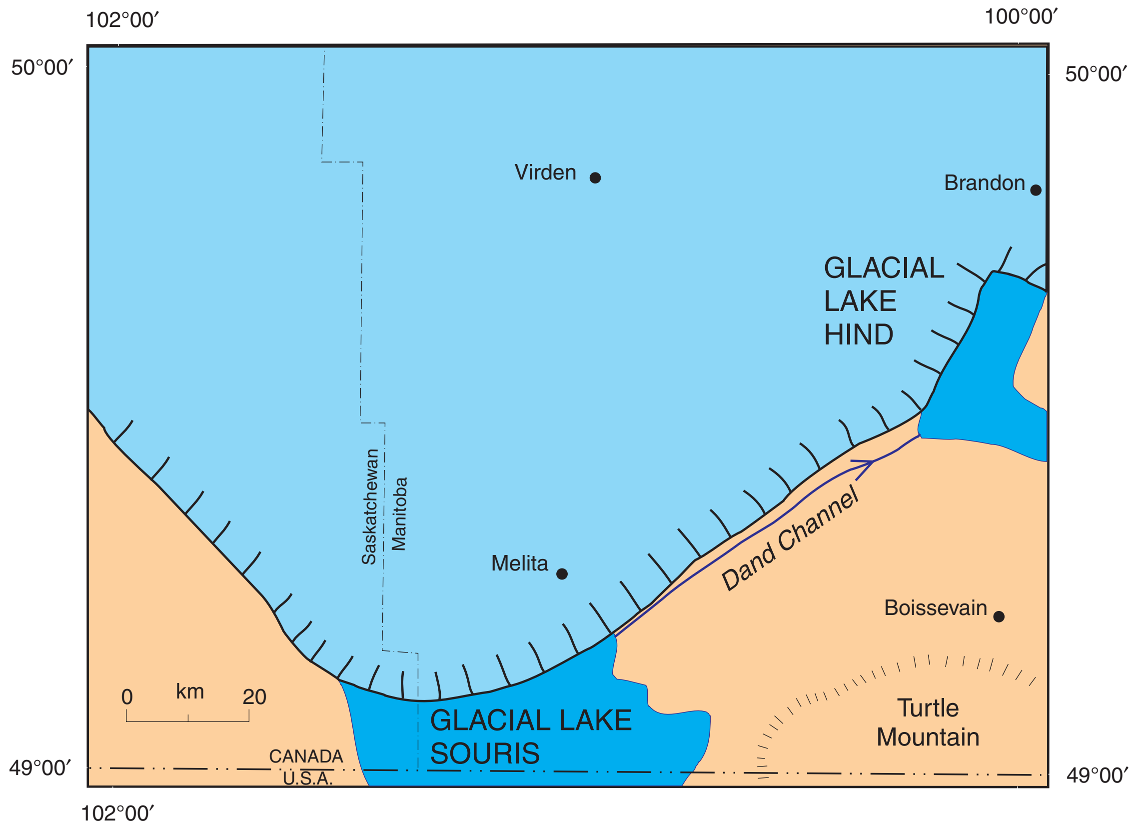

Figure 59. *Dand Channel phase: continued northwestward ice-front retreat led to drainage of glacial Lake Goodlands and opened an ice-marginal channel connecting glacial Lake Souris to glacial Lake Hind.*

this feature, just north of Antler River, suggest that this event occurred as ice was retreating from the area. This event is here referred to as the Antler By-Pass Flood. A comparison of the levels of deltas indicates that this flood occurred at about the same time as glacial Lake Hind extended northward as an interlobate lake separating the southeast directed Assiniboine Ice Lobe from the southwest directed Red River Ice Lobe (Fig. 60; Sun and Teller, 1997).

Glacial Lake Hind and Arrow Hills Flood phase

Continued retreat of the Assiniboine Ice Lobe permitted the merger of glacial Lake Souris and glacial Lake Hind. The drop in level that accompanied this merger resulted in glacial Lake Souris disappearing, although a shallow body of water (which should be given a different name) remained in northern McHenry County in North Dakota (Bluemle, 1985). At about this time, a subglacial flood occurred at the base of the Assiniboine Ice Lobe north of the present site of the Assiniboine River valley (Fig. 61). This event left behind an area of streamlined, boulder-gravel knolls and associated kames, and a prominent esker complex (Fig. 9).

It is suggested here that the Arrow River esker complex (Sun, 1996) and the glaciofluvial complex that reaches from the Assiniboine River north of Oak Lake, to the mouth of the Qu'Appelle River (75 km) to the north (*see* Surficial Materials Map NE; Klassen, 1979), was formed by a subglacial flood. The juxtaposition of glaciofluvial features in this belt makes it appear that the various deposits are genetically related. The Arrow Hills esker complex is at the downstream end of this series of features and consequently was formed nearest the ice margin. The pattern of esker ridges suggests that there was a funnelling of waters towards the central ridge of the complex. It is consequently possible that the esker system formed where a major meltwater flood, which had been flowing under high pressure at the base of the glacier, was funnelled into a converging system of channels when it reached a lower pressure area near the ice margin. Because of the downstream decrease in pressure, much of the load of comminuted shale that had been entrained upstream was deposited on the channel floors.

If the esker and associated glaciofluvial deposits and features were the product of a subglacial flood, what was the source of the water? The features discussed here appear to begin at the mouth of the Qu'Appelle River. It is known that ice-marginal lakes existed in what became the headwaters of the Qu'Appelle River and that the Qu'Appelle spillway was cut by meltwaters from several breached, ice-dammed lakes (Kehew and Lord, 1987; Kehew and Teller, 1994). Possibly, prior to deglaciation of the lower reaches of the Qu'Appelle River, a catastrophic subglacial flood moved down the valley and issued from the ice margin just north of Oak Lake. The flood could equally well have moved down the Assiniboine River valley. It has been shown that the Assiniboine spillway was cut by several meltwater floods (Wolfe and Teller, 1995). Possibly, a subglacial flood moved down the Assiniboine

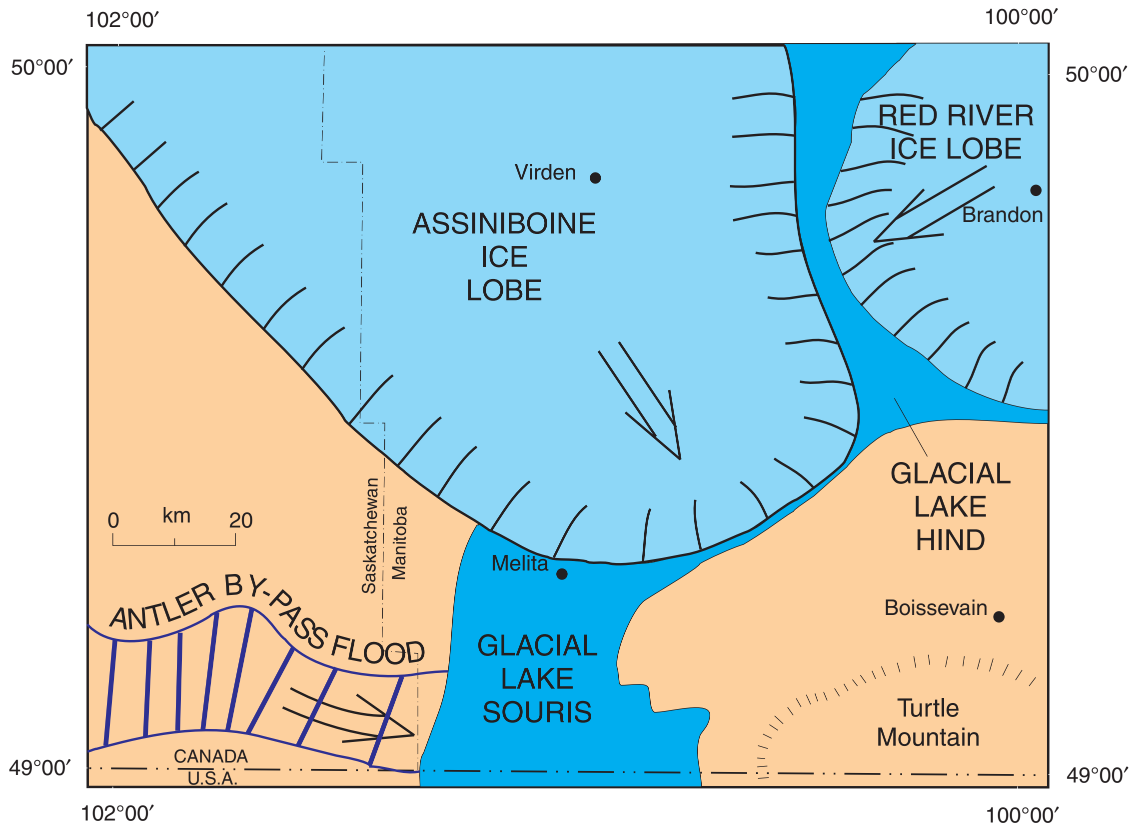

Figure 60. *Antler Bypass Flood phase: A catastrophic event, the Antler Bypass Flood, cut a complex of shallow channels, and deposited thin gravels in the saddle between the Souris spillway (just west of the Virden area) and the basin of glacial Lake Souris. At about this same time, glacial Lake Hind had extended northward as an interlobate lake separating the southeast-directed Assiniboine Ice Lobe from the southwest-directed Red River Ice Lobe.*

River valley prior to opening of the valley. One item in favour of a major subglacial flood in the Assiniboine River valley is an area of broad parallel ridges that appear to be casts of giant current ripples (wave length ~1 km and length of up 10 km) that lie east of the river, near Russell, north of the study area (Fig. 62).

Souris Valley Floods phase

Two, and possibly more, catastrophic floods entered glacial Lake Hind from the south (Fig. 63) . The earliest occupied a broad channel, and probably originated in glacial Lake Indian Head northwest of Moose Mountain (Sun, 1996). Because most fluvial erosion was in till, gravels related to this flood contain little shale and are of high quality. A later flood, which according to Sun (1996) originated in glacial Lake Regina, incised channels in shale. Consequently, the deposits in the Melita area related to this flood make poor quality aggregate (*see* Aggregate section). These major influxes of water deepened the Pembina spillway and caused lowering of the level of glacial Lake Hind.

During the later part of this phase, eastward retreat of the Red River Lobe opened a direct connection between glacial Lake Hind and glacial Lake Agassiz at Brandon. It is likely that for a period of time outflow from glacial Lake Hind also continued to use Pembina spillway (Sun, 1996; Fig. 63).

Assiniboine Floods phase

Northward ice retreat of the Assiniboine Ice Lobe permitted meltwater to enter glacial Lake Hind from the north (Fig. 64). Early sediments from the north were deposited in a delta north of Virden (*see* Surficial Materials Map NE). Assiniboine River valley floods, however, carved a spillway across the northern part of the lake Hind basin so that sediments could be flushed directly to the Assiniboine delta of glacial Lake Agassiz that lay just to the east of Brandon (Sun, 1993). Later floods in the Assiniboine spillway were responsible for the most important aggregate source in the area at Assiniboine Flats west of Brandon (*see* Aggregate section). This extensive gravel deposit was deposited where flow of the floodwaters, which upstream were confined to a narrow channel, expanded as they entered the broad valley at Assiniboine Flats.

Assiniboine Flats is a complex gravel bar that is located in a broad bend of the Assiniboine River valley. It is about 10 km long and 4 km wide (Fig. 10). The modern river floodplain marks the southern side of the bar and an equally large filled channel bounds the bar along its northern side (Sun and Teller, 1997). It consists of crossbedded and hummocky-bedded gravel sequences. There is a residual lag of boulders along the southern slope and the upstream margin of the bar. Deposition of the Assiniboine Flat gravels required a

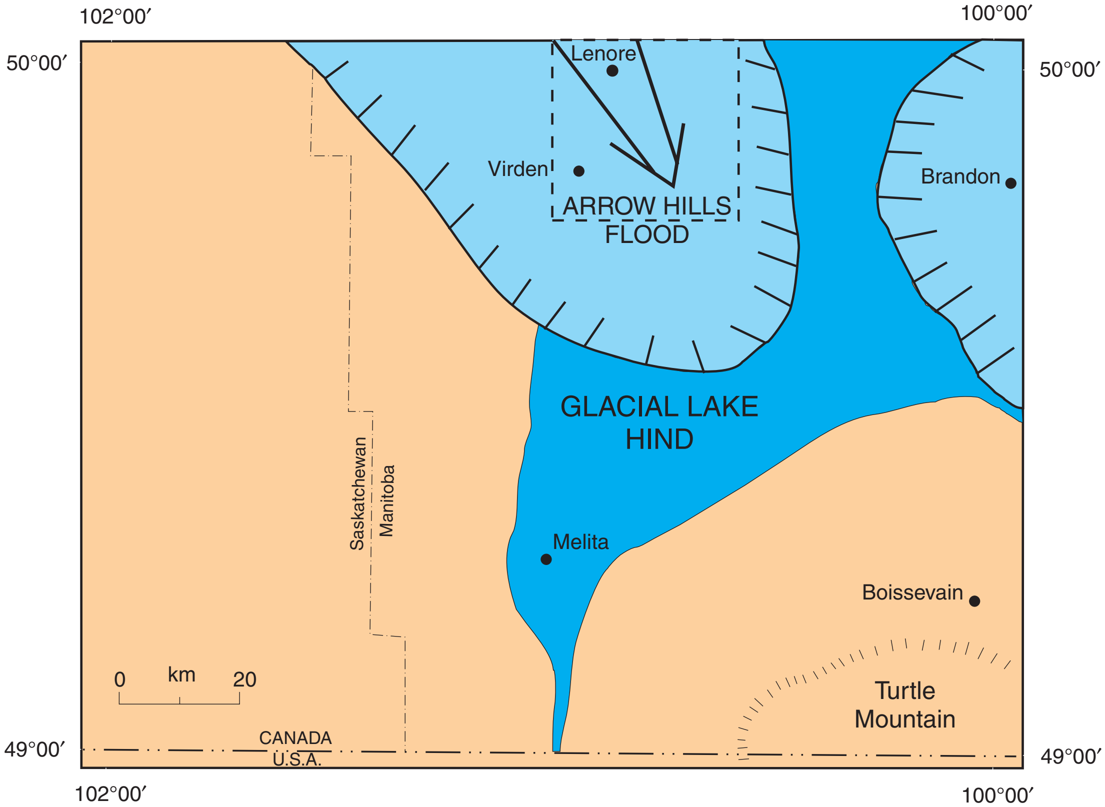

Figure 61. *Glacial Lake Hind, Arrow Hills Flood: continued retreat of the Assiniboine Ice Lobe permitted the downstream basin of glacial Lake Souris to merge with the basin of glacial Lake Hind. At about this time, the Arrow Hills Flood, a subglacial event, occurred. This subglacial flood left behind an area of stream-lined, boulder-gravel knolls and associated kames, and a prominent esker complex.*

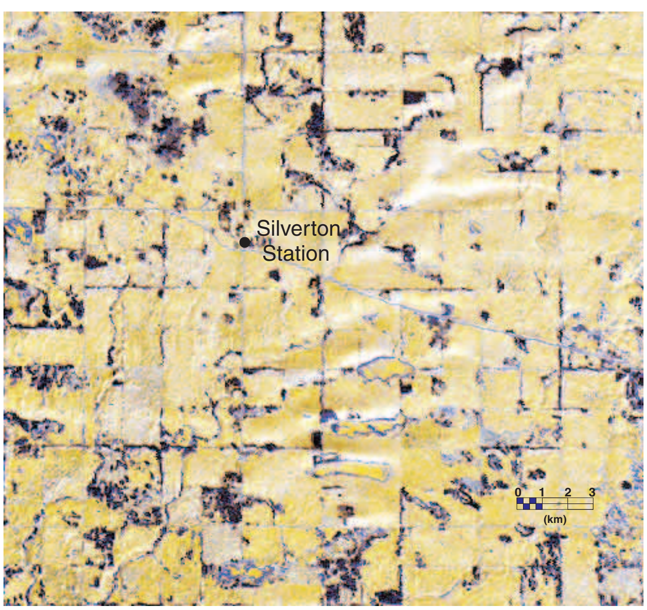

Figure 62. *Snow-cover LANDSAT image showing a series of broad parallel ridges that appear to be casts of giant current ripples that lie east of the Assiniboine River about 90 km north of the Virden map area.*

sequence of steps. First, the Assiniboine River valley had to be excavated by one or more floods prior to deposition of lower crossbedded successions. This was followed by one or more floods that eroded the upstream end of the bar, and deposited gravels in mega-ripples over the central part of bar. Subsequent entrenchment cut channels along the northern and southern margins of the bar. The northern route was later abandoned, perhaps as a result of differential isostatic rebound, or possibly because of infilling due to the high supply of sediment delivered by a system of gullies cut into glacial-lake sediment sand and shale (*see* Surficial Materials Map NE).

Postglacial climate and vegetation

Few studies of postglacial climate and vegetation have been attempted in the Virden map area. This is largely due to a lack of obvious, thick, organic-rich sequences. Several large and relatively deep lakes are present on Turtle Mountain, but the work of Vance and Last (1994) indicated that Max Lake, a typical water body in the area, contained a significant thickness of sediments, but the core bottom provided a radiocarbon age of only 3330 ± 70 BP. This suggests that the lake basin was dry during the Hypsithermal Interval, permitting erosion and oxidation of earlier organic-rich materials that might have been present. It appears that earlier sediments in most lake basins in the area suffered a similar fate (*see* Kenosee Lake *in* Vance and Last, 1994). Cores, including significant postglacial pollen records, have been obtained from Tiger Hills, 50 km to the east of the area

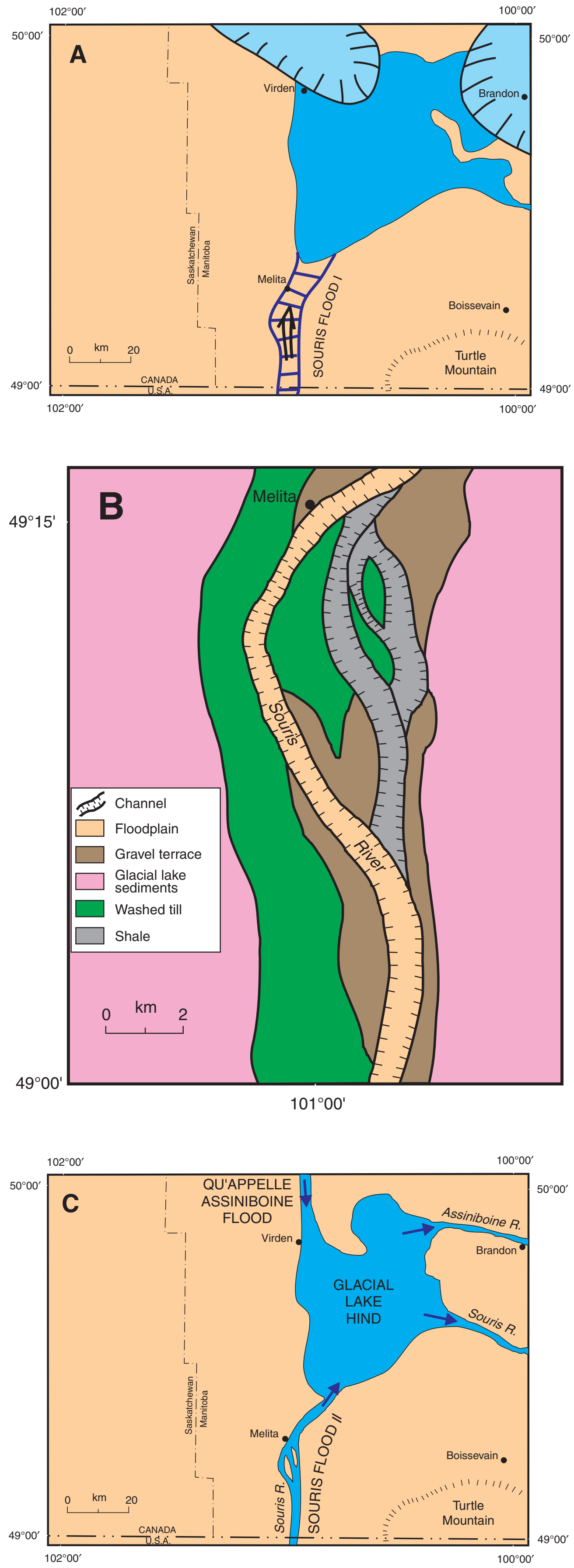

Figure 63. *Souris Valley floods: two and possibly more catastrophic floods entered glacial Lake Hind from the south. The earliest (**A**) occupied a broad channel (**B**), and a later one (**C**) incised channels into shale. These major influxes of water deepened the Pembina spillway and caused lowering of the level of glacial Lake Hind. During the later part of this phase, eastward retreat of the Red River Lobe opened a direct connection between glacial Lake Hind and glacial Lake Agassiz at Brandon.*

(Ritchie and Lichti-Federovich, 1968), from the Riding Mountains 75 km to the north (Ritchie, 1969), and recently, at Deep Lake, 120 km to the west of the area, where as much as 13 m of organic-rich lake sediments have been cored (Sauchyn et al., 1996). The following comments are based on summaries by Anderson et al. (1989) and Ritchie (1989). Early spruce forests gave way abruptly to grasslands about 10 000 years ago. This change from forest to grassland is attributed to a change to a warmer and drier climate. Warm dry conditions peaked 6000 to 8000 years ago with the boundary between prairie and forest vegetation migrating well to the north. The Boreal Forest moved south, reinvading grassland areas between 5500 and 2500 years ago when the climate apparently became cooler and more moist. The succession from Deep Lake might be typical of the environmental change that might be expected through out much of the Virden map area. The following information was provided by M.V. Sauchyn, (personal communication, 1996) and is based on a preliminary examination of the core (sampling at about 16 cm intervals). The oldest AMS radiocarbon age was 10 090 ± 180 BP (TO-5630) obtained from a depth of 12.5 m. In general, there was little variation in pollen composition throughout the 12.8 m of analyzed core. A pollen zone that might have been associated with the Hypsithermal Interval (the warmest part of Holocene time) appears to date from about 8650 to 4870 years ago and the present vegetation pattern appears to have been established about 1750 years ago.

APPLIED GEOLOGY

Aggregate resources

Introduction

The aggregate discussed in this report is naturally occurring sand and gravel. The majority of these materials are found within glaciofluvial, alluvial, eolian, and lake deposits. Aggregate quality depends on the grain size and grading of the material and the quantity of deleterious materials that is present. In general, glaciofluvial deposits provide aggregates with the largest content of coarse materials, but also tend to contain the greatest quantities of detrimental materials. Alluvial deposits generally contain lesser amounts of deleterious materials than glaciofluvial deposits, but can lack the coarser component required in a good aggregate. Lake and eolian deposits, in general, are too fine grained to be useful as aggregate and useful only when sand is the material required.

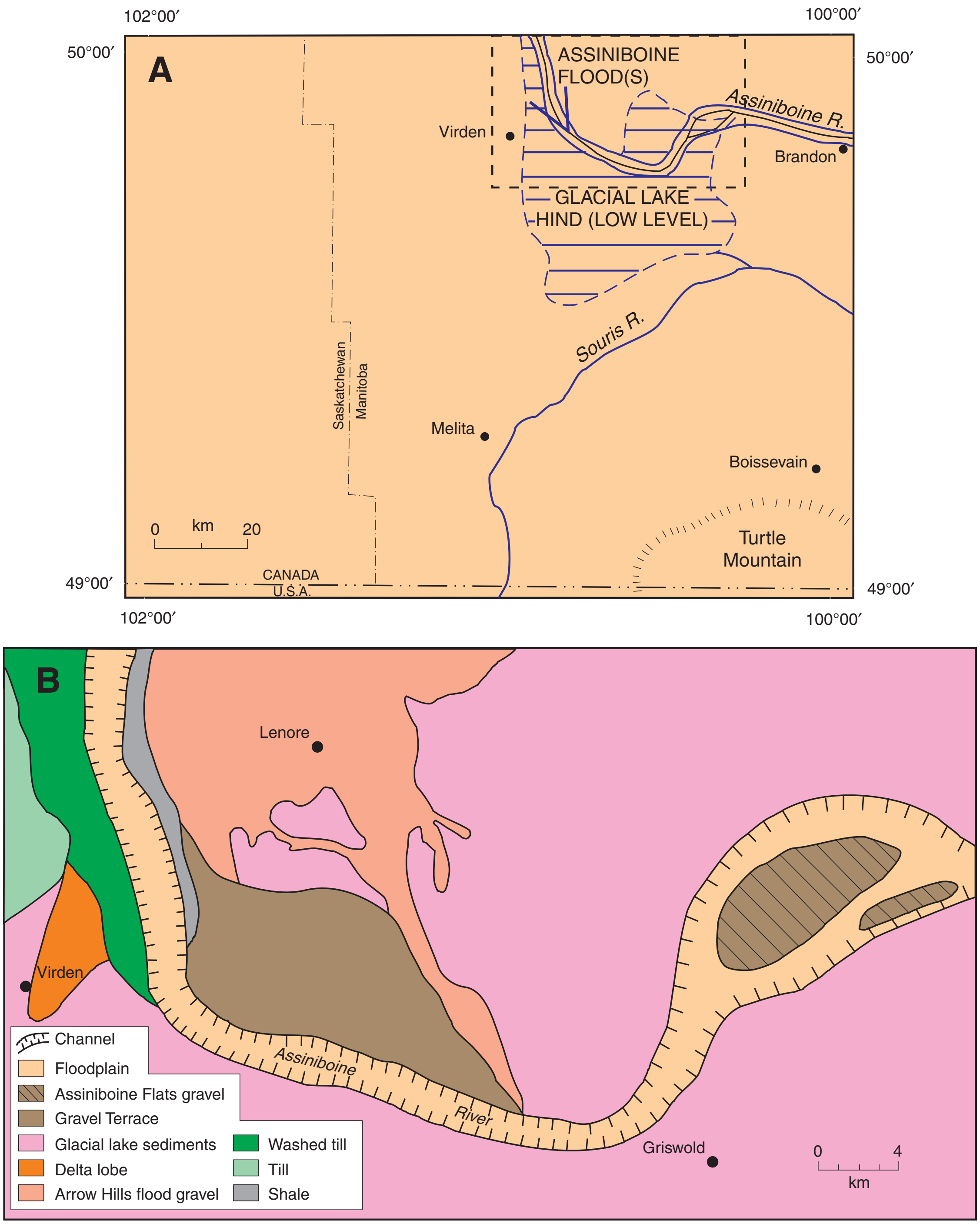

Figure 64. *Assiniboine floods: northward ice retreat of the Assiniboine lobe permitted meltwater to enter glacial Lake Hind from the north (**A**). Early sediments from the north were deposited in a delta north of Virden (**B**). Assiniboine River valley floods, however, carved a spillway across the northern part of the lake basin so that sediments could be flushed directly to the Assiniboine delta of glacial Lake Agassiz which lay just to the east of Brandon. Later floods were responsible for the important aggregate deposit at Assiniboine Flats.*

Most aggregate uses require aggregate containing more than 25% gravel-sized materials. The greatest quantities of coarse material occur in the units mapped as glaciofluvial deposits. Some glaciofluvial deposits, however, contain variable amounts of silt and clay, materials detrimental to aggregate quality. Detrimental quantities of fines are most often found in ridged and hummocky glaciofluvial map units — deposits that were poorly washed by meltwater. Alluvial materials and coarse lake sediments tend to contain less fines than glaciofluvial deposits, but, as mentioned above, can lack the coarser component necessary for a good aggregate.

Shale clasts are soft, tend to break down readily, and consequently are detrimental in aggregate. Shale content in aggregate materials in the Virden map area tends to be high. Shale content is highest in hummocky and ridged glaciofluvial map units, deposits most closely associated with deglaciation. Shale is also high where shale bedrock lies near the surface. Shale content of glaciofluvial gravels in the north-central part of the map area (south of Lenore, Fig 64) is extremely high (in places >95%) because bedrock lies near surface in this region, and meltwaters were cutting directly into shale. In addition, certain terraced gravels, such as those in the delta at the mouth of Dand Channel (Sun and Teller, 1997) and some of those associated with flood deposits in the Souris Valley east of Melita (Fig 65), were also derived directly from the erosion of shale bedrock and consequently are high in shale.

The thickness of aggregate deposits is difficult to estimate without drilling and can be extremely variable. In a general sense, alluvial and glaciofluvial gravels located within meltwater channels are thin, whereas those at the margins of or within glacial lake basins tend to be thicker. Hummocky and ridged glaciofluvial deposits tend to be among the thickest deposits in the area, but are also quite variable in thickness. In addition to thickness, water-table depth controls the volume of easily extracted aggregate. The water table tends to be high in low areas and valley-bottom locations. Consequently, unless the operator is prepared to dredge gravel from a pond, the exploitable thickness of aggregate in a low-lying deposit could be limited to <1 m if the water table is high. Thickness of overburden also controls the economic viability of an aggregate deposit. Most sand and gravel deposits in the Virden map area have a minimum of cover. In most places this amounts to <0.5 m of silty soil or silty sand. In one deposit on the flanks of Turtle Mountain (GP959 *in* AGGDAT database and FI940037 *in* FIELDAT database) gravel and sand are overlain by about 2 m of silt and till, and the Souris Gravel (GP514 *in* AGGDAT database and KJ670001 in FIELDAT database) in places are overlain by <2 m of silty sand.

The best aggregate deposit in the area occurs in the Assiniboine River valley on the northern side of Assiniboine Flats (Fig 65). The glaciofluvial materials in this area were deposited by floods of meltwater that passed through the Assiniboine River valley late in the deglaciation history (Sun, 1996, p. 94, 148). The gravels are well washed, coarse, and very large volumes are easily accessible above the water table (to see data, click on gravel pit site on AGGDAT Map; several of the pits in this area are GP232, GP345, GP807, and GP810 in AGGDAT database).

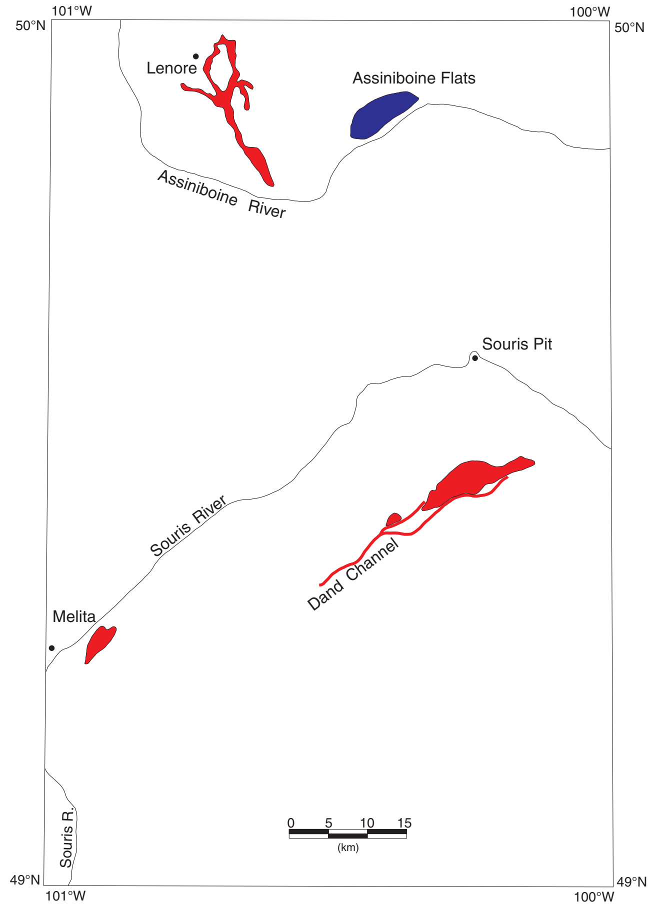

__Figure 65.__ Aggregate location map showing Lenore, Dand, and Melita shale-rich gravels, Assiniboine Flats deposits, and Souris gravel pit.

Excellent aggregate deposits are also located about 2 km to the east of Souris (Fig 65). These gravels are dominantly quartzite and a variety of types of chert from the Rocky Mountains and resemble preglacial gravels, except that they contain minor amounts of granitic, gneissic, and fine-grained dark lithologies from the Canadian Shield. (Elson, 1956). Klassen (1969) referred to these as the 'Souris Gravels'. The deposits are coarse, well washed, and do not contain shale. As noted above, they do, however, include chert. Chert can react with cement while concrete is setting, resulting in cracking of the concrete. Pits in this deposit are GP514 and GP516 (AGGDAT database) and KJ670001 (FIELDAT database).

This report contains a number of databases and maps that will aid those interested in obtaining more information about aggregate resources of the area.

1. *Spot Surficial-Materials Map*: This shows the nature of the surface material at each field observation site and at each borehole. If only a small quantity of aggregate is required, this map might indicate an occurrence of sand and gravel that lies outside an exploited area. (This map may be accessed as Spot Map 62 F BORDAT, 62 F FIELDAT).

2. *Sand and Gravel Interval Map*: The interval map for depths of 0 to 10 m indicates the total thickness of sand and gravel as indicated by the upper 10 m of boreholes. (This map may be accessed as sand and gravel interval map (referred to elsewhere in this report as 'Aquifer Materials Content Map') 0–5 m, 5–10 m, 10–20 m, 20–30 m, 30–40 m, 40–50 m, 50–60 m, 60–70 m, 70–80 m, 80–90 m, 90–100 m, 100–120 m).

3. *Natural Aggregate Suitability*: The suitability of each surficial map unit as a potential source of aggregate has been estimated (display aggregate suitability map 62 F SE, 62 F NE, 62 F NW, 62 F SW). The following section describes how these derived maps were constructed.

4. *AGGDAT Database*: This database includes aggregate information that was obtained from Manitoba Highways and Transportation, from the files of the disbanded aggregate unit of Manitoba Energy and Mines, and from Manitoba Energy and Mines publications (Groom, 1993, 1994).

A number of other Manitoba Energy and Mines publications provide information on the aggregate resources of the area: Berk (1985); Groom (1987a, b, 1990); Manitoba Energy and Mines (1988); Underwood McLellan and Associates Ltd. (1977).

Aggregate suitability map

Derived maps, referred to as a natural aggregate suitability maps, have been prepared as part of this package (for instructions on viewing this map *see* Aggregate Suitability Map 62 F SE, 62 F NE, 62 F NW, 62 F SW). These maps were prepared through a factoring process from the surficial-materials maps of the area (Blais-Stevens and Fulton, 1997; Blais-Stevens et al., 1997; Sun and Fulton, 1995a, b).

Unit textures, unit aggregate scoring values, and aggregate rating classes

The first step in preparing these maps was to describe the general texture of each map unit. The texture given was an average for the entire area based on field texture assignments. This estimated texture is part of the attribute table for the surficial-materials map. The general textures categories of materials are: fines — clay and silt (<0.062 mm); sand (0.062–2.0 mm); fine gravel — sand to cobble size (2.0–64 mm); and coarse gravel — cobble and larger clasts (>64 mm). The approximate textural composition is given in terms of general categories: >75%, 50–75%, 25–50%, 10–25%, <15% and <5%. The component scores that were assigned to each texture category are given in Table 11. Table 12 lists all map units, indicates the approximate textural composition of each, and assigns an aggregate-rating factor to each (factor value). The aggregate-rating factor is obtained by summing the factor assigned for each texture category and those assigned for special unit conditions or circumstances., Table 13 indicates the factor value range of each aggregate-rating class. This was set up subjectively by estimating the relative suitability of the various map units that had specific rating-factor scores. The classes assigned to each map unit are given in Table 12.

Table 11. Component aggregate score assigned to each category of map-unit texture.

Texture class	Aggregate value for each per cent composition category					
	>75	50–75	25–50	10–25	<15	<5
Fines	-4	-4	-2	-1	1	x
Sand	2	3	3	2		
Fine gravel			4	4	1	0
Coarse gravel			3	4	1	0

x Table cells lack values where this composition was not assigned to any map units in the area.

Till geochemistry

Sample collection

The objective of this work was to obtain uncontaminated samples of the unweathered sediment. In order to do this, it was important that organic material, weathered material, and contaminated, mixed-surface material be cleared from the sample site. Where samples could be collected from exposures, loose surface material was removed to expose fresh sediment before sampling the C horizon. In most places however, exposures were not available, so it was necessary to make a hole using a hand auger or shovel. Holes were extended to an average depth of 70 cm below the B soil horizon before collecting the sample. Here again, surface material was cleared from around this hole to avoid possible contamination. About 1 kg of material was included in each sample.

Sample analysis

Samples were submitted to the Saskatchewan Research Council (SRC) in Saskatoon, Saskatchewan for geochemical analysis. Samples were disaggregated and dry sieved. The <2 mm fraction was agate ground, and digested using $HF/HNO_3/HCl_4$. A suite of 25 elements and major-element oxides was analyzed mainly by ICP-MS (inductively coupled plasma mass spectrometry). Exceptions were Pb and K_20 which were analyzed using AAS (atomic absorption spectrometry — cold vapor technique). Carbonate values were analyzed separately from the suite of 25 elements using AAS. We followed the agricultural and environmental protocol of analyzing the <2 mm fraction in contrast to analyzing the <63 µm fraction, a common practice when gathering data for mineral exploration applications.

Map display of analyses

A variety of statistical parameters was determined for the geochemical data using Microsoft® Excel v.5.0 (*see* analyses of individual elements). Ranges of concentrations were determined and percentile values were calculated for each element. Following calculations, proportionally sized dots were

Table 12. Unit textures, aggregate scoring values, and aggregate relative-rating classes.

Unit[1]	Comp[2].	Fine[3]	F[4]	Sand[5]	S[6]	Fine Gravel[7]	fG[8]	Coarse Gravel[9]	cG[10]	Other[11]	Factor Value[12]	Class[13]	Unit
Er	0	10–25	-2	>75	2	<5	0	<5	0	0	0	1a[14]	Er
Cf	0	>75	4	10–25	2	<15	1	<5	0	0	-1.00	1	Cf
Ch	-6	10–25	-2	10–25	2	<15	1	10–25	3	0	-2.00	1	Ch
Cx	0	50–75	-4	25–50	3	<15	1	<15	1	0	1.00	1	Cx
Cx*	0	50–75	-4	25–50	3	<15	1	<15	1	0	1.00	1a	Cx*
Ap	0	50–75	-4	25–50	3	<15	1	<5	0	-1	0.00	1a	Ap
gAp	0	10–25	-1	50–75	3	10–25	4	<15	1	-1	6.00	3	gAp
Al	0	>75	-4	10–25	2	<15	1	<5	0	-1	-2.00	1a	Al
At	0	25–50	-2	25–50	3	10–25	4	<15	1	0	6.00	3a	At
Af	0	50–75	-4	50–75	3	10–25	2	<15	1	0	2.00	1a	Af
gAf	0	<15	1	50–75	3	25–50	4	10–25	4	0	12.00	5	gAf
Af*	0	<15	1	>75	2	10–25	4	<15	1	0	8.00	4	Af*
gAf*	0	<15	1	50–75	3	25–50	4	10–25	4	0	12	5	gAf*
Lr	0	<15	1	>75	2	<15	1	<5	0	0	4.00	2	Lr
Ll	0	>75	-4	10–25	2	<5	0	<5	0	0	-2.00	1	Ll
Ll+c	0	>75	-4	10–25	2	<5	0	<5	0	0	-2.00	1	Ll+c
sLl	0	10–25	-1	<75	2	<5	0	<5	0	0	1.00	1	sLl
sLl+r	0	10–25	-1	<75	2	<5	0	<5	0	2	3.00	1a	sLl+r
c/Ll	0	>75	-4	10–25	2	<5	0	<5	0	0	-1.00	1	c/Ll
c/sLl	0	25–50	-2	50–75	3	<5	0	<5	0	0	1.00	1	c/sLl
oLl	0	>75	-4	<15	0	<5	0	<5	0	-1	-5.00	1	oLl
Lp	0	>75	-4	10–25	2	<5	0	<5	0	0	-2.00	1	Lp
sLp	0	10–25	-1	>75	2	<5	0	<5	0	0	1.00	1	sLp
Lu	0	>75	-4	10–25	2	<5	0	<5	0	0	-2.00	1	Lu
Lh	0	>75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Lh
Lv	0	>75	-4	10–50	2	<5	0	<5	0	-1	-3.00	1	Lv
Lv/T	0	>75	-4	10–50	2	<5	0	<5	0	-1	-3.00	1	Lv/T
Gt	0	<15	1	50–75	3	25–50	4	<15	1	0	9.00	4	Gt
gGt	0	<15	1	25–50	3	25–50	4	10–25	4	0	12.00	5	gGt
g*Gt	-5	<15	1	50–75	3	25–50	4	10–25	1	0	7.00	3	g*Gt
Gl	0	<15	1	50–75	3	25–50	4	<15	1	0	9.00	4	Gl
gGl	0	<15	1	25–50	3	25–50	4	10–25	4	0	12.00	5	gGl
g*Gl	-5	<15	1	25–50	3	25–50	4	10–25	4	0	7.00	3	g*Gl
Gp	0	<15	1	50–75	3	25–50	4	<15	1	0	9.00	4	Gp
g*Gp	-5	<15	1	25–50	3	25–50	4	10–25	4	0	7.00	3	g*Gp
gGu	0	<15	1	25–50	3	25–50	4	10–25	4	0	12.00	5	gGu
gGr	0	10–25	-1	25–50	3	25–50	4	10–25	4	0	10.00	4	gGr
g*Gr	-3	10–25	-1	25–50	3	25–50	4	10–25	4	0	7.00	3	g*Gr
Gh	0	10–25	-1	25–50	3	25–50	4	10–25	4	0	10.00	4	Gh
Gv	0	10–25	-2	50–75	3	25–50	4	<5	0	-1	4.00	2a	Gv
Gv/T	0	10–25	-2	50–75	3	25–50	4	<5	0	-1	4.00	2a	Gv/T
T-w	0	50–75	-4	25–50	3	10–25	1	<15	0	4	4.00	2a	T-w
Th	0	50–75	-4	25–50	3	<15	1	<5	0	3	3.00	2a	Th
Tl	0	50–75	-4	25–50	3	<15	1	<5	0	0	0.00	1	Tl
Tl+r	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tl+r
Tl+c	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tl+c
Tp	0	50–75	-4	25–50	3	<15	1	<5	0	0	0.00	1	Tp
Tp+r	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tp+r
Tp+c	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tp+c
Tr	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tr
Tr*	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tr*
Tu	0	50–75	-4	25–50	3	<15	1	<5	0	0	0.00	1	Tu
Tu+r	0	50–75	-4	25–50	3	<15	1	<5	0	1	1.00	1a	Tu+r
Tm	0	50–75	-4	25–50	3	<15	1	<5	0	0	0.00	1	Tm
Tv	0	50–75	-4	25–50	3	<15	1	<5	0	-2	-2.00	1	Tv
gA*	0	<15	1	25–50	3	25–50	4	10–25	4	0	12.00	5	gA'

1 Map unit designator (see surficial geology map unit)
2 Special compositional factor reflecting detrimental effect of shale content on suitability as aggregate (decreasing suitability with increasing size of clasts)
3 Content of fine materials (finer than sand sized, <0.0625 mm)
4 Rating given to the content of fine sediment in the previous column
5 Content of material of sand size (0.0625–2 mm)
6 Rating for the content of sand-sized material given in the previous column
7 Content of fine gravel (coarser than sand, but finer than cobble, 2–64 mm)
8 Rating for the content of fine gravel given in the previous column
9 Content of coarse gravel (coarser than pebble sized, >64 mm)
10 Rating for the content of coarse gravel material given in the previous column
11 Additional considerations used in rating map unit, eg. +2 for local inclusion of sand ridges in fine-grained unit; -1 for unit in which water table is near the surface in many places
12 Aggregate-rating factor value arrived at through the formula S + fG + cG + F + Comp + Other
13 The aggregate-rating class or category of the map unit based on the Table 13
14 In places this unit includes small areas of material which rate one or two classes higher

Table 13. Aggregate values included in each aggregate relative-suitability class.

Class	Value	Suitability
1	<3	Unsuitable
1a	<3	Unsuitable, but may include small areas of material which rate one or two classes higher
2	3–4	Generally unsuitable, but in places marginally suitable for some purposes
2a	3–4	Generally unsuitable, but in places marginally suitable for some purposes and may include small areas of material which rate one or two classes higher
3	5–7	Moderate, but some limitations
4	8–10	Good, but some limitations
5	11–12	Good

allocated to percentile values. Maps of proportionally sized dots reflecting chemical concentrations were generated for each element (*see* Geochemical Analyses Maps).

Analyses of individual elements

Statistical analyses were conducted for each element to determine statistical parameters. In addition, percentile values and frequency histograms were compiled for each element. The 25 elements and major-element oxides analyzed were Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, Ni, Pb, Mo, P_2O_5, Zn, Cd, Co, MnO, Cr, V, Be, Cu, TiO_2, Zr, Y, La, Th, Sr, and Ba. In addition, total percent carbonate values were compiled. The result of the statistical analyses indicated that Cd values were too low to warrant displaying.

Geochemical-distribution results and discussion

With the exception of the northeast quarter and south-central portion of the map area, which is mainly covered by glacial lake sediments, till samples are distributed fairly uniformly across the map area. The results for specific elements/oxides are either shown in ppm (parts per million) or percentages. Elements/oxides, such as Cr, Pb, Ni, Co, Mo, Be, La, Th, Y, Cu, MnO, TiO_2, P_2O_5 are classed as low concentrations as they are less than 100 ppm or 1%. Zr, Zn, K_2O, MgO, and Fe_2O_3 concentrations are categorized as low to medium, varying from 100–300 ppm and 1–10 %. Only two elements, Sr with concentrations as high as 438 ppm, and Ba with concentrations as high as 2400 ppm, are considered as high concentrations. Total carbonates ($CaCO_3$) are also high with concentrations of 30–59%.

Geomorphological features and striations on boulder pavements suggest that the last ice-flow direction was southeastward. In general, the distribution of geochemical elements is uniform or random, and does not reflect a particular ice-flow direction. There are several possible explanations why the patterns of element concentrations do not indicate any particular preferred direction of glacial dispersal. The main two are 1) bedrock is flat lying and relief is low so that the same lithologies are at the surface over wide areas; 2) at least five glaciations have occurred and thick drift is common, so that over much of the area the last ice advanced over, and incorporated, homogenized drift rather than bedrock.

Nevertheless, we were able to identify some minor southeastward dispersal near Turtle Mountain, in the southeastern part of the map area, where the Turtle Mountain (Tertiary) and Boissevain (Cretaceous) formations outcrop (*see* Bedrock Map). These bedrock formations are composed mainly of poorly consolidated shale, sandstone, and lignite and sandstone containing minor clay and siltstone, respectively. The elements revealing minor southeastward dispersal in this area are Ba, Zn, Y, and Pb (*see* till Geochemistry Map Zn, Y, Pb and Ba). Other elements revealing a minor southwestward dispersal show higher concentrations in the northeastern part of the map area. These are Cr, Ni, Co, and Cu (*see* Till Geochemistry Map Cr, Ni, Co, and Cu). The bedrock provenance of these minor enrichments is thought to be mainly related to the underlying bedrock of Cretaceous age, the black shales of the Pierre Formation.

The total carbonate concentrations reveal enrichments in the surface-till samples of >30 to <59 % in the northeastern part of the map area, with a southwestward decrease. This fits with the interpretation that the last ice to occupy the northeastern corner of the area was Red River Ice Lobe that pushed into the area from the east (Elson, 1956; Sun, 1996; Fig. 60). The surface distribution of carbonate minerals also coincides with Klassen's (1989) observation of carbonate-pebble distribution in the southern Plains. Klassen mentioned that the number of carbonate pebbles coming from a northwestern source decreases southeastwardly as a result of the previous influence of the penultimate glaciation.

In conclusion, numerous glaciations originating from different sources and the flat-lying bedrock with few outcrops has produced several tills with a homogeneous surface till. The resulting geochemical signatures in the <2 mm fraction of till are also homogeneous, with minor evidence of southeastward dispersal. The carbonate content reveals a southwestward distribution, which coincides with a late southwestward ice flow.

HYDROGEOLOGY

Introduction

The Virden map area lies in the Interior Plains hydrogeological region described by Brown (1972). The area is underlain by thick sequences of roughly flat-lying Paleozoic, Mesozoic, and Tertiary sedimentary rocks underlain by Precambrian rock (*see* Bedrock section). Bedrock is overlain by a generally thick cover of surficial material consisting dominantly of glacial sediments. The sedimentary rocks lying near surface in the Virden area are dominantly variably indurated shale, sandstone, and siltstone which include regional aquifers. In general, water yields are small and quality is poor in these bedrock aquifers. The Virden area surficial sediments consist of till, lake sediments, and fluvial deposits. Sand and sand/gravel aquifers occur within the surficial sediments, but due to the generally haphazard distribution of permeable materials, finding adequate permeable beds can be a problem. Where aquifers are present, the water quality is generally good and yields can be high. General information on hydrogeological conditions in this part of the plains area of southern Canada can be found in Meyboom (1963, 1966a, 1967a, b) and Meyboom et al. (1966). Groundwater publications relating to the Virden area are Bakhtiari (1971), Betcher (1983), Eilers (1973), Freeze (1962), Halstead and Elson (1948, 1949a, b), Kohut (1972), Lissey (1968), MacKay and Hainstock (1936), Manitoba Water Control and Conservation Branch (1968), Manitoba Water Resources Branch (Planning Division), (1968), Meneley (unpub. rept., 1983), Render (1987, 1996), Rutulis (1976), Western Groundwater Consultants Ltd. (1982), and Whitaker (1974). Groundwater information for adjacent areas may be found in Halstead (1959) (to the east), Randich and Kuzniar (1984) (to the south), Parizek (1964) (to the west), Manitoba Water Resources Branch (1978) (to the north), and Christiansen (1971) (to the northwest).

This report contains a number of databases and maps that should aid those interested in locating water or in obtaining additional information on water wells, aquifers, water quality etc, in the Virden area.

Aquifer Map: This map shows the location of the main known aquifers (see Aquifer Map). This indicates general areas where sufficient information is available to suggest that an aquifer might be present. The next section provides additional information on the aquifers.

Aquifer Materials Content: This map shows the proportion of sand and gravel that the borehole database indicates lies within the specified depth interval (*see* Aquifer Materials Content Map, 0–5 m, 5–10 m, 10–20 m, 20–30 m, 30–40 m, 40–50 m, 50–60 m, 60–70 m, 70–80 m, 80–90 m, 90–100 m, 100–120 m). This indicates the proportion of the depth interval that consists of sand and gravel (maximum 10). Further explanation of this map is given below.

Drift Thickness Map: This map shows the modelled thickness of surficial sediments based on information from water wells (*see* Drift Thickness Map). The map provides an indication of the probable depth that would have to be drilled to reach bedrock. Additional information on this map may be found in the section on Surficial deposit stratigraphy.

Bedrock Surface Map: This map shows the elevation and shape of the surface of bedrock as modelled from water-well data (*see* Bedrock Surface Map). This map shows the modelled positions of interpreted valleys in the bedrock surface (choice sites for aquifer exploration). Additional information on this map may be found in the section on Surficial deposit stratigraphy.

Borehole Location Map: This map shows the location of water wells and stratigraphic test holes (see Borehole Location Map). The boreholes are displayed according to the use of the hole (test, production, observation, etc.). Once the Borehole Location Map is displayed, clicking on a borehole site will start BORVIEW, which displays the well as a stratigraphic column. Clicking on the borehole label will display data pertinent to the well as a whole; clicking on one of the units will display data pertinent to that unit.

BORDAT Database: This is the database that contains all water-well and stratigraphic test records. Information from this database can be accessed as indicated above, or the database can be downloaded into any database software that can handle .DBF files or Microsoft® Access database files. Tables of particular interest for groundwater purposes are LOCATN — location and general information concerning the use, owner, and drilling of the borehole; LITHOLOG — borehole logs including the original driller's log; CONSTRUCT — information on well construction (if available); WTR_QUAL — water analyses (if available); PMP_MON — information on pump testing and/or period during which water-table level was monitored (if available). Additional information on this database may be found in the section on Surficial deposit stratigraphy.

Additional information on groundwater in this region can be obtained from the Manitoba Water Resource Branch, Saskatchewan Water Corporation, and Saskatchewan Research Council.

Aquifer map

A generalized map of aquifers has been prepared for the Virden map area (see Aquifer Map). R. Betcher, Manitoba Water Resources Branch, is largely responsible for the Manitoba part of the area, and M. Simpson, Saskatchewan Research Council is largely responsible for the Saskatchewan area. The definition of aquifer does not specify the quantity of water that must be produced before a geological unit may be referred to as an aquifer. Here we assume that the unit has to provide economically useful quantities of water (i.e. sufficient water to provide for the needs of a single household). In addition to the definition of an aquifer being vague on the necessary yield, nothing is included about the quality of groundwater. Here, we will consider only aquifers or portions of aquifers which serve as sources or potential sources of fresh groundwater. The term 'fresh' will be applied to groundwaters containing less than 2000 mg/L total dissolved solids (TDS).

Surficial aquifers

Aquifers within surficial sediments in the Virden map area include sand, gravel, or sand and gravel that occur as surface, intertill and subtill, outwash, lacustrine, and alluvial deposits. Although individual aquifers are widely distributed throughout the surficial deposits of this region, most of these aquifers are thought to be of limited areal extent. Well yields from these aquifers fall within a wide range, as would be expected. Local yields of several tens of litres/second have been developed from some aquifers while other aquifers barely yield sufficient supplies for single-family dwellings.

Groundwater quality also shows considerable variability. Unconfined aquifers generally contain good quality water with typical TDS concentrations ranging from 200–500 mg/L. However, these aquifers are susceptible to contamination from near-surface sources. Confined sand and gravel aquifers generally contain poorer quality groundwater. The average TDS for 165 analyses of groundwater from these aquifers was 1340 mg/L (Betcher et al., 1995). These groundwaters tend to be very hard and frequently contain sulfate concentrations exceeding drinking-water guidelines.

The only large surficial aquifer that has been well studied and for which published information is available is the Oak Lake aquifer (Render, 1987). A number of buried valleys have been tentatively identified (Klassen and Wyder, 1970), but the aquifer properties of these have not been extensively explored.

Oak Lake aquifer

The Oak Lake aquifer consists of saturated fine- to medium-grained sands with some gravels extending over an area of approximately 2100 km^2 (Render, 1987). The sands and gravels are up to about 27 m thick and overlie a sequence of sandy silts, lacustrine clays, and glacial tills. Bakhtiari (1971) presented a detailed analysis of the part of the aquifer that lies along Stony Creek. The general stratigraphy of the aquifer is shown in cross-sections 6 and G (see cross-section 6, Fig. 16, cross-section G, Fig. 37) and in Sun (1996, p. 61). The aquifer is considered to be unconfined as the sands are exposed at ground surface. Recharge occurs by infiltration of snowmelt and rainfall and amounts to approximately 50 mm/year (F.W. Render, pers. comm., 1995). Render (1987) estimated the sustainable yield of the aquifer to be approximately 15 000 acre feet per year. Discharge occurs by evapotranspiration and as seepage and springs discharging into local surface water bodies. The Souris River and Oak and Plum lakes serve as regional groundwater discharge areas. The aquifer is an essential source of municipal, industrial, agricultural, recreational, and rural water supplies. Current groundwater abstraction is approximately 1450 dam^3 per year, including 1380 dam^3 per year licenced for irrigation.

As this unconfined aquifer is recharged directly by snowmelt and rainfall, groundwater quality is generally excellent, with total dissolved solids contents from about 200–400 mg/L. An area of poorer quality groundwater has been found along part of the west shore of Oak Lake.

Buried valleys and confined aquifers

Aquifers, enclosed in till or in filled valleys that are cut into till, bedrock, or till and bedrock, are present in several parts of the area (Meyboom, 1966b; Klassen and Wyder, 1970). In this area, much of the stratified sediment filling the valleys consists of silt and clay, but sands and gravels, several metres thick, are present in places. Little information is available on the location, nature, and continuity of these features. The known occurrences have been subdivided into intertill and subtill features. Intertill aquifers include both isolated and broad deposits of sand and gravel that do not appear to be associated with buried valleys, and sediment fills that occupy valleys cut into or through till deposits. The buried valley intertill deposits may, in part, consist of alluvial deposits formed between glaciations, whereas the other intertill gravels and sands are probably largely outwash deposited during glaciations. Subtill aquifers consist mainly of materials deposited in valleys prior to the advance of the first Pleistocene glaciers.

Estevan valley

The Estevan valley (Christiansen, 1965) has been traced into the southwestern corner of the area (Meyboom, 1966b; Whitaker, 1974). This feature was originally referred to as the valley of the preglacial Missouri (Meneley et al., 1957). As outlined by Klassen and Wyder (1970), it is a complex feature that probably was developed during more than one phase of erosion and fill. This valley has not been traced as far east as the Saskatchewan–Manitoba border.

Pierson valley

The Pierson valley is a broad, relatively shallow channel in the bedrock surface that generally parallels the modern Souris River, but lies 10–15 km to the west, (Klassen and Wyder, 1970). Because this feature is broad, it is poorly defined and tends to blend into the general saddle in the bedrock surface that extends through the Oak Lake area. This valley could be related to the ancestral Missouri River (Klassen and Wyder, 1970).

Virden valley

The relatively narrow (~3 km) deep (~130 m) buried Virden valley enters the area about 5 km west of the modern Assiniboine River valley. It has been traced to near Virden where it either swings eastward to join the Assiniboine or continues southeastward into the general low basin in the bedrock surface that underlies Oak Lake. It has been speculated that this valley was developed by glacial diversion of meltwater (Klassen and Wyder, 1970).

Medora valley

This is a narrow, deep feature that stretches from Waskada to Medora and probably continues into the basin that underlies Oak Lake. Klassen and Wyder, (1970) referred to this valley as being in a 'side-hill' position, implying that it might have been cut as an ice-marginal valley.

Bedrock aquifers

Bedrock aquifers include sandstone beds within the Boissevain, Eastend, Whitemud, Battle, Frenchman, Ravenscrag, and Turtle Mountain formations and the hard siliceous shales of the Odanah Member of the Pierre Formation (bedrock units are described in the Bedrock section). While older (and thus deeper) bedrock units also form aquifers in the map area, water quality in these units is very saline; they will not be considered further.

Boissevain and Turtle Mountain aquifers

Sands and sandstones of the Boissevain and Turtle Mountain formations (*see* Bedrock section) underlie an area of about 920 km^2 in the Turtle Mountain upland area. The thickness of sand and sandstone appears to vary significantly over short distances as does the grain size. As a result, the yields of wells drilled into these bedrock aquifers show considerable variation. Most wells yield less than 0.2 L/s although Western Groundwater Consultants (1982) stated that yields up to 5.5 L/s are possible towards the northern extent of the aquifers where the deposits appear to coarsen. Groundwater flow directions remain poorly understood. No estimates of recharge rates to these aquifers or the long term sustainable yield have been published.

Groundwater quality in the Boissevain and Turtle Mountain Formation sands and sandstones is generally quite poor. Total dissolved solids concentrations range from about 900 to 2400 mg/L. Groundwaters tend to be calcium-sulfate-bicarbonate type with very high hardness values or sodium-sulfate-bicarbonate types. Sulfate concentrations generally exceed drinking-water guidelines in both groundwater types. No spatial trends in groundwater chemistry have been established.

Eastend, Whitemud, Battle, Frenchman, and Ravenscrag Formation aquifers

The southwestern corner of the map area is underlain by uppermost Cretaceous and Tertiary bedrock of the Eastend, Whitemud, Battle, Frenchman, and Ravenscrag formations (*see* Bedrock section). These are correlative with the Boissevain and Turtle Mountain formations. According to Meneley (unpub. rept., 1983), as reported in Tokarsky (1986), the channel sands in these units have probable yield ranges of 0.06 to 0.6 L/s, while fractured hard coal and fractured sandstone could yield up to 2.9 L/s.

The water is highly mineralized with many wells yielding sodium chloride/bicarbonate water or sodium bicarbonate/chloride water. According to Meyboom, (1966b), sodium sulphate predominates in groundwater above about 625 m elevation, with groundwaters below this level being characterized by sodium chloride.

Odanah Shale aquifer

The Odanah Shale aquifer is formed by the siliceous shale of the Odanah Member of the Pierre Formation (*see* Bedrock section). The shale is locally fractured, providing a secondary permeability to deposits which are normally considered to form an aquitard. The Odanah Shale is recognized to underlie an area of about 1800 km^2 within the map area with the southwestern extent of the aquifer being poorly mapped. Several thousand individual farm and rural residential wells are currently drilled into the aquifer, particularly in areas where the overlying Quaternary deposits are thin, and sand or sand and gravel aquifers are not present. Well yields are highly variable with most wells drilled into the aquifer yielding less than 0.5 L/s. Yields in excess of 10 L/s have, however, been reported from a few wells. No studies of regional groundwater flow have as yet been conducted on the aquifer. Render (1996) estimated the sustainable yield of the entire Odanah Shale aquifer in southwestern Manitoba to be approximately 296 000 dam^3 per year which would translate to an annual sustainable yield of about 27 000 dam^3 within the area of this study.

Groundwater quality in the Odanah Shale aquifer varies over a wide range. Total dissolved solids contents ranging from 500 to more than 9000 mg/L have been found. A variety of groundwater quality types have been reported within this range, with fresher groundwaters generally containing a predominance of calcium, magnesium, sulfate, chloride, and bicarbonate ions. More saline groundwaters tend to be sodium-chloride or sodium-chloride-sulfate types and are normally quite soft. Water quality is generally considered to decline with depth although the relationship is not well structured.

Aquifer materials content map

The Aquifer Materials Content Map shows the proportion of sand and gravel that the borehole database suggests lies within the specified depth intervals. The data used are the net thickness of aquifer material (sand/gravel) within a given depth interval. The depth intervals used in this study are given in Table 14. The appropriate map can be accessed by clicking on the borehole interval listed in the table. In preparing this map only display wells were used. It must be noted that the amount of data available diminishes with depth. For the first interval (0–5 m) there are 4031 wells (there are 4392 display wells in the area but 361 do not reach a depth of 5 m). Table 14 provides information on the number of boreholes used for each. In addition to these intervals that begin at the surface, several other intervals have been included as maps (*see* Table 14). Contouring was done by means of an inverse distance algorithm run in a program called Surface II on an HP 3000 supermini computer.

Table 14. Aquifer-materials content map intervals and data points available.

Borehole interval	No. of boreholes
0–5 m	4031
5–10 m	3212
10–20 m	2136
20–30 m	1589
30–40 m	1100
40–50 m	779
50–60 m	632
60–70 m	476
70–80 m	344
80–90 m	313
90–100 m	218
100–120 m	83

AGRICULTURAL SOILS

R.G. Eilers, H. Veldhuis, and W.R. Fraser

Introduction

Productive soil is the most valuable resource on Earth. Most of our food and much of our shelter and clothing come from materials produced by the soil. Too few people realize how important the thin layer of topsoil is to the production of good crops. Soil is a vital concern to all people; those who work the land plus all the rest who live by the land. All people have a responsibility in seeing that our soils are used properly.

"The living form, whether of man or beast or of fish or fowl, that can be supported by any region, all depend for their subsistence primarily upon the plants produced in field and forest, lake and stream, and these in the final analysis are determined by the productivity of the soil and the climate" (Ellis, 1938).

The following discussion of soils has been designed to provide three levels of information. The first level is a general overview perspective common to all soils. The second level describes soil conditions typical for Manitoba's geographic environment and location, and finally, the third level culminates with a description more specific to localized soil conditions in southwestern Manitoba as presented in the accompanying maps. One map covering map sheet 62 F SE is provided. The map subdivides soils according to major taxonomic groups (soil classification) and to their dominant texture groups (*see* soil taxonomy map 62 F SE). The nature and origin of the parent materials is described in the section of this report on Surficial geology map units and their distribution is shown on the Surficial Geology map (see surficial geology map 62 F SE). Legends (soil map legend) and further information on this map are provided at the end of this section.

What is soil? — an overview

Soils comprise the uppermost layer of the Earth's surface. They developed over time through the action of climate on rock and sediments under the influence of flora and fauna. Mankind's first interest in the soil was related to its ability to produce food and fibre. In this context, soil has been defined as "The collection of natural bodies on the earth's surface supporting or capable of supporting plants".

However, soil is more than just a medium for plant growth. In the pedological sense, the term *soil* is defined as the naturally occurring unconsolidated mineral or organic material, at least 10 cm thick at the Earth's surface which, as a result of the physical and chemical changes owing to weathering, the leaching and depositional activities of soil water, the presence of soil bacteria and other organisms, and decaying vegetal and animal matter, has developed certain characteristics over time that differ physically and chemically from the underlying parent material from which it was derived. These differences may include such characteristics as colour, texture, structure, porosity, and reaction manifested in distinguishable layers or genetic horizons which comprise the soil profile. The kind, thickness, and arrangement of horizons in the profile are indications of the degree to which soil development has occurred.

Soils are composed of organic and mineral particles. Mineral particles have been derived from geological materials at the Earth's surface by processes of chemical and physical weathering. The mineral components of soil are usually grouped according to size into gravel, sand, silt, and clay fractions. Various proportions of these particle sizes constitute the soil texture.

Soils are not uniform. In the landscape, soils merge into non-soil entities such as exposed bedrock, gravel dumps, mine spoils, and permanent bodies of water. Soil extends from the surface, through genetic horizons, into the underlying material, usually to a depth of 90 to 180 cm, generally the limit of biological activity. Soil may also have water covering its surface to a depth of 60 cm or less.

Each soil has a combination of characteristics peculiar to itself. These characteristics reflect the effects produced by climate and vegetation as conditioned by relief and, hence, drainage, acting through time on the soil parent material. Soil formation is the result of the combined interaction of all these factors and thus it is difficult to discuss the role of each factor in the soil-formation process without discussing at the same time the influence of all the other factors.

Soil development

The most important active factors in soil formation are the temperature and moisture conditions within the soil (i.e. the soil climate). Under native conditions, the soil climate determines the type of organic matter, and the manner in which it is added to the soil. The soil climate also determines the microorganism activity, the rate of production and decomposition of organic matter, the rate and extent of mineral weathering, and the rate at which products of weathering are accumulated in, or removed from, the soil.

Climatic variation also influences vegetation characteristics of broad regions. In regions where temperatures during the growing season are moderate and precipitation is low with periodic drought, the natural vegetation is predominantly grass. In regions where temperatures during the growing season are cool and moisture loss through evaporation is moderate or low, the natural vegetation is predominantly forest.

The activities of mankind can be considered as a separate influence on soil development, different from the effects that other biota have on the soil. Man has altered such factors as vegetation and drainage, and although the effects of this alteration on the soil profiles or properties are not always readily apparent, they have been very significant nonetheless. For example, research has shown that altered conditions due to cultivation have led to the reduction of the organic-matter content of the soil by as much as 50 per cent.

Soil profile

Most soils develop a profile — a vertical section of the soil in which layers or horizons can be distinguished. The nature of these horizons depends upon the material in which they form through the interaction of the native vegetation, the amount of rainfall, and other climatic factors. Soils, therefore, will vary in depth (thickness), colour, texture, and other physical and chemical properties.

Most soils have three main horizons. The upper two are referred to as the A and B horizons. These are created by the action of climate, vegetation, topography, and drainage on the soil's parent material over time. The original soil parent material, or C horizon, is the third horizon common to all soils. By studying the nature and properties of these horizons we can piece together the story of how the soil developed.

The A horizon undergoes the strongest effects of climate, vegetation, and other biological activity. It forms at or near the surface where the removal of solid or dissolved material is at a maximum, as in forest soils, or where the maximum amount of organic matter is accumulated, as in grassland soils.

The B horizon is usually characterized by an accumulation of products such as clay and organic matter that moved down from the A horizon, although it may differ from the A horizon only in colour or structure. There is a close relationship between the A and B horizons because many biological and chemical reactions taking place in the one horizon have an effect on characteristics and properties of the other one. However, not all Manitoba soils have a B horizon for a number of reasons including age of the soil and drainage conditions. The A and B horizons make up the rooting zone for most annual crops, and a large portion of the root mass of perennial plants, including trees, are contained within these horizons as well.

The C horizon, or subsoil, is the deepest and as such is comparatively unaffected by climate and biological activity.

Soils of Manitoba

The midcontinental geographic location of Manitoba has meant that soils generally developed under modified climatic conditions acting on parent materials deposited and modified by glacial ice, water, and wind.

Soil variation

Soils vary significantly in their properties; they may be deep in some places, shallow in others, black or gray in colour, sandy or clayey in texture. Although the soil mantle covering Manitoba is far from uniform, all soils have some things in common. For example, all soil is a mixture of organic and mineral material plus water and air. While the major components remain the same, the proportion of each component in this mixture varies from soil to soil.

To date, more than 1000 different kinds of soil have been recognized in Manitoba. They are not scattered randomly about, but occur in definite geographic areas and as landscape patterns. Relatively small differences occur between adjacent soils on level fields of uniform texture, while marked differences set apart the soil of a poorly drained pothole from the one occurring on an adjacent well drained ridge or hummock.

Climate

Climate may be defined as the characteristically prevailing meteorological conditions, including precipitation, temperature, and wind, in a region. In an area as large as Manitoba, climate will vary from south to north and from east to west. This climatic variation is expressed in the amount, kind, and distribution over the year of precipitation, length of frost-free period, air temperature, and so on. Climatic variation results in zonation in vegetation as shown in species distribution, community composition, and growth rates. Soils show similar zonation as the types of soil that develop in an area express the direct and indirect effect of climate in the depth of profile development, profile characteristics (horizonation), and soil climate.

Parent material

Soils in the same climatic zone may differ due to the texture and mineralogical composition of the parent material. Soils developed on moderately coarse to medium-textured materials are more permeable to water and allow for a greater leaching of the soluble and colloidal fraction as compared to finer textured soils. Soils developed on moderately calcareous sediments are noticeably deeper than soils developed on strongly calcareous sediments; soils developed on the extremely calcareous material are very shallow under grassland, parkland, or forested conditions because of the difficulty of leaching the large quantity of calcium carbonate present.

Vegetation

The effect of vegetation on soil formation manifests itself in many ways. For example, shading of the soil by vegetation will modify the soil climate, nutrients are cycled from the soil through the plants back to the soil, root penetration influences soil aggregation, and the decomposition products of vegetation affect leaching, cation-exchange capacities, water-holding capacities, and soil consistence. These processes are intricately dependent upon other soil-forming factors and operate to varying degrees in all soils throughout the province.

Man

Man has also influenced the development of soils or altered the natural soils. Man has removed the natural vegetation, disturbed the surface layers, and has used practices that have altered the natural drainage and modified the natural differences between soils.

Time

Time is an important variable in soil development. Soils are generally considered to be in equilibrium with the environmental factors responsible for their formation. In the study area, the amount of time available for soil development is in the order of 12 000 years, that is, the period since deglaciation. Soil development normally progresses from youth through maturity to old age during which time soils come into a period of very slow change or equilibrium with the influencing factors. However, the development process can be influenced or interrupted by an alteration to any of the soil forming factors.

Important regional soils of Manitoba

Chernozemic soils, together with Gleysolic soils with improved drainage, provide a major portion of the resource base for Manitoba agricultural production. Luvisolic, Brunisolic, and Organic soils, in areas not limited by climate, provide a reserve of additional agricultural land in the province. Regosolic, and Solonetzic soils are common in occurrence but usually of limited extent.

Soils of the study area

Soil-forming factors

In the study area, the degree of soil-profile development is related to the regional climate and the degree of leaching, translocation, and accumulation of the soluble and colloidal fractions of the soil. In dominantly grassland areas, the amount of water available for leaching is low, but sufficient to support grass vegetation; this results in an annual accumulation of organic matter and development of black surface horizons in soils. The translocation of soluble and colloidal fractions is relatively slow and does not proceed to great depths, resulting in shallow profiles. These areas were mapped as Black Chernozemic soil.

In grassland to forest transition areas, the soil climate is more humid and cooler and is favourable for tree growth as well as grassland species. Here, there is a greater degree of leaching and translocation than in the grassland area proper. The result is the formation of soils with a 'dark grey' surface and identifiable accumulation of translocated products such as clay and organic matter lower in the soil profile. These areas have been mapped as Dark Grey Chernozemic soils. Under the more favourable moisture conditions of the forest regions, there is a greater degree of leaching and translocation of soluble and colloidal soil material resulting in generally deep soil profiles with a characteristic leaf mat, a bleached zone, and an accumulation zone dominantly composed of the translocated clay and organic matter. These soils are classified as Luvisols.

Parent material and geology of the underlying bedrock

The entire area is underlain by Upper Cretaceous shale of the Pierre Formation. In the Turtle Mountain area, the shale is overlain by the Boissevain Formation, a late Cretaceous–Tertiary sandstone, and above this the Turtle Mountain Formation, an early Tertiary sequence of shale, sandstone, and lignite-bearing beds. In the southwest corner of the area, the late Cretaceous–Tertiary sandstones are referred to as Eastend, Battle and Frenchman formations and the early Tertiary succession is referred to as the Ravenscrag Formation (*see* section on Bedrock geology).

Only very locally are soils in the study area developed on parent materials derived directly from in situ weathering of bedrock. Most of the parent materials have been derived from materials or particles which have been moved, sorted, and redeposited by the action of glacial ice, wind, and water. Thus, the soil parent materials have been derived largely from other sources as well as a mixture of materials derived from the immediately underlying bedrock. The underlying geology also has an important influence on soil drainage, relief, chemistry, and morphology.

Climate

The climate of an area affects both growing conditions and conditions below the soil surface. Air temperature, solar radiation, wind, precipitation, etc. directly influence the temperature and moisture condition of a soil: the soil climate. The soil climate may differ within relatively short distances because of differences in topography and drainage. Knolls or sloping areas are usually locally arid as a portion of the precipitation may run off. Depressions are often locally humid as they collect water and are wetter and cooler than adjacent soils. In the study area, the soils developed on sites with good internal drainage have a greater movement of soluble and weathered products and this results in the development of A, B, and C horizons, whereas soils in the level to depressional sites with poor or very slow internal drainage develop only A and C horizons.

Precipitation

Precipitation, or lack of it, in combination with evapotranspiration, which in turn is governed largely by air temperature and solar radiation, has a marked influence on soil formation. If only a small amount of water is available for leaching, either because of limited precipitation or due to high evaporation losses, generally shallow profiles will develop, which may contain large quantities of calcium carbonate and soluble salts. Under low-precipitation regimes, leaching in soils is most pronounced on lower slopes and in depressional areas where locally more humid conditions exist due to the collection of surface runoff waters. In contrast, under similar climatic conditions, well drained soils in upper and top slope positions characteristically have thin, less strongly developed profiles. In other depressions, however, high water tables combined with strong evaporation losses may result in the accumulation of soluble constituents in the soil profile.

Temperature

Soil temperature relates to areal climate, but the relationship is affected by soil depth, texture, soil water content, surface cover (vegetation, snow), landscape position, and man's manipulation. Soil temperature follows a wave pattern in response to seasonal air-temperature changes, the response being greater and more immediate near the surface than at depth where response is delayed and dampened. The soil gains heat during the period May to August and loses heat from September to March. The crossover of heat loss to heat gain takes place in April and from heat gain to heat loss in the latter part of August.

The temperature of the soil and the air influence the amount of water removed from the soil through evapotranspiration. When temperatures are cool or when the soil has less exposure to the sun (e.g. eastern and northern slopes of upland areas), evapotranspiration losses are lower and more of the precipitation is available for downward infiltration and leaching of the soil.

Relief, drainage, hydrology, and soil moisture

Relief

Elevation in the study area ranges from approximately 335 m in the Assiniboine River valley to 760 m on Turtle Mountain. Turtle Mountain is the most prominent relief feature, where elevation increases 213 m over 14 km distance. In the remainder of the survey area, relief is much less pronounced and topography varies from undulating to strongly rolling. Local relief is largely provided by a pattern of knolls and lows and drainage channels.

Drainage

The western half of the map area is drained largely by Gainsborough, Stony, and Pipestone creeks, and the Antler River. The creeks and river drain in a generally southeasterly direction and empty into the Souris River, which traverses the southeastern quarter of the area in a northeastward direction. The area to the east of the Souris River is drained by the Medora and Elgin creeks. The Assiniboine River, which occupies a large meltwater spillway, and tributary creeks drain the northeastern portion of the area. The Souris and Assiniboine rivers frequently flood their banks during periods of heavy spring runoff causing significant damage to cropland property. The majority of creeks flow intermittently throughout the year, primarily after spring thaw and after heavy summer rains. Numerous ephemeral stream channels leading from Turtle Mountain disappear abruptly between the 503 and 511 m elevation. One such creek is the Turtlehead Creek.

Drainage channels are generally more evident in the areas of pronounced slope and relief, while less-sloping terrain tends to have sloughs filled with water for all or part of the year. The Turtle Mountain area is dotted with lakes and swampy depressions. The north-facing slopes are dissected by numerous intermittent streams, which have carved deep channels.

Whitewater Lake Basin, north of Turtle Mountain, and Oak Lake–Plum Lake Basin, between the Souris and Assiniboine rivers, are large depressional areas and have more salinity than the surrounding till plain. Most of the soils in the area are imperfectly and poorly drained due to high water tables. Most of the water from local ephemeral stream channels collects in Whitewater Lake. After heavy rains, much of the agricultural land surrounding Whitewater Lake is flooded.

Any of the water not accounted for in surface runoff, plant uptake, or evaporation ends up as soil water. Water in excess of what the soil can retain percolates downward and eventually enters the groundwater. The following brief overview of groundwater conditions in the study are is provided as background for a discussion of the influence of hydrology on soil development.

Groundwater

Groundwater refers to water that is beneath the surface of the soil in the zone of saturation. Water collects and flows through the pores of the soil during infiltration until it eventually reaches a zone of saturation. The upper surface of this zone in unconfined conditions is called the water table. Since the water table generally conforms to the topography, groundwater in unconfined conditions tends to flow from topographic highs to topographic lows.

In general, the water table fluctuates throughout the year. Water-table levels are generally lowest during the winter months from December to March. The level rises in April and May as a result of snowmelt and rainfall. The more permeable soils respond more rapidly to changes such as snowmelt and high rainfall than the less-permeable medium- and fine-textured soils, where usually a greater lag time occurs between infiltration and rise of the water-table level. Water levels generally reach their maximum height in the latter part of May or the beginning of June and recede slowly over the course of the growing season. Meyboom (1966a, b, 1967a, b) provided an excellent description of groundwater movement and fluctuations in an area of Saskatchewan that is similar to the study area.

Hydrology and soil development

Water movement within and beneath the soil profile also plays a distinctive role in the development of soil profiles. The depth to the water table (upper boundary of the saturated zone) and the direction of water movement in the saturated zone affect the type and degree of profile development. Where water tables are at relatively deep levels (2–3 m), and water movement in the saturated zone is downward, the hydrological condition is described as groundwater recharge. Recharge areas are characterized by a net downward movement of water in the unsaturated soil zone (the area above the water table) through infiltration and percolation. Excess soil water is contributed to the groundwater zone and causes a rise in the water table.

Where water tables are relatively close to the ground surface (1–1.5 m), and water movement in the saturated zone tends to be upwards to the water table, the hydrological condition is described as groundwater discharge. In groundwater discharge areas, soil suction transmits water from a shallow water table directly to the soil surface whereupon it can evaporate. At the same time, it leaves behind the dissolved minerals and salts to accumulate near and/or on the soil surface.

There are, therefore, two distinct features of hydrology which may be directly related to soil development. They are recharge, which results in leaching (removal of soluble constituents) of soil profiles, and discharge, which results in deposition (accumulation) of soluble constituents in the soil profile.

Hydrological studies conducted in the area have shown that till deposits are primarily recharge areas. Most of the hydrological activity is focused in the shallow surface depressions and sloughs, the great majority of which act as recharge sites. The soils in these depressions are invariably leached to different degrees, which reflects the effects of this recharge activity. Orthic and Humic Luvic Gleysols and imperfectly drained eluviated profiles are diagnostic soils of groundwater-recharge sites.

In many localized low and depressional areas, non-leached, and often saline, soils also occur. These are sites in which the hydrological activity is primarily discharge, i.e. net water movement is towards the ground surface. Groundwater discharge sites in the glacial tills of this study area are generally limited and localized in nature. They commonly occur in the lowest depressions of the landscape, or where an abrupt change in the regional slope occurs, or in the vicinity of a change in the nature of the underlying geological materials. Imperfect and poorly drained carbonate and saline soil profiles are diagnostic groundwater discharge sites.

The most obvious sites of groundwater discharge are easily recognized by the conspicuous presence of white, crystalline, salt precipitates in and on the soil surface and the presence of salt-tolerant vegetation. Groundwater-recharge sites, on the other hand, can be recognized by the absence of salinity. The vegetation on such sites usually consists of grasses (mainly hydrophytic), willows, and other trees. Many groundwater-recharge sites may be cultivated and cropped and are thereby not as obvious to the untrained eye.

Soil moisture

The moisture regime of soils depends on many factors such as precipitation, texture, organic matter, vegetation, depth of water table, and especially topography. At a local scale, all soil surfaces, even those generally considered to be flat, can be thought of as sequences or patterns of highs and lows. This irregular configuration of the ground surface affects the soil moisture regime in two ways. Surface water moves from highs to lows where it often ponds after snowmelt or after heavy rains. Therefore, the soils in these two landscape positions exist and develop under two distinctly different moisture conditions. In general, soils developed on highs are warmer, drier, and have a shallower profile than soils developed on lows or in depressions.

In addition, soil moisture affects the chemical weathering processes in the soil such as oxidation and reduction, and the kind of vegetation, i.e. hydrophytic, mesophytic, or xerophytic, that will grow in the soil.

The soil climate map of Canada (Soil Research Institute, Ottawa, 1975) summarizes the study area as cool to moderately cool Boreal, having a subhumid moisture regime with a significant moisture deficit of 6 < 20 centimetres during the growing season.

Vegetation

The study area comprises parts of two vegetative regions according to Rowe's (1972) forest classification. They are the 'grassland' and the 'forest & grass' regions.

The grassland region is characterized by the mixed short and tall prairie grasses, associated with herbaceous plants (Ellis and Shafer, 1940). The soils formed in this grassland environment typically have black to dark grey Ah horizons. The decomposition of plant roots and the incorporation of organic matter into the Ah horizon increases the natural fertility, and generally imparts a granular structure and friable consistence to the soil. The depth of soil development varies from place to place but, in general, the soils formed under grass-type vegetation are the least eluviated and the most fertile soils in the province. Grassland soils are mainly Black and Dark Grey Chernozems.

The Whitewater Lake area, on the other hand, is a major wetland area and is dominated by tall prairie grass and salt-tolerant plants, because of its high water table and soil salinity. Whitewater Lake itself is characterized by aquatic vegetation varying from non-emergent to emergent species (Bossenmaier, 1953). Soils developed in wet grassland environments are typically Humic Gleysols.

The 'forest & grass' region is characterized by landscapes consisting of treed areas mixed with areas supporting short- and tall-grass herbaceous-plant associations. The native vegetation on Turtle Mountain consists of deciduous trees and shrubs with an undergrowth of herbs and grasses. The dominant tree is trembling aspen, with white birch being found at higher altitudes, and bur oak being more abundant at lower levels. Green ash, Manitoba maple, and black poplar are scattered throughout this region. A dense undergrowth of shrubs and herbaceous plants is characteristically associated with the tree stands (Ellis and Shafer, 1940). The isolated islands of forest and grass found within the Souris plain differ from the forest found on Turtle Mountain. Grassed depressions (sloughs) are fringed with trembling aspen and willow. The levels between the bottom of the depressions and the top of the knolls in between the depressions may differ by less than a few metres, but the vegetation varies from a xerophytic (dry) type on the knolls to hydrophytic (marsh or even aquatic, wet) vegetation in the lows. Surrounding the trees is a zone of shrubs including silverberry and Prairie Rose. Most of the grasses and herbs found are similar to those found in the grassland region.

As trees generally have about equal proportions of above- and below-ground growth, (biomass) and live relatively long compared to grasses and herbs, the accumulation in the soil of organic matter derived from roots is much smaller compared to that from grass roots, especially in the upper part of the soil profile. Organic matter in soils under forest vegetation is composed of tree-leaf fall, and stem- and leaf-decay products of herbaceous plants. These organic materials tend to accumulate in layers in varying stages of decomposition above the mineral-soil surface. Litter derived from deciduous-forest vegetation generally decomposes quite rapidly. Consequently, recycling of nutrients is also quite rapid in deciduous forests.

Soils developed under deciduous forest are generally high in exchangeable bases, and have granular and friable structure. The predominant soils in this region are Grey Luvisolic and Dark Grey and Black Chernozemic soils with minor occurrences of Humic Gleysols. The Luvisolic soils on Turtle Mountain are the most strongly leached soils in the study area.

Soil map legend

The information on the soil map follows the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). The soil legend structure (Table 15) and colour codes follow the format established for the Soil Landscapes of Canada Series (Canada Soil Inventory, 1989). Soils are shown according to Order and Great Group, and are differentiated on the basis of three broad textural categories which are represented by specific textural classes (*see* description at the end of Table 15). For additional information on the soils of this area see Eilers et al. (1978) and Ehrlich et al. (1956).

Soil-texture classes

Mineral particles that make up soil material are commonly grouped into sand, silt, and clay fractions. Sand-size particles are between 0.05 and 2.0 mm and are visible to the naked eye. Clay-size particles are smaller than 0.002 mm and are only visible with the aid of an electron microscope. Silt-size particles are between 0.05 and 0.002 mm. The term loam is used for a soil containing nearly equal parts of sand, silt, and clay sized particles. The proportion of particle sizes present in soil material is referred to as texture. A more detailed description of the specific soil texture classes used in this map area follows.

Sand - Soil material that contains 85% or more sand.

Loamy sands - Soil material that contains at the upper limit 85 to 90% sand, and the percentage of silt plus 1.5 times the percentage of clay is not less than 15; at the lower limit it contains not less than 70 to 85% sand, and the percentage of silt plus twice the percentage of clay does not exceed 30.

Sandy loam - Soil material that contains either 20% clay or less, with the percentage of silt plus twice the percentage of clay exceeding 30, and 52% or more sand; or less than 7% clay, less than 50% silt, and between 43 and 52% sand.

Loam **-** Soil material that contains 7 to 27% clay, 28 to 50% silt, and less than 52% sand.

Silt loam - Soil material that contains 50% or more silt and 12 to 27% clay, or 50 to 80% silt and less than 12% clay.

Sandy clay loam **-** Soil material that contains 20 to 35% clay, less than 28% silt, and 45% or more sand.

Clay loam **-** Soil material that contains 27 to 40% clay, and 20 to 45% sand.

Silty clay loam **-** Soil material that contains 27 to 40% clay and less than 20% sand.

Sandy clay **-** Soil material that contains 35% or more clay and 45% or more sand.

Silty clay **-** Soil material that contains 40% or more clay and 40% or more silt.

Clay **-** Soil material that contains 40% or more clay, less than 45% sand, and less than 40% silt.

Heavy clay **-** Soil material that contains more than 60% clay.

The equivalent of texture for organic soils is the amount of fibres that remain on a 100 mesh sieve (0.15 mm) after a an organic sample is rubbed. The amount of fibre in an organic soil is an indication of the amount of decomposition that has taken place. Three classes are recognized as follows.

Fibric - Organic soil material that contains 40% or more of rubbed fibre by volume.

Mesic - Organic soil material that contains between 10 and 40% rubbed fibre.

Humic - Organic soil material that contains less than 10% rubbed fibre.

Soil-texture groups

The soil-texture groups organize soil textures that, in general terms, are somewhat similar in moisture-holding capacity and/or natural fertility, and can be used to depict soil parent material or surface textures on generalized maps. The soil texture groups and the soil textures that are included in each texture group are shown below.

Sand texture group (SD) - Coarse sand, medium sand, fine sand, very fine sand, gravelly sand, very gravelly sand, cobbly sand, very cobbly sand, loamy sand, loamy fine sand, loamy very fine sand, gravelly loamy sand, very gravelly loamy sand.

Sandy loam texture group (SL) - Fine sandy loam, sandy loam, gravelly sandy loam, very gravelly sandy loam, cobbly sandy loam.

Loamy texture group (LM) - Loam, very fine sandy loam, cobbly loam, gravelly loam, silt loam, gravelly silt loam.

Clay loam texture group (CL) - Clay loam, gravelly clay loam, sandy clay loam, silty clay loam, very fine sandy clay loam.

Clay texture group (CY) - clay, sandy clay, silty clay, gravelly silty clay, heavy clay.

Table 15. Agricultrual land soil-slope classes.

Black Chernozemic Soils	Soils developed in the southern and southwestern part of Manitoba under a combination of relatively low rainfall and high summer temperatures and predominantly grassland and aspen parkland vegetation. The Black soils have dark coloured surface horizons reflecting a significant accumulation and decomposition of grasses and other vegetation. The Black soils are the most fertile and productive in Manitoba, capable of growing wheat, coarse grains and a wide range of regionally adapted crops.
Sand	
Sandy loam	
Loam	
Clay loam	
Clay	
Dark Grey Chernozemic Soils	Soils developed in the Turtle Mountain area where cooler temperatures and more humid conditions fostered a mix of grassland and forest vegetation. Dark Grey soils are very productive and are used to grow all of the regionally adapted crops of western Canada. Climatic limitations associated with these soils prohibit production of special crops requiring a high accumulation of heat units.
Sand	
Sandy loam	
Loam	
Clay loam	
Clay	
Gray Luvisolic Soils:	These soils are also called Grey Wooded soils, and developed on Turtle Mountain under even cooler and more humid climate conditions and under more continuous forest vegetation cover than the Dark Grey Chernozemic soils. The A horizons of Luvisolic soils contain modest amounts of organic matter and, as a result, are light grey in colour. In rolling or hilly areas, steeply sloping land is best suited to pasture and forage production. In addition, the shorter, cooler growing season prohibits the production of the long season crops.
Sand	
Sandy loam	
Loam	
Clay loam	
Clay	
Black Solonetzic Soils	Soils developed under grassland vegetation on salt-affected sandy and clayey materials. Solonetzic soils have distinct columnar structured B horizons as a result of the dispersive nature of abundant sodium in the soil. Sodium has been carried into these soils from groundwater seepage from the underlying or exposed Cretaceous shale bedrock.
Sand	
Sandy loam	
Loam	
Clay loam	
Clay	
Regosolic Soils	These soils lack soil-profile development due to recent exposure of parent material due to erosion, or due to the recent deposition of parent material by wind or water. In all cases, soil formation has only been active for a short time.
Sand	
Sandy loam	
Loam	
Clay loam	
Gleysolic Soils	Soils found in poorly drained depressions or flat areas where excess water and lack of air result in dull coloured and mottled subsoils. They vary in appearance according to the climate and vegetation. They can occur under wet grass and meadow vegetation on all types of parent materials.
Sand	
Sandy loam	
Loam	
Clay loam	
Clay	

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GLOSSARY OF SURFICIAL GEOLOGY TERMS

Introduction

The following glossary contains terms used in this report, and terms commonly used in surficial geology. The geological terms are based on list compiled by P. Bobrowsky, British Columbia Geological Survey, for *Guidelines and Standards for Terrain Mapping in British Columbia*, which was developed for the British Columbia Resources Inventory Committee with most additions and changes from Bates and Jackson (1980). The soil-term definitions are from Canada Soil Survey Committee (1976). The original sources of information are listed in the annotated bibliography and additional reference list that follow this glossary.

Glossary

^{14}C: An isotope of carbon that is formed when normal carbon (^{12}C) is bombarded by high-energy subatomic particles (generally cosmic rays) and which disintegrates to ^{12}C in a set period of time. Because the ^{14}C forms in the atmosphere at a relatively constant rate and the isotope disappears at a constant rate, measuring the amount of ^{14}C remaining in fossil organic material provides a relatively good measure of how long it has been since the living organism died.

ABLATION: The processes whereby mass is removed from a glacier; it includes melting, evaporation, and calving of icebergs.

ABLATION MORAINE: A moraine resulting from ablation; typically hummocks of ablation till formed by melting of stagnant ice.

ABLATION TILL: Material accumulated on top of a melting glacier; coarser textured and less consolidated than basal till; common where glacier recession is dominated by downwasting of stagnant ice.

ACTIVE: Said of a geological process where activity is occurring at the present time. For example, a fan is said to be active if there is erosion or deposition occurring on its surface under present conditions.

ADVANCE LIMIT: The position or limit reached by a glacier during a phase of advance.

AGATE: A variety of chalcedony.

AGGREGATE: Granular material of mineral composition such as sand, gravel, crushed rock, slag, or similar inert material, used with a cementing medium to form mortar, concrete, and asphalt, or alone as in railroad ballast, etc. Aggregate is described as gravel or coarse aggregate if it is retained on a 4.76 mm square (no. 4) sieve screen and as sand or fine aggregate if it passes this mesh size. In this report we are concerned only with naturally occurring aggregate and not with granular material that might be 'manufactured' by crushing bedrock.

AGGREGATE SUITABILITY MAP: A derived map on which map units are classified according to there suitability as sources of aggregate.

AIR PHOTO: A photograph of the Earth's surface taken from the air. It is usually a vertical view, and one of a series of photos taken from an aircraft flying a systematic pattern at a given altitude in order to obtain continuous photo coverage for mapping purposes.

ALLUVIAL: Pertaining to streams and rivers; similar to fluvial. Materials deposited by rivers and streams are in many cases referred to as alluvium.

ALLUVIAL FAN: A fan-shaped deposit of alluvial sand and gravel, usually located at the mouth of a tributary valley.

ALLUVIUM: Material deposited by a stream; alluvial materials.

ALLUVIAL PLAIN: i) *See* floodplain, ii) A plain underlain by alluvium, including alluvial (fluvial) fans and lacustrine deposits (stream-transported materials that have accumulated in small lakes).

ALLUVIAL TERRACE: A more-or-less flat surface bounded downslope by a scarp and resulting from fluvial erosion and deposition. Same as fluvial terrace and river terrace.

AMORPHOUS: Said of a material or mineral that lacks crystalline structure or shape.

ANASTOMOSING CHANNEL: Applied to stream channels that diverge and coverage around many islands. ('Islands' support mature vegetation and their surfaces are relatively high above mean maximum discharge levels.)

ANGULAR FRAGMENTS: Broken rock with sharp edges.

ANTHROPOGENIC MATERIALS: Earth materials modified by human activities to the extent that their initial physical properties (e.g. structure, cohesion, consolidation) have been drastically altered. Includes spoil heaps and fill.

APRON: Shape term used to describe a deposit; generally consist of a series of alluvial fans that are strung out along the base of a valley wall.

AQUIFER: A saturated, permeable, geological unit capable of transmitting significant quantities of water under ordinary hydraulic gradients. A well drilled into an aquifer will yield sufficient water to provide for normal use by a single-family household.

AQUITARD: An aquitard is a saturated, slightly permeable, geological unit capable of transmitting significant quantities of water when considered on a regional scale. A well drilled into an aquitard will not provide sufficient water for normal, single-family, household use.

ARCINFO: A particular Geographical Information System (GIS) program. The name is a registered trademark of Environmental Systems Research Institute Inc.(ESRI), Redlands CA, USA.

ARGILLACEOUS: consisting largely of clay-sized particles or minerals.

ASPECT: The direction toward which a slope is facing; recorded as a compass direction.

ASPHALT: A bitumen residue that is used in paving roads.

ATTRIBUTE TABLE: A tabular listing of characteristic ascribed to a feature, map unit, or object on a map.

AVALANCHE: A large mass of snow and/or ice, sometimes accompanied by rocks and vegetative debris, moving rapidly downslope.

AVALANCHE CONES: Cones of debris deposited by snow avalanches; similar to talus cones, but with concave longitudinal profiles and gentler slopes.

AVALANCHE TRACKS: Paths followed by snow avalanches; readily identified below the treeline by their characteristic vegetation of deciduous shrubs and young conifers, and bright green colour.

BASAL TILL: Material that accumulates underneath a glacier from basal ice; includes lodgement till and basal melt-out till.

BASE SATURATION PERCENTAGE: The extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen and aluminum. It is expressed as a percentage of the total cation-exchange capacity.

BASIN: An area in which sediment accumulates; a general term for a depressed sediment-filled area.

BASIN-FILL DEPOSITS: Materials that fill or largely fill a depression.

BEACH: The gently sloping shore of a body of water that is washed by waves and usually composed of loose sandy or gravelly material.

BEACH RIDGE: A low, continuous mound of beach materials (sand and gravel) heaped up by the action of waves.

BED: i) The ground on which any body of water lies, limited laterally by a bank or shore. ii) A single layer of sediment or rock, separated from layers above and below by more-or-less well defined boundary planes.

BEDDING: Collective term signifying the existence of beds or laminae. *Well bedded* indicates beds are immediately apparent, clearly defined, and can be easily traced across the deposit; *poorly bedded* means beds are only discernible after careful scrutiny, or bedding planes are discontinuous; *moderately bedded* is intermediate between the other two.

BEDROCK: Solid rock, usually older than Quaternary (except rock formed by cooling of lava); either exposed at the land surface or underlying surficial deposits or regolith of varying thickness.

BEDROCK GEOLOGY: Study of the bedrock of an area. The bedrock geology information in this report is limited to the material that immediately underlies Quaternary sediments (drift). These bedrock materials are generally poorly consolidated and in places can be mistaken for Quaternary sediments. For more information on the bedrock geology of the area the reader is referred to Bamburak (1978), McNeil and Caldwell (1981), and references in these publications.

BEDROCK-SURFACE CONTOUR MAP: A map that uses contours to show the elevation of the surface of bedrock.

BENCH: A long, narrow, relatively flat strip of bedrock or surficial sediment that is bounded by steeper slopes above and below and was formed largely by erosion.

BENTONITE: (bentonitic) A soft, plastic, light-coloured rock that consists dominantly of montmorillonitic clay and formed through the weathering of volcanic ash.

BIMODAL: Occurring in two parts. In geology, generally used to refer to the distribution of particle sizes in a sediment. A bimodal sediment is one in which two groupings of particle sizes are present e.g. a till (dominantly silt, sand, and clay, but including a significant content of pebbles and boulders)

BIRDTAIL–WASKADA AXIS: A linear zone of anomalous structures and unit thicknesses that coincides with the buried junction of the Superior and Churchill provinces in southwestern Manitoba.

BLANKET: A mantle of surficial material, thicker than about 1 m, that reflects the topography of the bedrock or older surficial material upon which it rests, although minor details of that topography may be masked.

BLOCK FIELD: A level or gently sloping area covered with blocks derived from underlying bedrock or drift by weathering and/or frost heave, that have undergone no significant downslope movement; characteristic of periglacial regions.

BLOCKS: Angular rock fragments with intermediate diameter greater than 256 mm.

BLOWOUT: A general term for a small saucer-, cup-, or trough-shaped hollow or depression formed by wind erosion on a pre-existing dune or other sand deposit.

BLUFF: A steep, precipitous slope of great lateral extent compared to its height.

BOG: A waterlogged area containing acidic, decaying, organic material which may develop into peat.

BORDAT: The name used in this report for a relational database that contains water-well and related borehole data.

BOREHOLE: A hole drilled into the Earth, commonly to great depth, as a prospective well for water or oil, or for exploratory purposes.

BOULDER: A grain size term used for particles that are larger than 256 mm in diameter (about volleyball size; Wentworth scale).

BOULDER PAVEMENT: A layer of boulders, at the surface or buried within sediments. In this area the boulder pavement is included in drift and the upper surface of the many boulders are faceted, striated, and polished. The trend of the striations provides a good indication of the direction of flow of the overriding ice.

BOULDERY: Said of a deposit that includes a significant number of boulder-sized fragments.

BRUNISOLIC: An order of soils whose horizons are developed sufficiently to exclude the soils from the Regosolic order, but that lack the degrees or kinds of horizon development specified for soils of the other orders. These soils, which occur under a wide variety of climatic and vegetive conditions, all have Bm or Btj horizons. The great groups Melanic Brunisol, Eutric Brunisol, Sombric Brunisol, and Dystric Brunisol belong to this order.

BULK DENSITY: The weight of material per unit volume (including pore spaces); commonly applied to bulk samples of soil and clastic sediments such as till; usually expressed as kg/m^3.

BURIED VALLEY: A valley which has been filled by unconsolidated deposits, such as glacial drift.

CALCAREOUS: Said of a substance that contains calcium carbonate. When said of a rock, it implies that a considerable percentage of the rock is calcium carbonate. When said of a soil, it indicates the presence of sufficient calcium carbonate to effervesce visibly when treated with cold 0.1 N hydrochloric acid.

CALCITE: A common rock-forming mineral consisting of calcium carbonate ($CaCO_3$).

CANADIAN SHIELD: The large region of central and northern Canada that is underlain by rocks of Precambrian age and is centred on Hudson Bay.

CANYON: A long, deep, relatively narrow, steep-sided valley confined between precipitous walls.

CAPILLARITY: The action by which a fluid, such as water, is drawn up (or depressed) in small interstices or tubes as a result of surface tension.

CARBONACEOUS: Term used to indicate that a material is rich in carbon or organic material.

CARBONATE ROCK: A rock composed of carbonate minerals; most commonly limestone or dolomite; a sedimentary rock composed of more than 50% by weight of carbonate minerals.

CATASTROPHIC FLOODS: A very large and sudden flood (also referred to as a jökulhlaup). In the context of this report, the *catastrophic floods* were related to bursting of dams consisting of glacial ice or drift. Most resulted in the drainage of glacial lakes and some may have, in part, occurred underneath the glacier.

CATION EXCHANGE: The interchange of a cation in solution and another cation on the surface of any surface-active material such as clay colloid or organic colloid.

CATION-EXCHANGE CAPACITY: The total amount of exchangeable cations that a soil can adsorb. It is expressed in milliequivalents per 100 g of soil or of other adsorbing materials such as clay.

CEMENTED: Particulate materials (such as sediments) that are bound together as a coherent mass by the precipitation of mineral material between the grains.

CENOZOIC: A formal geological time term. The period of geological time that extends from about 66 million years ago until present.

CHALCEDONY: A cryptocrystalline variety of quartz; a general term for crystalline silica masses that form concretionary masses with radial-fibrous and concentric structure.

CHANNEL: A narrow valley carved by flowing water.

CHALKY: Rich in or characterized by earthy calcium carbonate.

CHERNOZEMIC: An order of soils that have developed under xerophytic or mesophytic grasses and forbs, or under grassland-forest transition vegetation, in cool to cold, subarid to subhumid climates. The soils have a dark-coloured surface (Ah, Ahe, or Ap) horizon and a B or C horizon, or both, of high base saturation. The order consists of the Brown, Dark Brown, Black, and Dark Grey great groups.

CHERT: A hard dull to semi-vitreous cryptocrystalline sedimentary rock that consists largely of chalcedony.

CHROMA SATURATION: The relative purity, strength, or saturation of a colour. It is directly related to the dominance of the determining wavelength of light. It is one of the three variables of colour.

CHRONOSTRATIGRAPHY: The branch of stratigraphy that interprets geological history by determining the age and time sequence of the Earth's strata.

CHURCHILL PROVINCE: One of the structural subdivisions of the Canadian Shield.

CLAST: An individual particle of a detrital sediment or a sedimentary rock, initially produced by the disintegration of a larger mass of bedrock, classified according to size as clay, silt, sand, pebbles, etc.

CLASTIC: Pertaining to or being a rock or sediment composed principally of broken fragments that are derived from pre-existing rocks or minerals and that have been transported individually for some distance from their places of origin.

CLASTIC SEDIMENT: A sediment formed by the accumulation of fragments derived from pre-existing rocks or minerals and transported as separate particles to their places of deposition by purely mechanical agents.

CLAY: i) A rock or mineral fragment of any composition having a diameter less than 1/256 mm (4 Fm) (Wentworth scale); ii) any soft, adhesive, fine grained deposit; iii) a specific group of fine-grained hydrous silicate of aluminum minerals.

CLAYEY: Descriptive term used to indicate that a mineral material includes 20 to 50% clay-sized particles..

CLOSED DEPRESSIONS: A hollow below the general land surface that has no surface drainage outlet.

COARSE CLAST: A fragment that is the size of a pebble or larger.

COBBLE: i) A rock fragment between 64 and 256 mm intermediate diameter (Wentworth scale), ii) rounded and subrounded rock fragments between 64 and 256 mm intermediate diameter.

COHESION: The capacity of particles to stick or adhere together.

COHESIVE: Said of a material that has relatively high shear strength when dry.

COLLAPSE: A falling away because of a lack of support. In this report it is generally used to refer to the removal of supporting ice, and the result is a sediment in which layers are mixed together and are folded and faulted.

COLLOID: A substance in a state of fine subdivision, whose particles are 10^{-4} to 10^{-7} cm in diameter.

COLLUVIAL FAN: A fan-shaped mass of sediments deposited by colluvial processes, most commonly debris flows.

COLLUVIAL: A geological process that includes all forms of mass wasting, mass movement, and slope processes.

COLLUVIAL DEPOSITS: Colluvium or the geological deposits that result from mass wasting, mass movement, and slope processes. These vary from a blanket that mantles a surface to talus or landslide deposits that accumulate at the base of a slope.

COLOUR VALUE: The relative lightness of colour, which is approximately a function of the square root of the total amount of light.

COMPACTION: i) The degree of packing of the individual particles of detrital sediments. ii) The densification of soil or sediment by compression.

COMPRESSIVE STRESS: a force that tends to reduce the volume of the material on which it is acting.

CONCRETE: A construction material made by mixing cement and aggregate with sufficient water to cause the cement to set and bind the entire mass.

CONCRETION: A hard, compact, rounded mass of mineral matter generally formed by orderly and localized precipitation from aqueous solutions in the pores of sedimentary rock.

CONE: i) A mountain, hill, or other landform shaped like cone, having relatively steep slopes and a pointed top. ii) A sector of a cone with a straight or concave long profile and slopes generally steeper than 15 degrees (26%); includes talus cones and avalanche cones.

CONSEQUENT: Something that happened later; a stream developing on a newly exposed surface (e.g. a stream developing on the surface of glacial deposits)

CONSOLIDATION: The gradual reduction in volume of a sediment mass resulting from an increase in compressive stress; involves removal of pore water and a decrease in void ratio, (engineering definition). The term is used to describe the density of surficial materials, especially those that contain silt and clay; highly consolidated means of high density and low void ratio.

CONVOLUTE BEDDING: Bedding that is wavy, disorganized, crumpled, or folded on a relatively small scale.

CORRUGATED MORAINE: Terrain crossed by a series of subparallel, small, regularly spaced morainal ridges that are oriented transverse to the ice movement; collectively they resemble a washboard.

CRAG-AND-TAIL: A streamlined hill consisting of a knob of resistant bedrock (the crag) and a elongate tail of drift, usually till, pointing in the direction of glacier flow.

CRATONIC BASIN: A low area, generally occurring in a stable geological setting, that is receiving sediment but is not associated with an adjacent uplifted area.

CREEP: The imperceptibility slow, more or less continuous downhill movement of surficial materials on slopes. The movement is essentially flow of a highly viscous medium under shear stresses sufficient to produce deformation but too small to produce shear failure as in a landslide.

CRETACEOUS: A formal geological time term. The period of geological time that extended from about 144 until 66 million years ago

CREVASSE: A fissure formed in the brittle upper part of a glacier or ice sheet due to glacier flow.

CROSSBEDDING: The arrangement of sets of inclined beds or laminations between the main horizontal plains of stratification of a deposit; present in fluvial sands and gravels and eolian sands.

CRYOTURBATION: Heaving, churning, and sorting of surficial materials due to repeated freezing and thawing; resulting in the development of convoluted and flame-like structures in the unconsolidated material, and patterned ground such as stone stripes and sorted polygons.

CRYPTOCRYSTALLINE: A mineral mass in which individual minerals are so small that they can not be seen with a microscope.

CRYSTALLINE ROCKS: A rock consisting wholly of crystals or fragments of crystals.

dam^3: Equivalent to 1000 cubic metres or 106 litres of water.

DEBRIS: An accumulation of loose materials detached from a coherent mass.

DEBRIS AVALANCHE: Rapid downslope movement on steep slopes of saturated surficial material, commonly including vegetative debris; a very rapid to extremely rapid debris flow.

DEBRIS FALL: Descent of a mass of surficial material by falling, bouncing, and rolling.

DEBRIS FLOW: Rapid flow of a slurry of saturated debris, including some or all of soil, surficial material, weathered rock, mud, boulders, and vegetative debris. A general designation for all types of rapid downslope flow, including mudflows, rapid earthflows, and debris torrents.

DEBRIS-FLOW TRACKS: The paths followed by debris flows; marked by features such as levees, gullies, lack of vegetation or immature vegetation, and debris-flow deposits.

DEBRIS SLIDE: Downslope sliding of a mass of surficial material, initial displacement is along one or several surfaces of rupture (shear planes); debris may continue to slide downslope over the ground surface, or movement may be transformed into a debris flow.

DEBRIS TORRENT: A variety of debris flow that includes little fines (silt and clay) and that follows a pre-existing stream channel.

DEFLATION: The erosion of non-cohesive particulate material, chiefly sand and silt by wind.

DEGLACIATION: The uncovering of a land area from beneath a glacier or ice sheet.

DEPOSIT: An accumulation of particulate, organic, and/or chemical material resulting from naturally occurring physical, chemical, or organic processes.

DEPOSITION: The laying down of any material, the formation of a geological deposit; e.g. the laying down of sand by a river.

DELETERIOUS: Harmful, noxious; in this report used in referring to materials which degrade the quality of aggregate. Materials which degrade aggregate are fines (silt and clay) and particles that are prone to chemically reacting (such as ironstone concretions) or are physically weak (such as shale).

DELTA: An accumulation of stream-transported sediments deposited where a stream enters a body of water. The landform is flat or very gently sloping, and generally triangular or fan-shaped in plan,

DELTAIC DEPOSITS: The materials that are laid down in a delta; generally consist of gravel, sand, silt, and/or clay.

DEPOCENTRE: A site of maximum sediment deposition; the thickest part of a sedimentary unit in a basin.

DEPRESSION: A circular or irregular enclosed hollow separated from the surrounding area by a distinct slope break.

DERIVATIVE MAP: Map derived from information obtained from one or several maps and/or databases, that provides information relevant only to some specific theme or applications. An aggregate-suitability map is an example.

DETRITAL: Pertaining to or formed of detritus. The term is often used to indicate material that comes from a source located outside the immediate area where the sediment was deposited.

DETRITUS: A collective term for loose rock and mineral material that is worn off or removed directly by mechanical means, as by disintegration or abrasion; especially fragmental material, such as sand, silt, and clay, derived from older rocks and moved from its place of origin.

DEVONIAN: A formal geological time term. A period of the Paleozoic Era that covered the span of time between about 408 to 360 million years ago.

DIAMICTON: A textural term applied to nonsorted sediments consisting of sand and larger particles in a muddy matrix (silt and/or clay); particle size distribution is bimodal, with main concentrations in the silt/clay and sand/gravel fractions. Till is an example of a sediment that generally has a diamictic texture.

DIGITAL ELEVATION MODEL: A computer-generated map or other illustration that is based on spot-elevation data and shows the variation in elevation of a surface.

DIKE: A tabular intrusion (igneous or sedimentary materials) that cuts across the planar structures of the surrounding rocks

DISCORDANT: Somewhat out of line or not agreeing with. Said of strata lacking conformity or paralellism of bedding structure.

DISPLAY WELL: A borehole that is chosen as the best hole to be used as an indicator of the local stratigraphy etc.

DOLOMITE: A common rock forming mineral consisting of calcium and magnesium carbonate ($CaMg(CO_3)_2$). Also a sedimentary rock made up largely of the mineral dolomite.

DOWNWASTING OF ICE: Lowering of the surface of a glacier or ice sheet due to ablation.

DRIFT: A general term for surficial materials. In Canada this term is used almost exclusively for sediments deposited by glacial ice or by glacial meltwater (includes till, glaciofluvial, and glacial lacustrine materials). It is generally used in referring to a mixture of glacial deposits.

DRIFT PROSPECTING: Mineral exploration by sampling and geochemical analysis of sediments such as till, in conjunction with reconstruction of former ice-flow directions.

DRIFT THICKNESS: The depth of glacial deposits.

DRUMLIN: A streamlined hill or ridge of till or other drift, with a long axis that parallels the direction of flow of a former glacier; generally the upstream end is widest and highest, and the drumlin tapers in the downflow direction.

DUNE: A low ridge, hummock, or mound of loose sandy material transported and deposited by wind.

DUNE FIELD: An extensive area occupied by wind-formed dunes.

EARTH: Any or a mixture of soil, surficial materials, and weathered bedrock.

EARTHFLOW: A slowly (imperceptibly) moving mass of earth, commonly containing a high proportion of silt and clay.

ECOLOGICAL NICHES: The position of an organism or a population as determined by its needs and interactions with other organisms or populations. Here it is used for local special environments that differ markedly from those of the surrounding regional

ELEVATION: The height above sea level.

ELUVIAL HORIZON: A soil horizon that has been formed by the process of eluviation. *See also* illuvial horizon.

ELUVIATION: The transportation of soil material in suspension or in solution within the soil by the downward or lateral movement of water.

END MORAINE: A ridge-like accumulation of till, or less commonly other drift, formed at the terminus of a valley glacier or at the margin of an ice sheet; includes terminal moraines and recessional moraines.

ENGINEERING SOIL: Engineer's 'soil' is equivalent to surficial materials or Quaternary deposits.

EOCENE: A geological time term; the second oldest epoch of the Tertiary Period which lasted from about 58 to 37 million years ago.

EOLIAN: Produced by the wind; hence eolian (sometimes spelled aeolian) materials are sediments transported and deposited by wind.

EPHEMERAL: Short-lived. Used in this report for ephemeral water bodies which are streams and lakes that generally contain water only for part of the year.

EROSION: The loosening and removal of materials by wind, moving water, and glacial ice.

ERRATIC: Boulders or smaller clasts of rock types that are dissimilar to underlying bedrock.

ESCARPMENT: A steep slope that is usually of great lateral extent compared to its height, such as the risers of river terraces and steep faces associated with stratified rocks.

ESKER: A sinuous ridge of sand and gravel resulting from deposition by meltwater in a tunnel beneath or within a glacier or ice sheet. The ridges generally trend at right angles to a glacier margin, and the sand and gravel may be covered by till or glacial lacustrine sediments.

EUSTATIC: Pertaining to worldwide changes of sea level that affect all the oceans. Glacio-eustasy refers to changes in sea level brought about by the interchange of water between oceans and ice sheets.

EVAPORITE: A nonclastic sedimentary rock made up of minerals produced from a saline solution that became concentrated through the evaporation of water.

EVAPOTRANSPIRATION: The loss of water from a given area during a specified time by evaporation from the soil surface and by transpiration from the plants. Potential evapotranspiration is the maximum transpiration that can occur in a given weather situation with a low-growing crop that is not short of water and does not completely shade the ground.

EXCHANGEABLE CATION: The extent to which the adsorption complex of a soil is occupied by a particular cation.

FABRIC: The attitude of clasts within a sediment or sedimentary rock; recorded as the trend and plunge of clast long-axes.

FACETED BOULDERS: A boulder that has been ground flat on one or more sides by the action of a natural agent such as a glacier.

FACIES: A stratigraphic unit of rock or sediment distinguished by its composition or other characteristics.

FAN: An accumulation of detrital material in the shape of a low-angle cone, usually at the point where a stream emerges from a canyon or gully onto a plain.

FAN SEDIMENTS: The detrital materials that are deposited in a fan. In the area covered in this report fan sediments generally consist of a muddy mixture containing sand and some gravel.

FAULTED: In a geological sense, a fault is a surface or zone of fracture along which there has been displacement. *Faulted* means that beds have been broken or sheared and the segments on either side of the break have been offset.

FELSENMEER: A level or gently sloping area covered with blocks derived from underlying bedrock or drift by weathering and/or frost heave, and having undergone no significant downslope movement; characteristic of periglacial regions.

FIBRIC: A textural descriptor applied to organic materials. The least decomposed organic material: it consists largely (>40%) of fibres that are readily identifiable as to botanical origin, they retain their character upon rubbing.

FIELD CAPACITY: The percentage of water remaining in the soil 2 or 3 days after the soil has been saturated and free drainage has practically ceased. The percentage may be expressed in terms of weight or volume.

FIELDAT: The name used in this report for a relational database that contains information gathered during the course of field work and analyses of samples collected during fieldwork.

FINES: A term for very small particles. In a general sense it is used for silt and clay (particles smaller than 1/16 mm).

FIORD: A glacial trough with a floor below sea level, appearing as a long, narrow arm of the sea flanked by steep mountainsides and hanging valleys, commonly characterized by great depth.

FISSILITY: The property that permits a material to be easily split into roughly parallel sheets or layers.

FLAT: In the sense of this report, *flat* is used to describe a plain that is almost level (relief of <2 m).

FLOODPLAIN: Level or very gently sloping surface bordering a river that has been formed by river erosion and deposition; it is usually subject to flooding and is underlain by alluvium.

FLOW TILL: Formed when saturated supraglacial debris (ablation till) on melting ice moves downslope as a debris flow and comes to rest on an adjacent lower, stable surface; common in stagnant-ice deposits and typically interlayered with glaciofluvial and glacial lacustrine sediments.

FLUTINGS: i) Smooth, straight furrows, parallel to ice-flow direction and formed in bedrock by glacial abrasion. ii) Smooth, straight, shallow furrows, parallel to ice-flow direction, in till or other drift.

FLUVIAL: Pertaining to streams and rivers; similar to alluvial.

FLUVIAL DEPOSITS: Materials laid down by a stream; alluvial materials

FLUVIAL TERRACES: A more-or-less flat surface bounded downslope by a scarp and resulting from fluvial erosion and deposition. Same as fluvial terrace and river terrace.

FOLDED: A fold is a curve or bend in a layer . Here the term folded is used to describe stratified materials that have been distorted.

FOLIATION: A general term for a planar arrangement of textural or structural features in any type of rock.

FORMATION: The formal term used for the basic rock unit. It is a body of rock that is mappable, can be uniquely defined, and is a significant part of a geological deposit.

FRIABLE LITHOLOGIES: Friable means easily broken down. Friable lithologies are types of rock that readily disintegrate. The prime example in the report area is shale. Bedrock of the Boissevain and Turtle Mountain formations are also very friable.

FRONTAL RECESSION: Retreat of a glacier terminus by melting back up valley, or against the direction of ice flow; the common mode of retreat of valley glaciers.

FROST HEAVE: The lifting, outward pushing or general distortion of material or objects that is caused by a buildup of subsurface ice.

GENTLY UNDULATING: Term used to describe the surface of a plain. An undulating plain is one with a surface that consists of a regular sequence of gentle, relatively short slopes. In the terminology used in this report, a gently undulating plain is an undulating plain that has a local relief of between 2 and 5 m.

GEOCHEMICAL ANALYSIS: Laboratory analysis to determine chemical and/or mineralogical composition of earth materials.

GEOGRAPHICAL INFORMATION SYSTEM: Computer software used in the display, manipulation, and analysis of geographically referenced data.

GEOLOGICAL PROCESSES: Dynamic actions or events that take place on or below the Earth's surface, and result in effects that vary from water erosion to volcanism.

GEOLOGICAL STRUCTURE: The three-dimensional arrangement of geological contacts and discontinuities, such as bedding, stratification, joints, faults, dikes, plutons, and folds.

GEOMORPHOLOGY: The study of the origin of landforms, the processes whereby they are formed, and the materials of which they consist.

GEOMORPHOLOGICAL HISTORY: The evolution of landforms and landscapes, surface materials, and changes with time in geomorphological processes.

GEOMORPHOLOGICAL PROCESSES: Dynamic actions or events that occur at the Earth's surface due to application of natural forces resulting from gravity, temperature changes, freezing and thawing, chemical reactions, seismic shaking, and the agencies of wind and moving water, ice, and snow. Where and when a force exceeds the strength of the earth material, the material is changed by deformation, translocation, or chemical reactions.

GEOPHYSICAL LOG: A continuous record of material or fluid properties that is obtained by lowering an instrument or a sonde down a borehole; examples are resistivity, radioactivity, self-potential etc.

GLACIAL ABRASION: The scouring action of particles embedded in glacial ice.

GLACIAL DEPOSITS: The general term used for the variety of materials transported by a glacier and deposited by the variety of processes associated with glaciers.(The term *drift* is sometimes used synonymously for glacial deposits.) Examples of glacier deposits are till, glaciofluvial, and glacial lacustrine materials.

GLACIAL GROOVE: A pronounced, generally straight furrow or depression, larger and deeper than a striation, and produced by glacial abrasion of bedrock, or erosion or compression of drift.

GLACIAL HISTORY: The time-sequence of glaciations, glacial advances and recessions.

GLACIAL ICE: An accumulation of ice that formed through the compaction and recrystallization of snow and attained a large enough size so that it began to flow outward due to the stress of its own weight. Synonymous with glacier.

GLACIAL LACUSTRINE: The term used for processes and materials associated with a glacial lake. In general, glacial lacustrine materials consist of silt and clay with some sand. One convention uses this term for materials deposited in an open lake basin but reserves the term glaciolacustrine for glacial lake deposits laid down in intimate contact with glacial ice (e.g. in a lake on top of or under a glacier)

GLACIAL LACUSTRINE MATERIALS: Sediments deposited in or along the margins of glacial lakes; primarily fine sand, silt, and clay settled from suspension or subaqueous gravity flows (turbidity currents), and including coarser sediments (i.e. ice-rafted stones) released by the melting of floating ice; also includes littoral sediments (e.g. beach gravels); accumulated as a result of wave action.

GLACIAL LAKE: A lake that is dammed by a glacier, rests on, or is underneath glacial ice, or also a lake that derives much or all of its water from the melting of glacial ice.

GLACIAL LAKE HIND: A temporary body of water that existed in southwestern Manitoba during the last ice retreat. It was drained by the Pembina spillway and began in the vicinity of Souris as a narrow lake between two lobes of ice, but expanded as the glaciers retreated to occupy an area reaching from Melita in the south, to Brandon on the northeast, and to Virden in the northwest.

GLACIAL LAKE OUTLET CHANNEL: The channel or valley that drains a glacial lake; sometimes referred to as a spillway.

GLACIAL LINEATION: A collective term for linear features that indicate former ice-flow directions.

GLACIAL MELTWATER: Water that comes from the melting of glacial ice.

GLACIAL OUTWASH: Materials washed out of a glacier and deposited as stratified sediment beyond the margin of the glacier. Sand and gravel are the most common constituents of outwash.

GLACIAL TROUGH: A valley with a U-shaped cross profile due to erosion by a valley glacier.

GLACIATION: A climatic episode during which glaciers and ice sheets developed, attained a maximum extent, and receded.

GLACIER: A body of ice formed by the compaction and recrystallization of snow, that has definite lateral limits, and motion in a definite direction.

GLACIER-OUTBURST FLOOD: A catastrophic flood that result from collapse of an ice dam and rapid drainage of a glacial lake; synonymous with jökulhlaup.

GLACIER STILLSTAND: A stopping of the forward movement of a glacier. The term is commonly used in referring to a period of time during which the glacier was no longer moving forward.

GLACIOFLUVIAL: Pertaining to the channelized flow of glacial meltwater (meltwater streams), and deposits and landforms formed by meltwater streams.

GLACIOFLUVIAL MATERIALS: Sediments that exhibit clear evidence of having been deposited by glacial meltwater streams either directly in front of, or in contact with, glacial ice; most commonly sands and gravels.

GLACIOFLUVIAL OUTWASH PLAIN: A plain underlain by sand and gravel that was washed out of a glacier and deposited beyond the ice margin.

GLACIOLACUSTRINE: Pertaining to glacial lakes.

GLACIOMARINE: Pertaining to processes, sediments and landforms associated with glacier termini in marine waters, such as receding glacier in fiords and ice shelves.

GLACIOMARINE MATERIALS: Sediments of glacial origin laid down from suspension in a marine environment in close proximity to glacial ice, and deposits of submarine gravity flows, includes particles released due to the melting of floating ice and ice shelves, primarily fine sand, silt and clay, and stony muds; marine shells or shell casts may be present.

GLACIOMARINE DRIFT: Sediments deposited in a glaciomarine environment; includes well sorted clays, silts, sands and gravels, stony muds, and diamictons.

GLEYSATION: A soil-forming process, operating under poor drainage conditions, which results in the reduction of iron and other elements and in grey colours, and mottles.

GLEYSOLIC: An order of soils developed under wet conditions and permanent or periodic reduction. These soils have low chromas, or prominent mottling, or both, in some horizons. The great groups Gleysol, Humic Gleysol, and Luvic Gleysol are included in the order.

GOODLANDS MEMBER: The lower of the two members making up the Turtle Mountain Formation. It is about 40 m thick and consists of nonmarine bentonitic carbonaceous sands, silts, and clays including lignite seams (Bamburak, 1978).

GNEISS: A foliated metamorphic rock with a granular texture.

GRADIENT: The rate of ascent or descent; in this report generally refers to the slope of a stream bed.

GRADING: An engineering term pertaining to the degree of sorting by size of particles in a clastic sediment or sedimentary rock; sandy and gravelly materials with a wide range of particle sizes are termed *well graded*; material with a small range of sizes is *poorly graded*. (Note that these terms are the reverse of the geological expressions *well sorted* and *poorly sorted*.)

GRAIN SIZE: The general dimensions of the particles that make up a sediment or rock.

GRANITIC ROCK: A term loosely applied to any light-coloured coarse-grained plutonic rock containing quartz as an essential component, along with feldspar and mafic minerals.

GRANULAR TEXTURE: A rock that is made up of grains that are roughly equal in size.

GRAVEL: An unconsolidated, naturally occurring accumulation of rounded rock fragments consisting primarily of fragments coarser than sand (>2 mm) but generally including a high proportion of sand-sized material. It is some times used synonymously with pebbles (the 4–64 mm grain-size category).

GRAVITY FLOWS (SUBAQUEOUS): Downslope flow of a dense mixture of water and sediment; commonly generated by subaqueous slumping of deltas.

GREAT GROUP: A category in the Canadian system of soil classification (Canada Soil Survey Committee, 1978). It is a taxonomic group of soils having certain morphological features in common and a similar pedogenic environment. Examples are Black, Solonetz, Grey Brown Luvisol, Humic Podzol, Melanic Brunisol, Regosol, Gleysol, and Fibrisol.

GROUND CHECKING: Fieldwork carried out to assess the correctness of air photo interpretation or other sources of information.

GROUND ICE: All ice, no matter what the origin, that is found beneath the surface of the ground.

GROUND MORAINE: A plain or very gently undulating area underlain by till.

GROUNDWATER: All subsurface water (as distinct from surface water).

GROUNDWATER DISCHARGE: The release of water from the zone of saturation by any means.

GROUNDWATER RECHARGE: The processes involved in the absorption and addition of water to the zone of saturation.

GROUP: The rock stratigraphic unit that is next higher in rank than formation. A group generally includes two or more formations.

GRUS: The fragmental products of in situ granular disintegration of coarse crystalline rocks, especially granitic rocks.

GULLY: A small valley or ravine, longer than wide, and typically from a few metres to a few tens of metres across.

GULLY EROSION: Formation of gullies in surficial materials and/or bedrock by a variety of processes including erosion by running water; erosion as a result of weathering and the impact of falling rocks, debris slides, debris flows and other types of mass movement; and erosion by snow avalanches.

GWDRILL: A database of water-well and related records maintained by the Manitoba Water Resource Branch, 1577 Dublin Ave., Winnipeg, Manitoba, R3E 3JR.

GYPSUM: A relatively soft and soluble mineral consisting of hydrous calcium sulfate ($CaSO_4 2H_2O$)

HANGING VALLEY: A tributary valley whose floor is higher than that of the trunk valley in the vicinity of their junction; most commonly applied to glacial troughs.

HARDPAN: A general term for a hard, often clayey and impervious layer. In glaciated country, such as Canada, often used in referring to till.

HILL: Rounded elevation of the land surface generally having relief of <300 m.

HILLOCK: A small low hill, a mound.

HOLOCENE: The most recent epoch (period) of geological time. It extends from present back to 10 000 years ago.

HORIZON: A layer of soil or soil material approximately parallel to the land surface; it differs from adjacent genetically related layers in properties such as colour, structure, texture, consistence, and chemical, biological, and mineralogical composition. A list of the designations and some of the properties of soil horizons and layers follows. More detailed definitions of some horizons and layers may be found in, Canada Soil Survey Committee (1978). Primary horizons are as follows:

Organic layers (contain 17% or more organic carbon).

O: An organic layer developed mainly from mosses, rushes, and woody materials.

L-F-H: Organic layers developed primarily from leaves, twigs, and woody materials, with a minor component of mosses.

Mineral horizons (contain less than 17% organic carbon):

A: A mineral horizon formed at or near the surface in the zone of removal of materials in solution and suspension, or maximum in situ accumulation of organic carbon, or both.

B: A mineral horizon characterized by one or more of the following:

1) An enrichment in silicate clay, iron, aluminum, or humus.

2) A prismatic or columnar structure that exhibits pronounced coatings or stainings associated with significant amounts of exchangeable sodium.

3) An alteration by hydrolysis, reduction, or oxidation to give a change in colour or structure from the horizons above or below, or both.

C: A mineral horizon comparatively unaffected by the pedogenic processes operative in A and B, except gleying, and the accumulation of carbonates and more soluble salts.

R: Underlying consolidated bedrock that is too hard to break with the hands or to dig when moist.

Horizon characteristics may be indicated by lowercase suffixes. The following are some of the letters that have been used.

e-A horizon characterized by removal of clay, iron, aluminum, or organic matter alone or in combination and higher in colour value by one or more units when dry than an underlying B horizon. It is used with A (Ae).

f-A horizon enriched with amorphous material, principally Fe and Al combined with organic matter. It usually has a chroma of 3 or more. The criteria for an f horizon except for Bgf are: it contains 0.6% or more pyrophosphate-extractable Fe plus Al in textures finer than sand and 0.4% or more in sands; the ratio of pyrophosphate-extractable Fe plus Al to clay (less than 2 Fm) is greater than 0.5; and organic carbon exceeds 0.5%. These horizons are differentiated on the basis of organic carbon content into:

Bf - 0.5% to 5% organic carbon

Bhf - more than 5% organic carbon

h-A horizon enriched with organic matter:

Ah-An A horizon of organic matter accumulation. It contains less than 17% organic carbon. It is one Munsell unit of colour value darker than the layer immediately below, or it has at least 0.5% more organic carbon than the underlying C horizon, or both.

Ahe-This horizon has been degraded, as evidenced by streaks and splotches of light and dark grey material and often by platy structure.

Bh-This horizon contains more than 1% organic carbon and less than 0.3% pyrophosphate-extractable Fe; the ratio of organic carbon to pyrophosphate-extractable Fe is 20 or more.

j-This is used as a modifier of suffixes e, g, n, and t to denote an expression of, but failure to meet, the specified limits of the suffix it modifies; for example, Aej is an eluvial horizon that is thin, discontinuous, or faintly discernible.

k-Presence of carbonate.

m-A horizon slightly altered by hydrolysis, oxidation, or solution, or all three, to give a change in colour, or structure, or both.

n-A horizon in which the ratio of exchangeable Ca to exchangeable Na is 10 or less.

p-A layer disturbed by man's activities, for example, Ap.

s-A horizon containing detectable soluble salts.

t-A horizon enriched with silicate clay, as indicated by a higher clay content (by specified amounts) than the overlying eluvial horizon, a thickness of at least 5 cm, oriented clay in some pores, or on ped surfaces, or both, and usually a higher ratio of fine (less than 0.2 Fm) to total clay than in the underlying C soil horizon.

Ae: 'A' horizon characterized by removal of clay, iron, aluminum, or organic matter alone or in combination and higher in colour value by one or more units when dry than an underlying 'B' horizon.

Ah: An 'A' horizon of organic matter accumulation. It contains less than 17% organic carbon. It is one Munsell unit of colour value darker than the layer immediately below, or it has at least 0.5% more organic carbon than the underlying 'C' horizon, or both.

Ahe: This 'A' horizon has been degraded, as evidenced by streaks and splotches of light and dark grey material and often by platy structure. *See* Ah.

Bf: 'B' horizon enriched with amorphous material, principally Fe and Al combined with organic matter. It usually has a chroma of 3 or more. The criteria for an f horizon, except for Bgf, are as follows: it contains 0.6% or more pyrophosphate-extractable Fe plus Al in textures finer than sand and 0.4% or more in sands; the ratio of pyrophosphate-extractable Fe plus Al to clay (less than 2 Fm) is greater than 0.5; and organic carbon exceeds 0.5%, but is <5%. These horizons are differentiated on the basis of organic carbon content into:

Bh: This 'B' horizon contains more than 1% organic carbon and less than 0.3% pyrophosphate-extractable Fe; the ratio of organic carbon to pyrophosphate-extractable Fe is 20 or more.

Bhf: 'B' horizon enriched with amorphous material, principally Fe and Al combined with organic matter. It usually has a chroma of 3 or more. The criteria for an f horizon except for Bgf are: it contains 0.6% or more pyrophosphate-extractable Fe plus Al in textures finer than sand and 0.4% or more in sands; the ratio of pyrophosphate-extractable Fe plus Al to clay (less than 2 Fm) is greater than 0.5; and organic carbon exceeds 5%. These horizons are differentiated on the basis of organic carbon content into:

Bm: 'B' horizon slightly altered by hydrolysis, oxidation, or solution, or all three, to give a change in colour, or structure, or both.

Bt: 'B' horizon enriched with silicate clay, as indicated by a higher clay content (by specified amounts) than the overlying eluvial horizon, a thickness of at least 5 cm, oriented clay in some pores, or on ped surfaces, or both, and usually a higher ratio of fine (less than 0.2 Fm) to total clay than in the underlying C soil horizon.

Btj: *See* 'Bt'. 'j' is used as a modifier of suffixes e, g, n, and t to denote an expression of, but failure to meet, the specified limits of the suffix it modifies.

HUE: The aspect of colour that is determined by the wavelengths of light, and changes with the wavelength. Munsell hue notations indicate the visual relationship of a colour to red, yellow, green, blue, or purple, or an intermediate of these hues.

HUMMOCK: A rounded or conical knoll, generally equidimensional in shape.

HUMMOCKY: A complex sequence of steep-sided hillocks and hollows, non-linear and chaotically arranged, and with rounded or irregular cross-profiles.

HUMMOCKY MORAINE: A moraine consisting of an apparently random assemblage of knobs, kettles, hummocks, ridges, and depressions; *see* ablation moraine.

HUMUS: The decomposed organic material in soil. This is what gives surface soil horizons their dark colours.

HYDROGEOLOGICAL REGION: An area of similar geological and climatic conditions, producing, on a broad scale, a region with a degree of hydrogeological uniformity. For instance, the Canadian Shield hydrogeological region is a vast area underlain by crystalline igneous and metamorphic rocks covered by generally thin glacial-derived overburden.

HYDROLOGY: The scientific study of the distribution and characteristics of water at and close to the Earth's surface.

HYDROLOGICAL FEATURES: Refers to water-related features visible at the land surface, such as stream channels, seepage zones, springs, and soil moisture, including soil-moisture characteristics as deduced from vegetation characteristics.

HYDROLYSIS: The process by which a substrate is split to form two end products by the intervention of a molecule of water.

HYDROPHYTE: A plant that requires large quantities of water for its growth.

HYPSITHERMAL: Early to mid-Holocene warm interval; also referred to as 'xerothermic interval' and 'climatic optimum'.

ICE-DISINTEGRATION MORAINE: A moraine resulting from the accumulation of ablation till and other drift on top of stagnant ice; similar to hummocky moraine and ablation moraine.

ICE-CONTACT: Pertains to sediments deposited against, on top of, or in tunnels underneath a glacier or ice sheet.

ICE-RAFTED STONES: Stones dropped into glacial lacustrine and glaciomarine sediments from melting icebergs.

ICE SHEET: A continental-scale, more-or-less continuous cover of land ice that spreads outward in all directions and is not confined by underlying topography.

ICE SHELF: A floating tabular mass of ice at the margin of, and attached to, an ice sheet.

ICE THRUST: The lateral movement of material caused by the pushing or dragging of a glacier. This can vary from a displaced layer of sediment to a series of closely spaced ridges piled up by the advancing ice.

ICE WEDGE: A wedge-shaped mass of ground ice, produced in permafrost, occurring as a vertical or inclined sheet, dike, or vein tapering downwards.

ICE-WEDGE CASTS: Infilled cavities formerly occupied by ice wedges; cavities are vertical and taper downward; width at the top is typically between a few centimetres and a metre, and the vertical dimension of most cavities is greater than their width; used as indicators of former periglacial conditions.

IGNEOUS ROCKS: Rock that formed by the solidification from a molten material.

ILLUVIAL HORIZON: A soil horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension as a layer of accumulation. *See also* eluvial horizon.

ILLUVIATION: The process of depositing soil material removed from one horizon in the soil of another, usually from an upper to a lower horizon in the soil profile. Illuviated substances include silicate clay, hydrous oxides of iron and aluminum, and organic matter.

INACTIVE: Term used for a process that is not operating at the present time. For example, a fan is said to be inactive if there is no erosion or deposition occurring on its surface under present conditions.

INCISED: Cut down into; said of a stream that become entrenched in a surface.

INDURATED: Compacted or cemented to form a coherent mass.

INFILTRATION: The movement of water or solutions into rock or soil through pores or fractures from another area.

INTEGRATED: Said of drainage that has reached a mature stage with few lakes and an intricate pattern of channels servicing all parts of the area.

INTERGLACIAL: A period between two episodes of glaciation; generally a time when conditions and climate were not too different from those at present.

INTERIOR PLAINS: The area of Canada stretching from the Cordilleran mountain belt on the west to the Canadian Shield on the east and extending from the 49th parallel to the Arctic coast.

IRONSTONE CONCRETION: A concretion consisting of clayey material mixed with iron carbonate (siderite). These concretions are common in some of the bedrock units in this area.

INTERSTITIAL: Pertaining to the interstices (pore spaces) of a particulate sediment.

INTERSTRATIFIED: Strata alternating with layers of a different character.

INTERTILL: Enclosed by or occurring between till units.

INTRACRATONIC BASIN: A low area, generally occurring in a stable geological setting, that is receiving sediment but is not associated with an adjacent uplifted area.

INUNDATION: Applied to areas seasonally or occasionally covered by water.

ISOPACH: A line drawn on a map through points of equal thickness of for a particular stratigraphic unit; also, loosely used to mean unit thickness.

ISOSTASY: The condition of equilibrium of the Earth's surface; gradual depression or elevation of the Earth's surface due to the addition or removal of ice sheets is termed glacio-isostasy.

JOINT: A fracture surface or parting in a rock.

JÖKULHLAUP: An Icelandic term in general usage for glacial-outburst flood.

JURASSIC: A formal geological time term. The middle period of the Mesozoic Era; it covered the span of time between about 208 to 144 million years ago.

KAME: Irregular or conical hillocks composed chiefly of sand and gravel; formed by deposition of meltwater-transported sediments in contact with (against, within, or upon) stagnant glacial ice.

KAME DELTA: A delta of sand and gravel constructed in contact with (against or on top of) glacial ice; commonly a conspicuous terrace-like landform bounded by a steep ice-contact face or by hummocky collapsed ground; a type of glaciofluvial deposit.

KAME TERRACE: A terrace of drift, chiefly sand and gravel, deposited by meltwater in a depression between a melting glacier and the adjacent valley side, and left as a terrace when the glacier melted; the terrace is commonly irregular or fragmentary, and shows topographic and stratigraphic evidence of collapse; a type of glaciofluvial deposit.

KAME-AND-KETTLE TOPOGRAPHY: Hummocky topography with enclosed depressions, commonly resulting from ice stagnation, and underlain by ablation till and ice-contact glaciofluvial materials.

KARST REGION: An area where the topography has resulted largely from the solution of the underlying rocks (generally limestone or gypsum). Such areas are generally characterized by sinkholes, caves, and underground drainage.

KETTLE: A closed depression or hollow in glacial drift which has resulted from the melting of a buried or partly buried mass of glacial ice; common in glaciofluvial deposits.

KNOLL: A small, low, rounded hill, a hillock, or mound.

LACUSTRINE: Pertaining to a lake.

LACUSTRINE MATERIALS: Sediments that have settled from suspension or underwater gravity flows in lakes; also includes littoral sediments (e.g. beach gravels) accumulated as a result of wave action.

LAG DEPOSIT: Residual deposit of coarse material from which the fine fraction has been removed by wind or water erosion.

LAKE SEDIMENTS: Deposits formed in a lacustrine environment (lake); generally consist of clay and silt, or silt and sand.

LAMINAE: The thinnest or smallest, recognizable unit layer of original deposition in a sediment or sedimentary rock, differing from other layers in colour, composition, or particle size.

LAMINATED: Term used to describe deposits that consist of a series of individual beds that generally are thinner than about 1 cm.

LANDFORM: Any physical, recognizable form or feature of the Earth's surface, having a characteristic shape, and produced by natural processes.

LANDSCAPE: A particular part of the Earth's surface, such as can be seen from a vantage point or examined on an air photo, and the various landforms and other physical features which together make up the field of view.

LANDSLIDE: A general term for the downslope movement of large masses of earth material and the resulting landforms.

LANDSLIDE SCAR: The part of a slope exposed or visibly modified by detachment and downslope movement of a landslide; usually lies upslope from the displaced landslide; commonly a steep, concave slope.

LATERAL MORAINE: A low ridge of drift carried on or deposited at the side of a glacier.

LATE WISCONSINAN: A period of geological time. It includes the time of the last major ice advance and is the period from about 23 to 10 thousand years ago.

LEACHING: The removal from the soil of materials in solution.

LEGEND: The brief explanatory list of the symbols, geological units, etc. that appears on a map, chart or diagram.

LETTER DESIGNATOR: A letter or series of letters that is used as a label on a map unit. It is used as a key to tie the map unit to the map unit description that is provided in the legend.

LEVEE: A low ridge or embankment that parallels a channel and is built by deposition from an overflowing stream or from accumulation of sediments at the margin of an avalanche or debris flow gully.

LIGNITE: A brownish-black coal that generally is soft and poorly consolidated.

LIMESTONE: A sedimentary rock consisting chiefly of calcium carbonate (calcite).

LIQUID LIMIT: The water-content boundary between the semiliquid and the plastic states of a sediment.

LITHOFACIES: A unit of sediments or sedimentary rock that contains a record of a particular environment of deposition.

LITHOFACIES CODE: A system for the description of lithofacies, cf. Eyles et al. (1983).

LITHOLOGY: The characteristics of a rock.

LITTORAL: Pertaining to the shore of a water body.

LOAM: Soil material consisting of approximately equal parts of clay, sand, and silt.

LODGEMENT TILL: Material that accumulates at the base of a moving glacier, typically highly consolidated.

LOESS: A homogeneous, nonstratified, not indurated, yellowish to buff-coloured wind-borne deposit consisting predominantly of silt-sized particles with subordinate amounts of fine sand and clay; porous and permeable, commonly with incipient vertical joints.

L/s: Litres per second. One litre per second equals 13.2 Imperial gallons per minute.

LUVISOLIC: An order of soils that have eluvial (Ae) horizons, and illuvial (Bt) horizons in which silicate clay is the main accumulation product. The soils developed under forest or forest-grassland transition in a moderate to cool climate.

MAP UNIT: A subdivision of geological materials that is displayed as a polygon on a map.

MARINE MATERIALS: Sediments deposited in the ocean by settling from suspension and by submarine gravity flows, and sediment accumulated in the littoral zone due to wave action.

MARL: Soft calcium carbonate, usually mixed with varying amounts of clay and other impurities; may include fossils.

MARSH: Periodically flooded or continually wet areas having the surface not deeply submerged. They are covered dominantly by sedges, cattails, rushes, or other hydrophyitc plants and are not characterized by significant accumulation of organic materials.

MASS MOVEMENT: A general term for downslope movement of earth materials by processes such as soil creep, rockfall, and debris slides.

MASS WASTING: A general term for a variety of processes, including weathering and erosion, that together effect reduction of slopes and lowering of the land surface.

MASSIVE: Rocks or sediments without stratification, bedding, or foliation.

MATRIX: The groundmass of smaller grains in which larger particles are supported.

MEANDERING CHANNEL: Refers to a stream channel characterized by meanders.

MEANDERS: Regular and repeated bends of similar amplitude and wave length along a stream channel.

MEDIAL MORAINE: A morainal ridge in the middle of a glacier, parallel to the direction of glacier flow, and formed by the union of lateral moraines of two coalescing glaciers.

MELT-OUT TILL: Material that accumulates directly by melt out from stationary or stagnant glacial ice; may accumulate on top of the ice, *supraglacial melt-out till*, or underneath the ice, *basal melt-out till*.

MELTWATER: Water derived form the melting of snow and ice, especially the stream water flowing in, under, or from melting glacial ice.

MELTWATER CHANNEL: A channel or a valley formed or followed by a glacial meltwater stream; according to their position, they are divided into ice-marginal (lateral) channels, subglacial channels, and so on.

MEMBER: The rock stratigraphic unit that is next below formation in the formal lithostratigraphic unit hierarchy; a member is always part of a Formation.

MESOPHILE: An organism growing best at moderate temperatures of 25 to 40°C.

MESOPHYTE: A plant that cannot survive extreme conditions of temperature or water supply.

MESOZOIC: A formal time term. The era of geological time that lasted from about 245 to 66 million years ago (from Paleozoic until Tertiary).

METAMORPHIC ROCK: Rock that is derived from pre-existing rock by mineralogical, chemical, and structural changes in response to marked changes in temperature, pressure, shearing stress, and chemical environment at depth.

mg/L: Milligrams per litre. An expression for the mass of a dissolved chemical in a litre of water.

MILLWOOD MEMBER: Soft, greenish-brown, bentonitic, slightly silty clay shale that ranges from 23 to 76 m in thickness and occurs at the base of the Pierre Formation (Bamburak, 1978).

MINERAL EXPLORATION: The search for ore deposits or mineral-bearing formations.

MISSISSIPPIAN: A formal geological time term. It is the period of the Paleozoic Era that lasted from about 360 to 320 million years ago.

MODERN: Occurring at the present time.

MONTMORILLONITE: A group of expanding-lattice clay minerals that are generally derived from alteration of other minerals or volcanic glass. They are a major constituent of bentonite and tend to swell and become very sticky on wetting.

MORAINE: A landform that consists of till and/or other drift; it exhibits a variety of shapes, ranging from plains to mounds and ridges, that are initial constructional forms independent of underlying bedrock or older materials.

MORAINAL: Pertaining to moraines. In this report it is used to refer to the deposits that make up the moraines, i.e. till or drift.

MORTAR: A plastic building material such as that made by mixing lime, cement, or the like with sand and water.

MOTTLES: Spots or blotches of different colour or shades of colour interspersed with the dominant colour.

MOTTLING: Formation or presence of mottles in the soil.

MOUNDS: Low, isolated, rounded, topographic rises.

MUCK: Dark, finely divided, well decomposed, organic material, that may include an admixture of fine mineral material.

MUD: i) Soft, wet, sticky or slippery mixture of water and predominantly fine-textured sediments. ii) A textural term used to refer to silt, clay, or a mixture of silt and clay.

MUDFLOW: A debris flow consisting predominantly of mud.

MUNSELL COLOUR SYSTEM: A colour designation system specifying the relative degrees of the three simple variables of colour: hue, value, and chroma.

NATURAL EXPOSURE: An opening produced by natural processes, such as stream erosion or slumping, that provides a view of what lies below the ground surface.

NONCALCAREOUS: Said of a substance that does not contains calcium carbonate.

NONCOHESIVE: Said of a material that has relatively low shear strength when dry.

NONSORTED: Said of a sediment that consists of a mixture of different grain sizes; similar to *poorly sorted* and *well graded*.

OBSERVATION SITES: Sites at which field checks are carried out.

ODANAH MEMBER: A hard, grey, siliceous, bentonitic, slightly silty, clay shale that ranges in thickness from 170 to 230 m and lies in the middle of the Pierre Formation (Bamburak, 1978).

OFFLAP: The progressive offshore regression of sedimentary units.

OMAROLLUK FORMATION: A unit of late Precambrian rock that outcrops in the Belcher Island and adjacent coast of Hudson Bay. The part of this unit of most interest to Quaternary geologists is a distinctive greywacke containing concretions that comes from the upper part of the formation. This unique rock has been found scattered across an area reaching from Illinois to Alberta. The distribution of 'Omarolluk' erratics has been used in plotting glacial transport directions and working out the history of ice sheet development (*see* for instance Prest, 1990).

ORDER: A category in the Canadian system of soil classification (Canada Soil Survey Committee, 1978). All the soils of Canada have been divided into eight orders: Chernozemic, Solonetzic, Luvisolic, Podzolic, Brunisolic, Regosolic, Gleysolic, and Organic. All the soils within an order have one or more characteristics in common.

ORDOVICIAN: A formal geological time unit. It is in the early part of the Paleozoic Era and lasted from about 505 to 438 million years ago.

ORGANIC: Pertaining to a substance containing carbon derived from a living organism.

ORGANIC (SOIL ORDER): An order of soils that have developed dominantly from organic materials. The majority of Organic soils are saturated for most of the year, unless artificially drained, but some of them are not usually saturated for more than a few days. They contain 17% or more organic carbon, and

1) If the surface layer consists of fibric organic material and the bulk density is less than 0.1 (with or without a mesic or humic Op less than 15 cm thick), the organic material must extend to a depth of at least 60 cm; or

2) If the surface layer consists of organic material with a bulk density of 0.1 or more, the organic material must extend to a depth of at least 40 cm; or

3) If a lithic contact occurs at a depth shallower than stated in 1) or 2) above, the organic material must extend to a depth of at least 10 cm.

ORGANIC MATERIAL: Sediments formed by the accumulation of decaying vegetative matter. Peat is an example.

ORGANIC-RICH SEDIMENTS: Mineral sediments that contain an admixture of organic materials.

ORGANIC MUCK: Dark, finely divided, well decomposed, organic materials intermixed with a high percentage of mineral matter, usually silt.

OUTCROP: An exposure of geological material. In this report the term is used for exposures of bedrock.

OUTWASH: Glaciofluvial sediments deposited by glacial meltwater downstream from a glacier.

OUTWASH PLAIN: A flat or very gently sloping surface underlain by glaciofluvial sediments.

OVERBURDEN: i) Barren material overlying an economic mineral deposit that must be removed before mining. ii) The upper part of a soil or sedimentary deposit that causes the consolidation of the material below. iii) Surficial material that overlies bedrock.

OXIDIZE: To combine with oxygen; by extension to change from a lower to higher valance (e.g. from ferrous oxide, Fe0, to ferric oxide Fe_2O_3).

PALEOCENE: A formal geological time term. The earliest geological time epoch of the Tertiary Period; it lasted from about 66 to 58 million years ago.

PALEOSOL: A soil buried by younger surficial materials.

PALEOZOIC: The era of geological time that lasted from about 570 to 250 million years ago (from Precambrian to Mesozoic).

PARENT MATERIAL: The unconsolidated and more-or-less chemically weathered mineral or organic matter from which the solum of a soil has developed by pedogenic processes.

PARTICLE-SIZE ANALYSIS: Determination of the grain-size distribution of a sediment by laboratory analysis.

PATTERNED GROUND: Land surface with a distinctive arrangement of stones or microtopography due to the effects of ground freezing and seasonal frost; characteristic of periglacial environments; includes stone stripes, sorted circles, and tundra polygons.

PAVEMENT: A surface that suggests a paved road; often used when referring to pebbles or boulders that have flat surfaces arranged in a plane.

PEACE GARDEN MEMBER: The upper of the two members making up the Turtle Mountain Formation. It is about 100 m thick and is made up of marine silty clay with minor thin very fine-grained sand beds (Bamburak, 1978).

PEAT: Black or brown, partly decomposed, fibrous vegetative matter that has accumulated in a waterlogged environment such as a bog.

PEBBLE: A rounded rock fragment with a diameter between 4 and 64 mm (Wentworth scale).

PEBBLY: A material that includes scattered fragments of pebble size.

PEDOGENIC: The mode of origin of the soil, especially the processes or soil-forming factors responsible for the development of the solum, the true soil, from unconsolidated parent material.

PEDOLOGY: The aspects of soil science dealing with the origin, morphology, genesis, distribution, mapping, and taxonomy of soils, and classification in terms of their use.

PERCOLATION: Downward flow of water through small openings in a porous material.

PERIGLACIAL: An environment in which frost action is an important factor, or a term used to describe processes that are induced by conditions found in an area where frost action is important.

PERMEABLE: A material through which a fluid can readily pass. Permeability is a measure of the relative ease of fluid flow under unequal pressure.

PERMAFROST: The state of natural materials that exist at below freezing temperatures for a relatively long period of time (2 or more years)

PHANEROZOIC: A formal geological time term for all time since Precambrian (about the past 570 million years).

PHYSIOGRAPHIC REGION: An area of similar relief and topography, bedrock geology and structure, geomorphological history and landforms.

PIPING: Erosion by percolating water in a layer of subsoil, resulting in caving, and in the formation of narrow conduits, tunnels, or pipes.

PLAIN: An extensive region of comparatively smooth and level to gently undulating land, having few or no prominent surface irregularities, and usually at a low elevation with reference to surrounding areas.

PLASTIC: Said of materials in which strain produces continuous, permanent deformation without rupture.

PLASTICITY INDEX: The water-content range of a soil at which it is plastic, defined numerically as the liquid limit minus the plastic limit.

PLASTIC LIMIT: The water-content boundary of a sediment between the plastic and semisolid state.

PLEISTOCENE: An epoch of the Quaternary Period, after the Pliocene of the Tertiary and before the Holocene; characterized by repeated glacial and non-glacial intervals (defined as extending from .01 to 1.65 million years ago).

PLIOCENE: The final epoch of the Tertiary period (extended from about 5.3 to 1.65 million years ago).

PLUTON: An igneous intrusion.

PODZOLIC: An order of soils having podzolic B horizons (Bh, Bhf, or Bf) in which combinations of amorphous organic matter (dominantly fluvic acid), Al, and usually Fe are accumulated. The sola are acid and the B horizons have a high pH-dependent charge. The great groups in the order are Humic Podzol, Ferro-Humic Podzol, and Humo-Ferric Podzol.

POLISHED: Said of a rock surface that has been abraded to a glistening smoothness by the abrasion of fine particles carried by a glacier.

POLYGON: In the strict sense, a figure with many sides. In a mapping sense, it is the term used for an area bounded by a line.

POORLY GRADED: An engineering term indicating that all the particles of a material are of about the same size. In geological terms, this material would be *well sorted*.

POORLY STRATIFIED: Stratification not pronounced, bedding not distinct.

POORLY SORTED: Consisting of particles of many sizes mixed together (*well graded* in engineering terms).

POORLY CONSOLIDATED: Not well compacted or lithified. Generally used for bedrock that disintegrates readily.

PORE SPACES: The spaces between the particles of detrital sediments that are not occupied by mineral matter.

PORE WATER: The water that occupies the spaces between the particles of detrital sediments that are not occupied by mineral matter.

POROSITY: The amount of pore space present, expressed as a percentage of the total volume of the material.

POROUS: Having numerous open spaces or openings between grains.

POSTGLACIAL: Pertaining to the time interval since the disappearance of glaciers or since glaciers affected the geological processes in a particular area.

POTHOLE: i) a shallow depression often containing an intermittent pond, ii) a smooth roughly circular hole formed in a stream bed by the swirling grinding action of sand or a stone.

PRAIRIE: A tract of level to rolling, temperate grasslands.

PRECAMBRIAN: A formal geological time term. The period of geological time before the Paleozoic era (ending about 570 million years ago).

PREGLACIAL: Occurring before glaciation (generally assumed to be before the first Pleistocene glaciation); used in referring to materials between glacial deposits and bedrock or to bedrock topography that is covered by glacial deposits.

PROCESS: In a geological sense it is one or a related series of naturally occurring actions e.g. stream erosion and mass wasting are geological processes.

PROGLACIAL: Immediately in front of or just beyond a glacier. Generally used when referring to near-glacial processes or deposits.

PUMP TEST: A test aimed at estimating aquifer yield. A pump test consists of withdrawing groundwater from a well at a known rate for a period of time and measuring the resultant lowering in water level in the pumped well and nearby monitoring wells. A pump test provides information which allows the determination of the capability of a geological unit to transmit and store groundwater.

PYROCLASTIC SEDIMENTS: A general term applied to detrital volcanic materials that have been explosively or aerially ejected from a volcanic vent; examples are volcanic ash and cinders.

QUARTZ: Crystalline silica (SiO_2); it is the second most common mineral at the Earth's surface.

QUARTZITE: Either a metamorphic rock that formed through the partial recrystallization of a quartz-rich sandstone, or a very hard unmetamorphosed sandstone that consists mainly of quartz.

QUATERNARY PERIOD: A formal geological time term. The most recent geological time period; subdivided into the Pleistocene and Holocene (Recent) epochs; currently defined as beginning about 1.65 million years ago.

QUATERNARY DEPOSITS: Sediments deposited during the Quaternary Period; similar to surficial materials.

RAILROAD BALLAST: Unscreened gravel or broken rock that is used as the foundation for the ties and rails.

RAISED DELTA: A delta now standing above the level of the water body into which is was deposited; commonly resembles a terrace, with the terrace top marking the former water level.

RAPID MASS MOVEMENT: Rapid downslope movement of surficial material by falling, rolling, sliding, or flowing; includes rockfall, debris flows, and rapid landslides.

RECESSIONAL MORAINE: An end moraine built during a temporary but significant halt or minor re-advance of the ice front during a period of overall glacial recession.

REDBEDS: Sedimentary rocks such as sandstone and shale that were deposited in a continental environment and are predominantly red in colour due to content of ferric iron oxide.

REGOLITH: The mantle of loose material that overlies bedrock; includes weathered rock, soil and surficial materials.

REGOSOLIC: An order of soils having no horizon development or development of the A and B horizons insufficient to meet the requirements of the other orders. Regosol is the only great group in this order.

RELIEF: Difference between the elevation of two points or more loosely, the general variation in height of the land surface.

RESIDUAL: Term used for the material that is left behind after the weathering of rock in place.

REWORKED: Geological materials that have been displaced from their place of origin and incorporated in a still recognizable form in a younger formation.

RIDGES: Elongate hillocks with slopes dominantly between 15 and 35 degrees (26–70%) on unconsolidated materials and steeper on bedrock; local relief is greater than 1 m.

RIDING MOUNTAIN FORMATION: The name given to the Pierre Formation (McNeil and Caldwell, 1981) by Bamburak (1978).

RIM RIDGE: A minor ridge of drift that surrounds or partly encloses a central depression.

RIVER TERRACE: A more-or-less flat surface bounded downslope by a scarp and resulting from fluvial erosion and deposition. Same as fluvial terraces and alluvial terraces.

ROCHE MOUNTONNÉE: A knob of rock with a whaleback form, the long axis of which is oriented parallel to former ice flow, and having a smooth, glacially abraded stoss (upflow) slope and a much steeper and rougher, glacially plucked lee (downflow) slope.

ROCK AVALANCHE: Rapid downslope movement of a large mass of rock fragments derived from bedrock; the rock fragments in motion, although not saturated, take on the character of a (dry) flow and are highly mobile; typically the result of very large rock falls and rock slides.

ROCK CREEP: Slow downslope movement of rock fragments; commonly associated with the presence of interstitial ice and/or solifluction.

ROCK FALL: The relatively free falling or precipitous movement of a newly detached fragment of bedrock of any size from a cliff or other very steep slope; it is the fastest form of mass movement.

ROCK GLACIER: A tongue shaped or lobate, ridged accumulation of angular fragments containing interstitial ice which moves slowly downslope; morphologically similar to a glacier.

ROCK SLIDE: Rapid or slow downslope movement of a large mass of rock by sliding along one or more well defined surfaces of rupture.

ROCK UNIT: A body of rock having a large degree of lithological homogeneity that can be recognized and mapped as being distinct from adjacent rock.

ROLLING: (surface expression) Elongate hillocks with slopes dominantly between 3 and 15 degrees (5 and 26%), slopes relatively long (generally >0.5 km) and with local relief generally greater than 25 m.

ROUNDNESS OF CLASTS: Pertains to the sharpness or degree of rounding of the edges of clasts; commonly described by the terms: rounded, subrounded, subangular, and angular.

RUBBLE: I) Angular rock fragments, ii) Angular particles between 2 and 256 mm; may include interstitial sand.

SACKUNG: On mountainsides, trenches and uphill-facing scarps trending parallel to contours and developed as a result of gravitational movements.

SAND: A detrital particle having a diameter in the range of 1/16 to 2 mm (Wentworth scale).

SANDSTONE: The consolidated equivalent of sand. A medium-grained, clastic, sedimentary rock composed of sand-sized fragments.

SANDY: Descriptive term used to indicate that a mineral material includes 20 to 50% sand-sized particles.

SAPROLITE: A soft, earthy, clay-mineral-rich product of chemical weathering of igneous and metamorphic rocks.

SCARP: A steep slope that is usually of great lateral extent compared to its height, such as the risers of river terraces and steep faces associated with stratified rocks (abbreviated term for escarpment).

SCOUR: The powerful and concentrated clearing and digging action of flowing air or water.

SEDIMENT: Solid fragmental material that originates from the weathering of rocks and is transported by, suspended in, or deposited by air, water, or ice or that is accumulated by other natural agents such as chemical precipitation or secretion by organisms and forms layers on the Earth’s surface.

SEDIMENTARY: Formed by the deposition of sediment or pertaining to the process of sedimentation.

SEDIMENTARY ROCK: A rock resulting from the accumulation of sediment in layers.

SEEPAGE ZONE: An area where soil is saturated due to emerging groundwater.

SEISMIC: Pertaining to earthquakes.

SELENITE: A clear colourless variety of gypsum that typically is found as crystals in clay.

SEPTARIAN NODULE: A large concretion (usually ironstone) that is characterized by series of cracks that appear like dessication cracks and trace a polygonal pattern on the concretion surface.

SHALE: Detrital sedimentary rock formed by the consolidation of clay, silt, or mud and marked by a finely stratified structure or a fissility that is parallel to bedding.

SHAPE OF CLASTS: The shape of clasts as defined by the relative lengths of their a (long), b (intermediate), and c (short) axes; terms such as spherical (a=b=c) and discoid (a=b>c) refer to clast shape.

SHEAR: Strain resulting from stresses that tend to cause contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact.

SHEAR FAILURE: A failure or breaking apart caused by shear .

SHEAR PLANE: A surface along which differential movement has taken place parallel to the surface.

SHEAR STRENGTH: The internal resistance of a body to shear stress.

SHEAR STRESS: The component of stress that acts tangentially to a plane through any given point on a body.

SHORELINE: The intersection of a water body with land; features that develop at shorelines and can often be used in determining the former position of a shoreline include beach ridges, strandflats, and escarpments.

SHORELINE SEDIMENTS: Deposits formed by processes acting along the margin of a body of water.

SILICA: The chemical compound silicon dioxide (SiO_2). It sometimes occurs as an amorphous admixture (as in some shales) but most commonly occurs as quartz, the most abundant mineral in silt and sand.

SILICEOUS: Said of a material containing abundant silica.

SILT: A detrital particle having a diameter in the range of 1/256 to 1/16 mm (0.004 to 0.0625 mm) (Wentworth scale).

SILTSTONE: An indurated silt having the texture and composition of a shale but lacking the fine lamination or fissility.

SILTY: Descriptive term used to indicate that a mineral material includes 20 to 50% silt-sized particles.

SINKHOLES: A funnel-shaped depression in the land surface that communicates with a subterranean passage developed by solution; common in limestone and karst regions; also applied to similar features caused by piping.

SLAG: The rocky refuse produced during the smelting of metals.

SLIP SURFACE: A surface along which displacement in a landslide occurs.

SLOPE BREAK: The point on a slope where gradient changes rather abruptly.

SLOPE FAILURE: Rupture and collapse, or flow, of surficial materials and bedrock due to shear stress exceeding the shear strength of the material.

SLOPE PROCESSES: Mass-movement processes, such as debris slides, and surface wash whereby fine sediments are transported downslope by overland flow.

SLOPE STABILITY: Pertains to the susceptibility of slope to landslides and the likelihood of slope failure.

SLOPE WASH: Fine sediments, on or at the foot of hillsides, that have been moved downslope by overland flow.

SLOUGH: A small marsh; especially a marshy tract lying in a swale or other local, shallow, and undrained depression.

SLOW MASS MOVEMENT: Slow, usually imperceptible, downslope movement of masses of surficial material or bedrock by creeping, flowing, or sliding; slow slope failure.

SLUMP: A landslide characterized by a shearing and rotary movement of a cohesive mass of rock or earth along a concave, upwardly curved, slip surface.

SLUMPING: The slow sliding downslope of a mass of sediment.

SLUMP-EARTHFLOW: A complex landslide displaying characteristics of a slump in its headward zone, and characteristics of an earthflow in its downslope zone.

SLUMP STRUCTURE: Warped or faulted bedding or stratification within a deposit, resulting from downslope movement due to gravity since deposition.

SOIL (biological): The natural medium for growth of land plants; the result of the combined effects of physical, chemical and biological processes.

SOIL (engineering): All unconsolidated earthy material over bedrock.

SOIL CLIMATE: Temperature and moisture conditions within the soil.

SOIL CREEP: Slow (imperceptible) downslope movement of soil.

SOIL DRAINAGE: Refers to the rapidity and extent of water removal from the soil in relation to additions, especially by surface runoff and by percolation downwards through the soil.

SOIL HORIZON: A zone in the soil (biological definition) that is generally parallel to the land surface and distinguished from zones above and below by characteristic physical properties, such as colour, structure and texture, and soil chemistry.

SOIL MOISTURE: The water content of the soil in its natural state.

SOIL PIT: A pit excavated for the purpose of examining the soil, most commonly dug by hand using shovels, and usually less than 1 m deep.

SOIL PROFILE: A vertical section of the soil through all its horizons and extending into the parent material.

SOIL SURVEYS: i) Mapping the distribution of soil types; requires air-photo interpretation and fieldwork by soil scientists. ii) Assessing the engineering properties of surficial materials, such as bearing strength and plasticity, at a site or in an area where construction is proposed. iii) Collecting soil or surficial material samples for geochemical analysis for the purposes of mineral exploration.

SOIL TYPE: i) In a general sense, pertains to classes of soil (biological definition) defined according to soil horizons present and horizon thickness. ii) A subclass of the Canadian soil classification system that is no longer in use.

SOLIFLUCTION: Slow downslope movement of moist or saturated, seasonally frozen surficial material and soil.

SOLONETZIC: An order of soils developed mainly under grass or grass-forest vegetative cover in semiarid to subhumid climates. The soils have a stained brownish solonetzic B (Bnt or Bn) horizon and a saline C horizon. The surface may be one or more of Ap, Ah, or Ae horizons. The order includes the Solonetz, Solodized Solonetz, and Solod great groups.

SOLUM (plural SOLA): The upper horizons of a soil in which the parent material has been modified and in which most plant roots are contained. It usually consists of A and B horizons.

SOLUTION: The process of dissolving.

SORTING: A geological term pertaining to the variability of particle sizes in a clastic sediment or sedimentary rock; materials with a wide range of particle sizes are termed *poorly sorted*; material with a small range of sizes is *well sorted*. (Note that these terms are the reverse of the engineering expressions *well graded* and *poorly graded*.

SOURIS GRAVEL: Gravel and sand in southwestern Manitoba that overlie bedrock in buried valleys and contain a higher percentage of quartzite and chert pebbles than typical gravels in the region (Klassen, 1969).

SPRING: A place where groundwater issues from the ground.

STAGNANT ICE: Part of a glacier or ice sheet within which ice is no longer flowing; stationary ice; usually melting by downwasting.

STEEP SLOPE: A planar surface steeper than about 35 degrees (70%).

STONEY: A general term indicating that a material includes a high percentage of coarse clasts (generally >15 cm).

STRAIN: Change in shape or volume of a body as a result of stress.

STRANDFLAT: A wave-cut platform extending along a strandline or shoreline.

STRANDLINE: An abandoned shoreline.

STRATA: Plural of stratum; a series of sheet-like masses or layers.

STRATIFICATION: Horizontal or inclined structure in a sedimentary unit that results from its mode of deposition; includes beds, laminae, abrupt and gradual texture changes, and orientation and concentrations of particles.

STRATIFIED: Formed, arranged, or laid down in layers or strata.

STRATIFIED ROCKS: A rock displaying stratification; sedimentary rock.

STRATIGRAPHIC UNIT: A bed or series of beds with characteristics that differ from those of overlying and underlying materials; a subdivision of a larger sequence of sediments or sedimentary rock.

STRATIGRAPHY: The arrangement, description, and interpretation of bodies of rock in terms of items such as origin, occurrence, thickness, lithology, age, and history.

STREAM DEPOSIT: Materials deposited by running water; generally consist of gravel, sand, silt, and clay and referred to as alluvium.

STRESS: The force per unit area acting on a solid.

STRIAE, STRIATIONS: Fine, cut lines (scratches) on the surface of bedrock or clasts formed by glacial abrasion; oriented parallel to former ice-flow direction; more than one ice-flow direction may be represented by crisscrossing striae.

STRUCTURE: (geological) The three-dimensional arrangement of geological contacts and discontinuities such as bedding, stratification, joints, faults, dikes, plutons, and folds.

SUBCROP: Occurrence of a geological unit underneath an unconformity (e.g. The Pierre Formation occurring below overlying drift).

SUBGLACIAL: Pertaining to the area underneath a glacier or the base of a glacier.

SUBGLACIAL TILL: Material that accumulates directly from melting ice at the base of a glacier; includes basal till and lodgement till.

SUBTILL: Underneath till; can be used in two different ways 1) underlies at least one till and therefore can be assumed to predate at least the last ice advance, 2) underlies all glacial deposits and hence can be assumed to predate the earliest (Pleistocene) glaciation.

SUPRAGLACIAL: Pertaining to the upper surface of a glacier.

SURFACE EXPRESSION: Refers to small topographic features and landforms that are not usually shown adequately on a topographic map, and to the relation of a surficial material to the underlying surface; terminology, such as *terrace*, or *cone*, is defined in a non-genetic sense.

SURFICIAL DEPOSITS: Unconsolidated and residual, alluvial, colluvial, lake, or glacial deposits lying between bedrock and the surface.

SURFICIAL GEOLOGY: Geology of surficial deposits.

SURFICIAL GEOLOGY MAP: A map that shows the distribution of surficial deposits that have been organized into geological units and fitted into a chronostratigraphic framework.

SURFICIAL MATERIAL: Unconsolidated and residual, alluvial, colluvial, lake, or glacial deposits lying between bedrock and the surface.

SURFICIAL SEDIMENT: Unconsolidated and residual, alluvial, colluvial, lake, or glacial deposits lying between bedrock and the surface.

SWALE: A slight depression in the midst of a generally level to gently undulating area.

SWAMPY: Water saturated; intermittently or permanently covered with water, but not having a significant accumulation of organic material.

TALUS: Angular rock fragments accumulated at the foot of a steep rock slope and being the product of successive rock falls; a type of colluvium.

TALUS CONE: A small cone-shaped or apron-like landform at the base of a cliff and consisting of poorly sorted talus that has accumulated episodically by mass wasting.

TALUS SLOPE: A slope of about 35 degrees, the natural angle of rest of non-cohesive rock fragments, and underlain by talus; usually located at the foot of a rock slope that is steeper than 35 degrees.

TDS: Total dissolved solids. The sum of all dissolved minerals present in a water sample. Normally expressed in mg/L.

TENSILE STRESS: A normal stress that tends to cause separation across the plane on which it acts.

TENSION CRACKS: Open fissures in bedrock or surficial materials resulting from tensile stress; typically located at or near the crest of a steep slope, and indicative of potential slope failure.

TEPHRA: A collective term for all pyroclastic sediments; all detrital volcanic materials.

TERMINAL MORAINE: The end moraine that marks the furthest point reached by an advancing glacier.

TERRACE: Any relatively level or gently inclined surface, generally less broad than a plain, and bounded along one side by a steeper descending slope or scarp and along the other by a steeper ascending slope or scarp. The term is generally used for a bench that is cut in valley fill and alluvium .

TERRACED: Either one or several step-like forms, each consisting of a scarp face and a horizontal or gently inclined tread upslope.

TERRAIN FEATURES: Landforms and related phenomena, such as striations, gravel pits, and fossil sites, shown on a terrain map by on-site symbols.

TERRAIN MAP: A map showing surficial materials, their texture, surface expression, present-day geomorphological (geological) processes, and other features.

TERTIARY: A formal geological time term. The period of geological time which extended from about 66 to 1.65 million years ago.

TEXTURE: Pertains to the grain sizes, shape, and arrangement of particles in a sediment.

THRUST MORAINE: A moraine formed by the overriding and pushing forward of a glacier. In many cases, the term is used to refer to stacks of thrust sheets of drift and bedrock that are piled up by advancing ice.

TILL: Material deposited by glaciers and ice sheets without modification by any other agent of transportation. *See also* basal till, lodgement till, ablation till, flow till, melt-out till.

TOR: A small castellated hill of bedrock with open joint planes rising abruptly from a relatively smooth hilltop or slope; commonly surrounded by fallen blocks.

TRANSGRESSION: Spread of a sea over a land area.

TRANSLOCATION: Act of changing location; displacement.

TREELINE: The elevation or latitudinal limit at which tree growth stops.

TURBIDITY CURRENT: A density current caused by different amounts of matter in suspension: a bottom current in a body of water that is laden with suspended sediment.

UNCONFORMITY: A substantial break or gap in the geological record where a rock unit is overlain by another that is not next in stratigraphic succession, such as an interruption in the continuity of a depositional sequence of sedimentary rocks or a break between eroded igneous rocks and younger sedimentary rocks.

UNCONSOLIDATED: Loosely arranged, not compacted or cemented.

UNDULATING: Gently sloping hillocks and hollows with multidirectional slopes generally up to 15 degrees (26%), slopes relatively short (generally <0.5 km) and with local relief generally < 10 m.

UNIFIED SOIL-CLASSIFICATION SYSTEM: Soil classification used by engineers; based on particle size of coarse materials and consistency of fines (silt/clay mixtures).

UPLAND: An extensive area of relatively elevated land.

UTM: Universal Transverse Mercator grid; present on most topographic maps and used for quantitative description of locations. In this system the world is divided into a series of zones, and points are located according to grid co-ordinates (eastings and northings) in each zone. Manitoba and eastern Saskatchewan lie in zone 14.

VALLEY: An elongate, relatively large, gently sloping depression of the Earth's surface often containing a stream and commonly formed by stream erosion.

VALLEY FILL: Surficial materials that fill or partly fill a valley.

VALLEY GLACIER: Glacier confined by valley sides; usually much longer than broad.

VARVES: Sedimentary beds or laminae where annual layers are distinguishable; most commonly present in glacial lacustrine and lacustrine sediments.

VENEER: A thin mantle of surficial material that does not mask the topographic irregularities of the surface upon which it rests; ranges in thickness from 10 cm to about 1 m.

VISCOUS MEDIUM: A material that does not readily flow.

VOID RATIO: The ratio of the volume between grains (void space) to the volume of the grains.

VOLCANIC ASH: Pyroclastic material less than 2 mm in size.

VOLCANIC CINDERS: Uncemented volcanic fragments of various sizes (generally 4–32 mm).

VOLCANIC MATERIALS: Any of the materials resulting from the various processes of volcanism.

VOLCANISM: The process by which molten rock and its associated gases rise into the crust and are extruded onto the Earth's surface and into the atmosphere.

VOLCANIC GLASS: A natural glass produced by the cooling of molten lava or a liquid fraction of it, too rapidly to permit crystallization.

VOLCANIC VENT: An opening in the Earth's surface through which volcanic materials move.

WASHBOARD MORAINE: Terrain crossed by a series of subparallel, small, regularly spaced morainal ridges that are oriented transverse to the ice movement; collectively they resemble corrugations.

WASHED TILL: Till that has been modified by washing (removal of fines by the action of waves or running water). As a result of washing, a lag deposit commonly overlies unmodified till.

WASHING: Removal, of fines from a surficial material due to the action of waves or running water; winnowing; results in the formation of lag deposits.

WASHING LIMIT: The extreme margin at which washing has occurred. Where washing is due to wave action, this limit is used to define the extent of a former lake.

WATER QUALITY: A general term indicating the suitability of a water source for a particular use such as drinking, supporting aquatic life, etc.

WATER TABLE: The upper surface of the zone of groundwater saturation in permeable rocks or surficial materials.

WATER YIELD: The rate at which water can be obtained from a well. This is a general term and does not necessarily refer to the long-term capability of a well to supply water nor the maximum rate of water production which the well can support.

WEATHERING: The decomposition and disintegration of bedrock in situ due to chemical and physical processes.

WEATHERED BEDROCK: Bedrock that has decomposed or disintegrated in place due to mechanical and/or chemical weathering.

WELL GRADED: An engineering term referring to a material that has a continuous gradation of particle sizes (smaller particles fit into the spaces between the larger). It is equivalent to the geological term *poorly sorted*.

WELL SORTED: Material with a small range of sizes (this is equivalent to the engineering expressions *poorly graded*).

WENTWORTH PARTICLE-SIZE SCALE: A logarithmic scale for size classification of sediment particles; defines terms such as sand, silt, pebbles, and boulders.

WELL WASHED: A term indicating that fines are not present.

WELL STRATIFIED: Said of materials that are well washed, well sorted, and have well defined bedding.

XEROPHYTES: Plants that grow in or on extremely dry soils or soil materials.

ZONE OF SATURATION: A subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere.

ANNOTATED BIBLIOGRAPHY OF GLOSSARIES

The following references contain glossaries relevant to surficial geology.

Bates, R.L. and Jackson, J.A. (ed.)
1980: Glossary of geology; American Geological Institute, Falls Church, Virginia, 751 p. (second edition).

The most comprehensive dictionary of geological terms covering most terms in use by surficial geologists. This publication is a standard reference for all geologists.

Bird, J.B.
1980: The natural landscapes of Canada; John Wiley and Sons, Toronto, Canada, 260 p.

The text provides very brief definitions for more than 150 terms. Basic geology, geomorphology, and terms emphasizing conditions unique to northern environments comprise this glossary.

Birkeland, P.W. and Larson, E.E.
1989: Putnam's geology; Oxford University Press, Toronto, 646 p.

Definitions for approximately 600 general geology terms are included in this text. The text and glossary are aimed at a individuals with an undergraduate level understanding of geology.

Canada Soil Survey Committee
1976: Glossary of terms in soil science; Research Branch, Canada Department of Agriculture, Publication 1459, 44 p.

Definitions, with Canadian conventions, of about 1000 terms commonly used in soil science and surficial geology. A French version of this glossary is also available.

Catto, N.R.
1988: Geology 482 field and laboratory manual; Quaternary Research Group, University of Alberta, Edmonton, 215 p.

This text provides detailed definitions for over 300 terms of direct interest to Quaternary geology, surficial mapping, and sedimentology. Explanations are lengthy, accurate and useful to those individuals with a significant background in geology. Highly recommended source of information which may be difficult to obtain.

Cormier, C.
1992: Canadian Quaternary vocabulary; Canada Communication Group, Ottawa, Terminology Bulletin 209, 154 p.

This book is a bilingual terminological publication meant to accompany the Quaternary Geology of Canada and Greenland text. Although the publication covers a number of terms and concepts that deal specifically with North American Quaternary geology, about half are not defined but simply presented in both languages.

Gartner, J.F., Mollard, J.D., and Roed, M.A.
1981: Ontario engineering geology terrain study users' manual; Ontario Geological Survey, Ministry of Natural Resources, Toronto, 51 p.

The text provides short, accurate and informative definitions for over 100 terms unique to Quaternary geology and surficial mapping. The explanations are written in simple English suitable for individuals with limited geological training. It is a highly recommended source of information to those interested in mapping terminology.

Howes, D.E. and Kenk, E.
1988: Terrain classification system for British Columbia; British Columbia Ministry of Environment, Recreational Fisheries Branch, and Ministry of Crown Lands, Surveys and Resource Mapping Branch, MOE Manual 10, 90 p.

This publication provides short definitions for 76 terms of importance to surficial geology mapping. Most of the definitions are abbreviated from *The Glossary of Geology* and are incorporated into the glossary provided above.

Keser, N.
1979: Interpretation of landforms from aerial photographs; Research Branch, Ministry of Forests, Victoria, British Columbia, 271 p.

The text provides 10 separate glossaries following thematic chapters devoted to air-photo interpretation. Numerous terms and lengthy definitions comprise the publication. The compilation is useful for consultation in surficial geology.

Kupsch, W.O. and Rutter, N.W.
1982: Mineral terrain terminology; National Research Council of Canada, Ottawa, Technical Memorandum No. 131, 153 p.

This publication provides over 1500 definitions devoted to surficial geology and mapping. It is intended for non-geologists interested in terrain and landform studies who require easy access to technical literature. Accompanying illustrations clarify many of the terms. The text is highly recommended for all users of surficial geology information.

Mollard, J.D.
1982: Landforms and surface materials of Canada. Commercial Printers Ltd., Regina, 410 p. (sixth edition).

Over 2500 terms in the glossary relevant to several disciplines including geology, biology, forestry and pedology. All definitions are lengthy and useful to those with a minor understanding of geology.

Mollard, J.D. and Janes, J.R.
1984: Air photo interpretation and the Canadian landscape; Energy Mines and Resources Canada, Ottawa, 413 p.

Approximately 600 definitions of terms of direct relevance to air-photo interpretation and landform analysis. Many of the entries are of use in the field of surficial geology. The compilation is an updated and shortened version of the earlier version by Mollard.

Sharp, R.P.
1991: Living ice, understanding glaciers and glaciation; Cambridge University Press, New York, 225 p.

The glossary consists of about 400 entries which cover both general geology and terms primarily applicable to glaciology. Many of the terms included are also of direct relevance to surficial geology. The brevity of the definitions makes this compilation of primary use to individuals with limited knowledge in geology

ADDITIONAL REFERENCES CONTAINING USEFUL DEFINITIONS

ASTM Committee E-8 on Nomenclature and Definitions
1976: Compilation of ASTM standard definitions; American Society for Testing and Materials, (ed.) Easton, M.D., 731 p. (third edition)

Fairbridge, R.W. (ed.)
1968: The encyclopedia of geomorphology; Reinhold Book Corporation, New York, Encyclopedia of Earth Sciences Series, Volume III, 1295 p.

Luttmerding, H.A. Demarchi, D.A., Lea, E.C., Meidinger, D.V., and Vold, T. (ed.)
1990: Describing ecosystems in the field; British Columbia Ministry of Environment and Ministry of Forests, MOE Manual 11, 213 p. (second edition)

Paine, D.P.
1981: Aerial photography and image interpretation for resource management; John Wiley and Sons, New York, 571 p.

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1978: Landslides, analysis and control; Special Report 176, (ed) R.L. Schuster and R.J. Krizek, National Academy of Sciences, Washington, D.C., 234 p.

Washburn, A.L.
1973: Periglacial processes and environments; Edward Arnold Ltd., London, England, 320 p.

Whittow, J.B.
1984: Dictionary of physical geography; Penguin Books Ltd., Middlesex, England, 591 p.