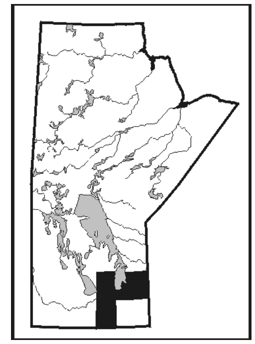
GS-28 **GEOLOGY OF THE WINNIPEG REGION NATMAP PROJECT (NTS 62H/W, 62I AND 52L/W)**



by G.L.D. Matile, L.H. Thorleifson[1], N. Grant[2], A. Burt[3], and J. Mann[2]

Matile, G.L.D., Thorleifson, L.H., Grant, N., Burt, A. and Mann, J. 1998: Geology of the Winnipeg region NATMAP project (NTS 62H/W, 62I and 52L/W); **in** Manitoba Energy and Mines, Geological Services, Report of Activities, 1998, p. 161-171.

SUMMARY

Under the auspices of the National Geoscience Mapping Program (NATMAP), Manitoba Geological Services Branch (MGSB) and Geological Survey of Canada (GSC) are cooperating in the completion of 3D geological mapping in the Winnipeg Region, from 49° to 51° N, and from 95° to 98° W. Emphasis is on engineering and environmental geology, surficial geological mapping, and linkage to bedrock mapping initiatives in the area. Mapping of the area southeast of the City of Winnipeg was completed under a first phase of investigations between 1991 and 1996. Coverage of the expanded study area is scheduled for completion in the year 2000.

INTRODUCTION

The NATMAP program was established by Canada's federal, provincial, industry, and academic geoscience community in 1990 to promote multidisciplinary, cooperative, computer-based programs of new geological mapping, that include opportunities to address mineral resource development, environmental and societal concerns, as well as fundamental geological knowledge, along with ensuring the training of student geologists in mapping procedures (St-Onge, 1990).

Under the Prairie NATMAP project, initiated in 1991, new 1:100,000 surficial geology maps were completed (Figure GS-28-1) for the Whitemouth Lake area (52E/SW; Matile and Thorleifson, 1995), the Falcon Lake area (52E/NW; Matile and Thorleifson, 1996a), the Steinbach area (62H/NE; Matile and Thorleifson, 1996b) and the St. Malo area (62H/SE; Matile and Thorleifson, 1996c). This work included synthesis of data previously collected by the former Aggregate Resources Section of Manitoba Energy and Mines, Mines Branch. Also included was a till geochemical and indicator mineral survey, based on surface till sampling and coring of the Quaternary sequence at 23 sites (Thorleifson and Matile, 1993).

Under the current Winnipeg NATMAP project (1997-2000), similar mapping and glacial sediment sampling is being completed, in the following areas: Morris (62H/SW), Winnipeg (62H/NW), Stonewall (62I/SW), Arborg (62I/NW), Selkirk (62I/SE), Pine Falls (62I/NE), Pinawa (52L/SW), and Nopiming (52L/NW).

The objectives of this expanded, Winnipeg-region NATMAP project are: 1) to obtain an enhanced understanding of the environmental framework and geological history of the Winnipeg region, through the synthesis of available information and collection of new field data, and to communicate this knowledge to users primarily in the form of new, computer-based geological maps; 2) to make major strides in understanding geological features such as the Belair/Sandilands glaciofluvial complex; 3) to further the establishment of a Winnipeg- and Ottawa-based infrastructure for the rapid production of high-quality, interactive digital cartographic products; 4) to support the training of field geologists in the production of new maps; 5) to facilitate mineral exploration, particularly in the exposed shield east of the Winnipeg River, by producing new geological and geochemical maps of the area; 6) to provide an upgraded information base designed to support construction and other engineering activity; 7) to better define geological factors that control the quantity, quality, and long term sustainability of groundwater resources in the Winnipeg region; 8) to support efforts to manage the Lake Winnipeg basin, by interpreting the evolution of the lake in recent geological time, and the role played by geology in controlling shoreline erosion; and 9) to support environmental and land use management, by mapping the composition and extent of lithological units that are relevant to issues such as waste disposal, soil geochemistry, and vulnerability of aquifers to contamination.

Fieldwork for the second phase was initiated by a seven-person team during the summer of 1997, at which time data were collected in the Winnipeg area under the direction of G. Matile of MGSB, in the Stonewall area by N. Grant of the University of Manitoba, and in the Selkirk area by A. Burt of the University of Waterloo. In the summer of 1998, systematic data collection was completed, in the Morris area by Matile, the Arborg area by Grant, and the Pine Falls area by Burt. In addition, systematic coverage of both the Pinawa and Nopiming areas was completed during the summer of 1998 by J. Mann of the University of Manitoba. Air photo interpretation and digital production of surficial geological maps is now underway. Final follow-up field investigations are planned for the summer of 1999.

Mapping of the Quaternary sediments in the study area will be extended into the subsurface, using drillhole data and geophysical surveys, in order to obtain a 3D model. In addition to new drilling, modelling will be based on available existing databases including: the Manitoba Stratigraphic Database (MSD) managed by MGSB; the water well database held by Manitoba Water Resources Branch (GWDrill); and an engineering drillhole database originally compiled in the early 1970's by the City of Winnipeg and the GSC.

Surficial geological mapping in the Winnipeg region is being coordinated with the MGSB Capital Region study; an effort to upgrade mapping of the Phanerozoic sequence in the Winnipeg area, and to inventory extractable industrial mineral resources. On the shield to the east, work will be coordinated with digitizing of available Precambrian geological maps.

Surficial geological mapping has progressed to a stage in which the following descriptive summaries of the geology may be provided.

Morris/Winnipeg area

The Morris and Winnipeg map areas cover much of what is commonly known as the Lake Agassiz clay plain that represents the offshore lake bottom deposits of glacial Lake Agassiz. Hence the area is nearly flat, with elevations rising gently eastward and westward from the Red River, at a rate that begins at less than 1 m/km and increases away from the river. Subtle landforms within the Lake Agassiz clay plain include flutes and iceberg scours. Just southwest of Winnipeg, fluted clay forms with up to 3.5 m of local relief, oriented northwest to southeast, are formed by clay draped over a fluted till surface 5 to 10 m below (Teller et al., 1996). Drainage in the area, including the Morris River, is governed by this subtle ridge and swale topography. Iceberg scours formed in Lake Agassiz, with up to 1 m of local relief, occur throughout the area. These curvilinear ridges are up to 10 km in length, and comprise a former groove in the clay that was infilled with clayey silt, followed by topographic inversion during dewatering and differential compaction (Nielsen and Matile, 1982; Woodsworth-Lynas and Guigne, 1990). Nearly the entire area is utilized for agriculture. Crops such as cereal grains, flax, canola, sunflowers and beans are the principal land cover.

Depth to bedrock increases to the southwest, from virtually zero in the northwestern part of the City of Winnipeg, to >120 m in the Winkler area (Teller et al., 1976). The northern half of the area is underlain by Devonian, Silurian and Ordovician carbonate rocks, and the southern half by an eastward-trending, channel-fill-like tongue of Jurassic shale, limestone, sandstone and evaporites (Manitoba Energy and Mines, 1990).

Industrial mineral extraction is, or has been, active within the map area at several sites. Aggregate to the west of the area typically is high in shale, and thus dramatically decreases the quality and potential end uses, where as aggregate within the area, to the east, and to the

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8
[2] Department of Geological Sciences, University of Manitoba, Wallace Building, Winnipeg, Manitoba, R3T 2N2
[3] Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, N2L 3G1

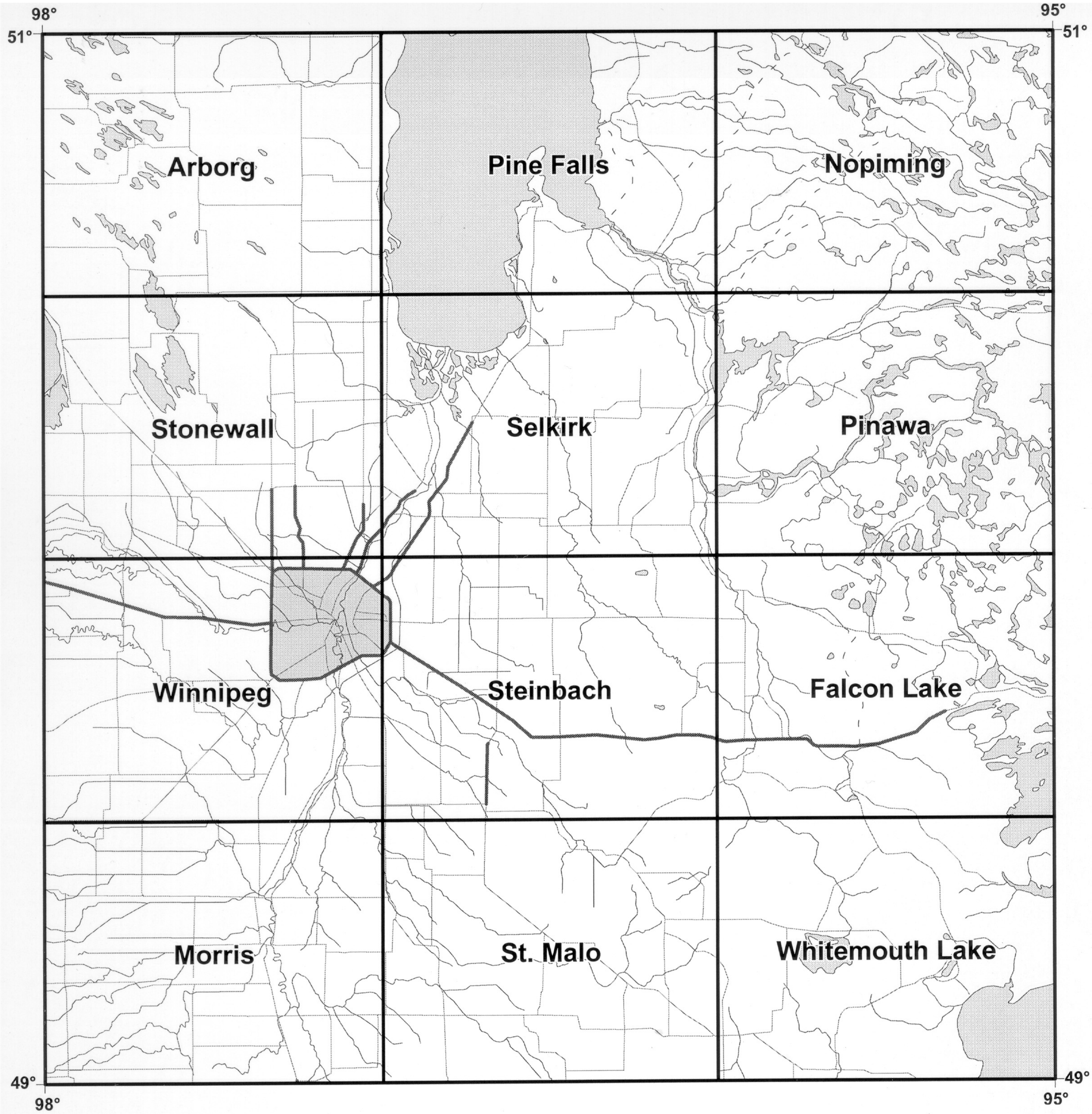


Figure GS-28-1: Index maps showing named 1:100 000 surficial geological map areas within the NATMAP project area.

north contains only trace amounts of shale and is generally of higher quality. Four aggregate pits occur 3 to 8 km east of Morris, on an anomalous topographic high. Two of these pits were active in 1998. Other isolated aggregate pits occur in southeastward-trending eskers, 2 km north-northeast of St. Francois Xavier, 5 km northeast of Elie, and in north-western Winnipeg, near the junction of Inkster Boulevard and Route 90. A rehabilitated pit in the west end of the Birds Hill esker complex extends into the area, at the town of Birds Hill. Although there is an active aggregate pit in what is commonly known as the Winkler Aquifer, approximately 1 km west of the study area and just north of Winkler, there is no surface expression of this deposit in the map area. Abandoned limestone quarries are located in northwest Winnipeg at Little Mountain Park. Clay pits, in southwest Winnipeg, at Fort Whyte are currently being used for the production of cement. An underground gypsum mine was active near Aubigny from 1964 to 1974.

Several studies have been conducted on fine-grained Lake Agassiz glaciolacustrine sediments in the area. Mineralogy and stratigraphy of these sediments was reported by Last (1974) and Teller (1976), hydrogeochemistry by Day (1977), Mkumba (1983) and Pach (1984), soil mechanics by Mishtak (1961) and Wicks (1965). Stratigraphic investigations that extended to the underlying till were reported by Teller and Fenton (1980) and Fenton et al. (1983).

Collection of mapping data and sediment samples in the Winnipeg map area (Fig. GS-28-1) was completed by G. Matile and assistants between June 3 and September 10 in 1997, and in the Morris map area from June 3 to July 31 in 1998. A network of section roads at one-mile intervals provides good access to virtually any point in the area (Fig. GS-28-2). Paved and gravel-surface roads are passable in all conditions, but in wet conditions numerous unsurfaced farm-access roads are impassable with a two-wheel drive vehicle.

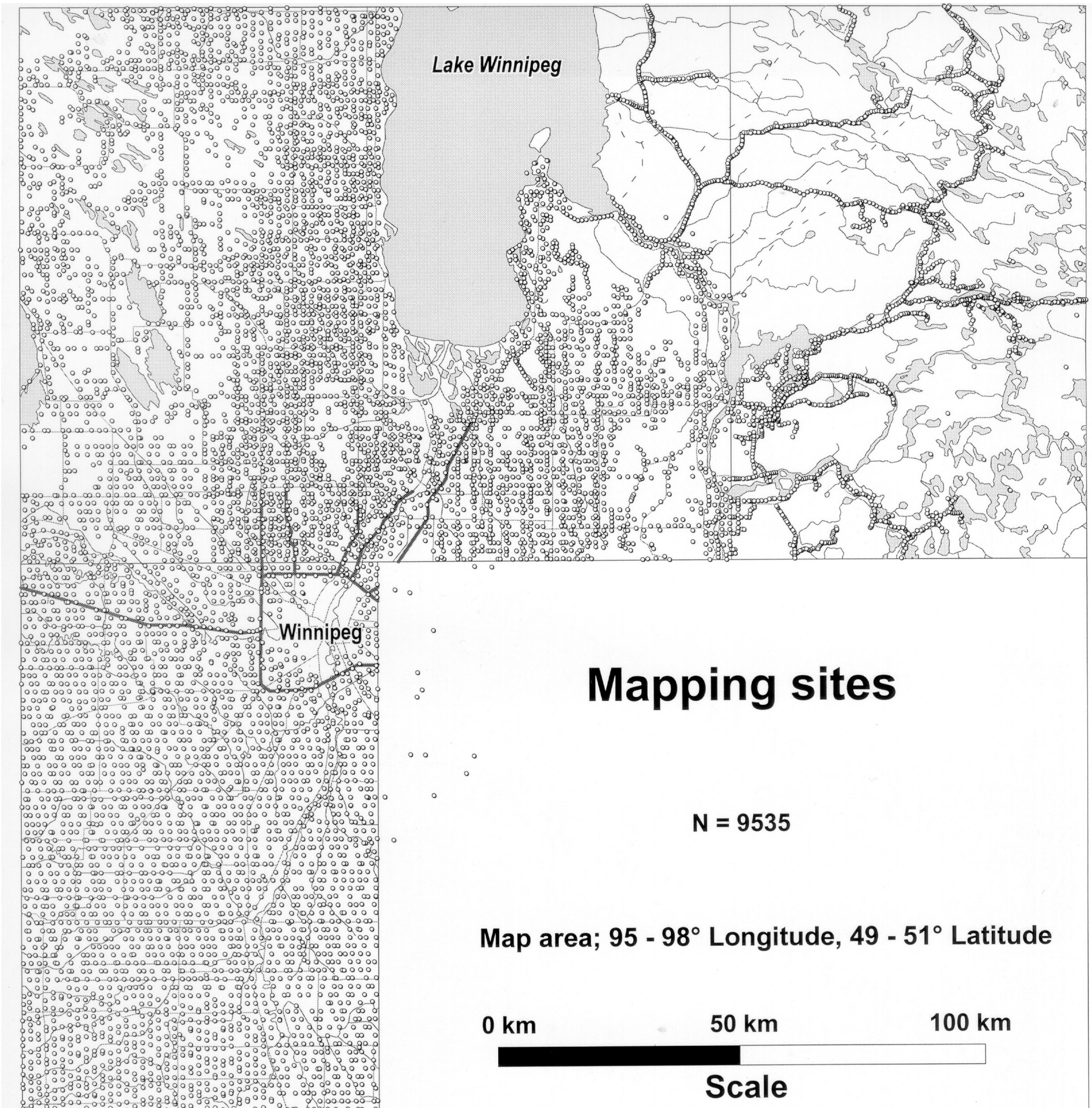


Figure GS-28-2: Field observation site locations, 1997 and 1998.

Mapping data were collected at an average spacing of 1.6 km, at a randomly chosen point 0.4, 0.8, 1.2 or 1.6 km into each cell, as defined by the one-mile-square legal survey sections. At each site, a hole was augered by hand to 1 m. Site and sediment descriptions were entered on a paper form in 1997, however, in 1998, a hand-held computer was used to directly enter data into a database on site. In 1997, a total of 1533 sites were logged, 1998 the total was 1317 sites. Aerial photographs at a scale of 1:56 000, dating from 1980 and 1981, are used in stereo to extrapolate from data collection sites and construct geological maps. Given the difficulty that would be encountered by any attempt to obtain systematic data in the City of Winnipeg, information for this area is being obtained from a geotechnical drillhole database originally compiled for the GSC and the City of Winnipeg by Reid, Crowther and Partners Limited (1972).

In addition to mapping data, a regional sampling program was carried out in order to assess the physical, mineralogical and geochemical characteristics of the major sediment types within the region. Sampling in both the Winnipeg and Morris map areas was completed in 1997. A total of 6 samples of till, 98 of fine-grained Lake Agassiz glaciolacustrine sediment, 10 of Red River alluvium and 26 of 1997 flood alluvium were collected. Samples of till (Fig. GS-28-3) and fine-grained Lake Agassiz sediments (Fig. GS-28-4) that occur at or near surface were collected at a 10 km spacing. Till samples approximately 11 litres in volume were collected from a depth of approximately 1 m. Fine-grained clay/silt samples, approximately 0.2 litres in volume, were recovered from depths of 0.3 and 1.0 m. Where present samples of alluvium were also collected, at a 10 km spacing. Along the Red River, alluvial sediments were sampled at depth of 0.3 and 1.0 m. However, within the area flooded in 1997, freshly deposited alluvium was sampled at surface.

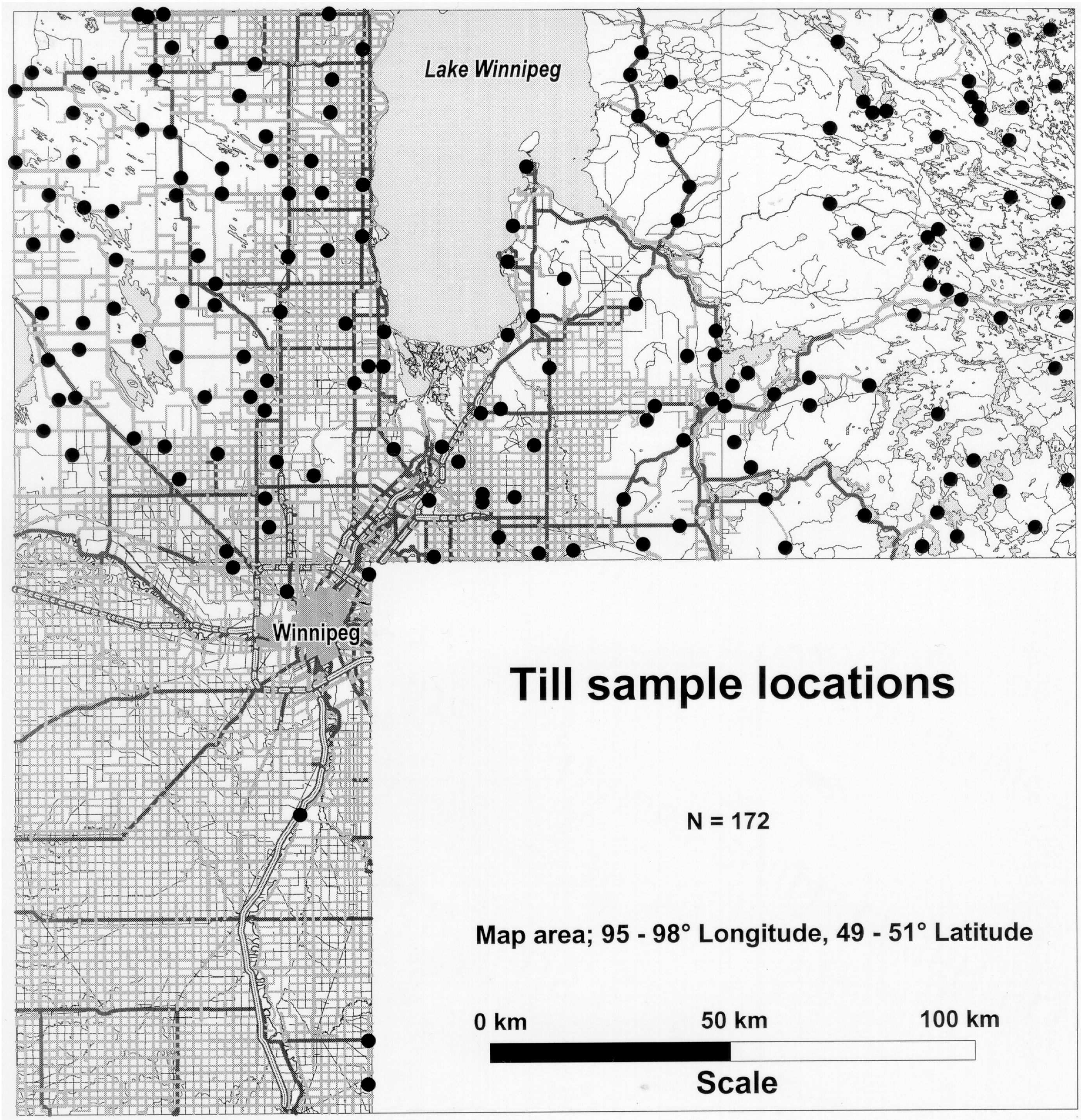


Figure GS-28-3: Till sample locations.

Silt diamict, generally considered till of northwestern provenance, underlies the glaciolacustrine clay throughout the area. The upper portion of the diamict sequence, however, typically is intercalated with glaciolacustrine clay, likely a result of deposition as debris flows on the lake floor, as well as shear and ploughing by icebergs (Matile, 1984). Small outcrops of silt till occur in northwestern Winnipeg and southeast of Dominion City, along the eastern edge of the map sheet. Small outcrops also occur along the banks of the Red River, north and south of Ste. Agathe and along the banks of the Assiniboine River in western Winnipeg. Till is also likely to be observed near or at surface adjacent to and within aggregate pits. Glaciofluvial sediments are present at surface or near surface, in several areas as indicated by aggregate pits, but these deposits are not exposed as geomorphic features within the landscape. These deposits consist of carbonate-rich sand, gravelly sand, and gravel.

Fine-grained glaciolacustrine sediment occurs throughout the area. These sediments generally thicken to the southwest, from <10 m at Winnipeg to >45 m at Winkler. At 7% of the sites in the Winnipeg map area, and 23% of the sites in the Morris map area, the massive clay to silty clay that occurs throughout the area is overlain by laminated silt to clayey silt, which typically is a much lighter colour than the clay. Near Winkler, glaciolacustrine fines are discontinuously overlain by littoral

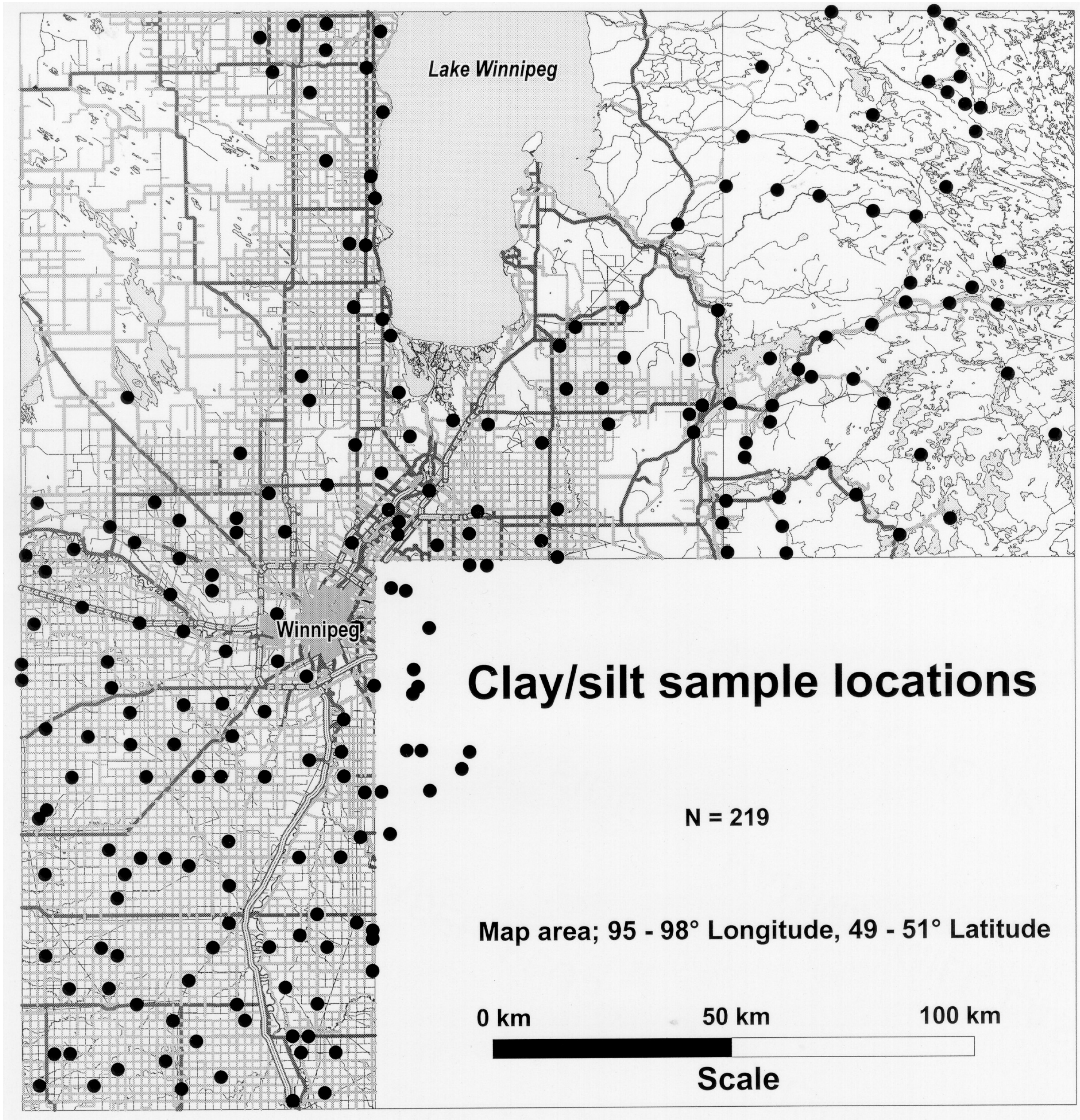


Figure GS-28-4: Fine-grained sediment sampling locations.

sand and silt. Clusters of authigenic selenite crystals, one to a few millimetres across, commonly occur in the upper metre of the fine-grained glaciolacustrine sediments, although coarser crystals are known to occur at greater depth (Fig. GS-28-5; Matile and Betcher, 1998). The distribution of these crystals, which were diligently noted, is non-random, and thus indicated regional variation in the controls on their formation. Near the southwestern corner of the area, selenite crystals occur between two minor Lake Agassiz shorelines that trend parallel to the Manitoba Escarpment, at elevations of about 265 and 275 m. These shorelines are generally erosional and associated with only minor sand and gravel deposits.

Alluvial sediments occur in a large fan that marks the position of former Assiniboine channels near Portage la Prairie, as well in terraces <15 m thick formed along the Red River. The Portage la Prairie fan consists of radiating ridges of alluvium, that reflects repeated cycles of aggradation and avulsion (Rannie et al., 1989). In the map area, these sediments comprise of laminated clayey silt, sandy silt and, rarely, sand. Eolian sand was transported eastward into the area from the distal margin of the Assiniboine Delta during the mid-Holocene (David, 1971). Stabilized sand dunes occur near Elm Creek. Organic deposits are of limited extent within the area. Several marshes remain, but many more have been drained in order to utilize the land for agriculture.

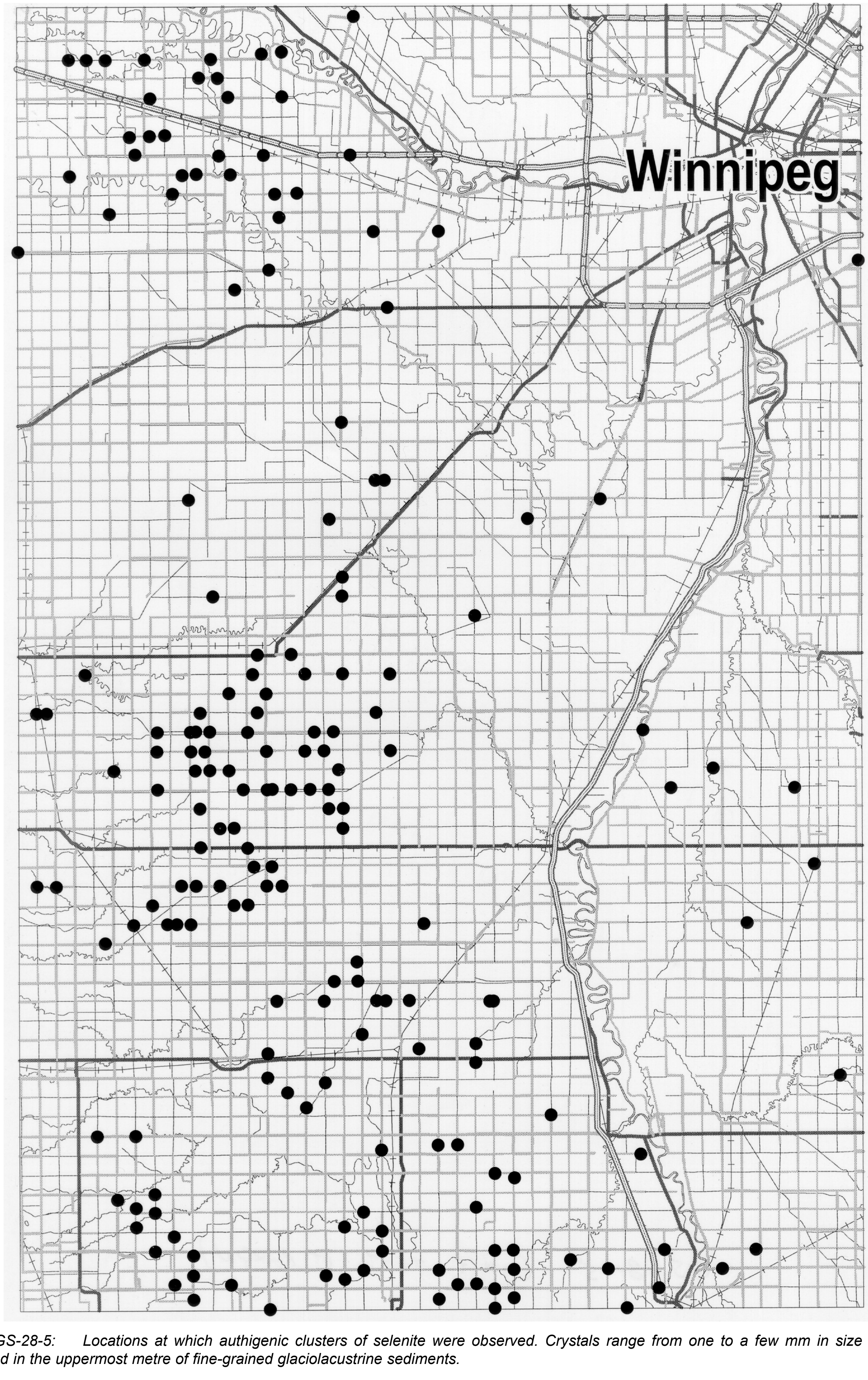


Figure GS-28-5: Locations at which authigenic clusters of selenite were observed. Crystals range from one to a few mm in size and were observed in the uppermost metre of fine-grained glaciolacustrine sediments.

Stonewall/Arborg area

The Stonewall and Arborg map areas include the southernmost portion of the streamlined till plain of the Interlake, as well as the northernmost portion of the Lake Agassiz clay plain. Topography is gently undulating, with no prominent relief features. Highest elevations, at about 275 m, are along a drainage divide parallel to, and midway between, Lakes Manitoba and Winnipeg. The land surface slopes west to Lake Manitoba, at 248 m, and east to Lake Winnipeg, at 217 m. Arcing from the southwest corner of the area to the east, and then to the north, are a series of strandlines and glaciofluvial deposits. These mark the break between the till plain to the north and west and the clay plain to the south and east. The till plain is characterized by a thin, almost continuous cover of sediments, dominated by silt diamict (till), that range in thickness from <1 m to 30 m (Betcher, 1986), largely in relation to the irregular bedrock surface. The till plain is strongly streamlined into regional-scale fluting that has a northwest to southeast orientation. Individual fluting ridges are up to 10 km long, 1 to 2 m above intervening depressions, and irregular in plan view, although considerable variability exists. The ridges lie across the direction of regional slope, and produce a significant barrier to drainage. Where till occurs at surface, the combination of thin, stoney soils, high alkalinity and salinity, and poor drainage limits agriculture to livestock operations (Pratt et al., 1961). The clay plain slopes gently toward Lake Winnipeg. The eastern part of the area is drained by the Icelandic River, Netley Creek and Wavey Creek, all of which have their headwaters at the edge of the till plain and drain into Lake Winnipeg. In the south, an extensive drainage network ultimately drains into the Red and the Assiniboine Rivers. The clay plain is almost entirely cultivated. Grains, canola, and hay are the primary crops. Groundwater discharge is an important surface water process, and is the primary source of water for the Shoal Lakes, the largest lakes within the area (Goff, 1971).

Paleozoic Devonian, Silurian, and Ordovician carbonate underlie the entire area. The most prominent surface expressions of the irregular bedrock surface are large outliers of the upper portion of the Ordovician sequence at Stonewall and Stony Mountain that reflect surface exposure of a buried Silurian, and bedrock controlled ridges on the western edge of Lake Winnipeg.

Rock quarries are located at Stonewall, Stony Mountain, Gunton, north of Teulon, and northwest of Winnipeg. Only the Stonewall quarries are presently active. Broad areas of near-surface bedrock extend along a north to south line between Broad Valley and Inwood. Most gravel extraction is associated with Lake Agassiz beaches, as well as scattered glaciofluvial deposits that tend to be small and shallow.

The Quaternary geology of the area has been described by Groom (1985), and by Nielsen (1989), who recognized two till units referred to as the Inwood Till and the overlying Komarno Till, both of which may occur at surface.

In the east half of the area, road access is almost complete at one-mile intervals, but in the west half, large areas have no road access due to the presence of wetlands. Field data collection was completed by N. Grant and assistant in the Stonewall map area between June 3 and September 5, 1997, and in the Arborg area from May 20 to August 14, 1998. In addition, data were collected from portions of the Selkirk and Pine Falls map areas west of the Red River and Lake Winnipeg. Systematic descriptions of near-surface sediments were obtained by hand augering to a 1 m depth at 1654 sites in 1997, and 1507 in 1998. Using the township grid roads, data sites were selected randomly within each east-west and north-south mile road.

Striations were recorded at 21 sites, 9 of which showed multiple ice flow directions toward the south, southwest and west. In 1997 till sampling was carried out over both map areas. Seventy four till samples of approximately 11 litres each were collected at a 10 km spacing, from a depth of about 1 m. Till clasts larger than 16 mm were rejected in the field. Samples of glaciolacustrine fines (approximately 0.2 litres by volume) were collected at depths of both 0.3 m and 1.0 m. A total of 39 sites were sampled, 22 in 1997 and 17 in 1998. An elevation survey, using differential carrier-phase global positioning system methods, was completed to determine the elevation of all Lake Agassiz strandlines. Backhoe excavations were used to examine diamict sequences at several sites. Aerial photographs at a scale of either 1:50 000 or 1:56 000, taken in 1989 and 1994 respectively, are used to complete the mapping.

Silt diamict, most of which probably was deposited as basal till, dominate sediments of the area, and are of northern- and northwestern-provenance, with a minor lithological component derived from the Canadian Shield. The till plain was subjected to scouring by icebergs, in Lake Agassiz, to produce intersecting, curvilinear grooves, with 1-2 metres of relief. Glaciofluvial deposits consist of a few eskers in the Teulon area. These are oriented northwest to southeast, and are truncated at their down-flow ends by beach ridges. Thin patches of coarse gravel deposits occur throughout the area, typically on the edges of depressions. Within the clay plain, buried eskers are oriented west to east and northwest to southeast. Outcropping or near-outcropping inliers of these deposits have largely been removed for aggregate.

The clay plain across the southern portion of the Stonewall map area is the northern edge of the thick Lake Agassiz deposits (10-40m) that extend throughout the Red River valley. The clay plain extends to the western shore of Lake Winnipeg and north to the Icelandic River lowland in the vicinity of Arborg and Riverton. These deposits are low relief and level, except where broad ridges are formed by topographic highs on the bedrock and till surface. The sediments range from clay to silt to sand and are extensively reworked by icebergs. The scours occur as ridges where grooves in clay were infilled with silt. Iceberg scour has produced a complex assemblage of glaciolacustrine deposits and diamicts.

Organic deposits are widespread and generally less than 1 m thick. These are typically localized in fluting depressions that contain perennial water in the till plain. In the clay plain, former marshes have mostly been drained, the largest remnant is Oak Hammock Marsh. There is an extensive network of drainage channels, and the few natural small creeks that have their headwaters in the till plain. They generally lack significant alluvial deposits. Significant alluvial deposits are, however, associated with the Assiniboine River.

Selkirk/Pine Falls Area

The Selkirk and Pine Falls map areas are composed of various landscape elements including extensive fluted till plain, the northeastern extension the Lake Agassiz clay plain, the lower Red River and Netley Marsh, the south basin of Lake Winnipeg, prominent glaciofluvial complexes and exposed shield to the northeast. The area lies between elevations of 218 and 310 m asl. South and west of the Winnipeg River, the Belair and Milner Ridge moraine complexes form two north-south trending topographic highs that rise up to 60 m above surrounding terrain. These moraines have steep northern slopes and gentle southern slopes. An additional glaciofluvial complex exhibits significant local relief and is located at Birds Hill. The clay/till plain is fluted in the Beausejour area. North of the Winnipeg river, Precambrian bedrock outcrops have local relief that rarely exceeds 5 m. Land use within the map area consists of agriculture on the clay/till plain south of Lake Winnipeg and along the Winnipeg River, recreational use along lake shores and seasonal logging in the remainder of the region.

To the east the bedrock geology consists of Precambrian English River Subprovince gneisses and migmatites. From the east shore of Lake Winnipeg west, the Precambrian basement is overlain by southwest-dipping Ordovician Winnipeg Formation sandstone and shale and Ordovician Red River Formation limestone and dolomite (Manitoba Mineral Resources Division, 1979).

Active rock quarries at Garson produce limestone that is marketed as Tyndall stone and granite is quarried near Lac du Bonnet. Glaciofluvial deposits and Lake Agassiz beach ridges are currently exploited for gravel and sand, from active pits at Victoria Beach, Traverse Bay Trading Post, Gull Lake, Milner Ridge, Seddon's Corner, Beausejour and Birds Hill. In addition, there are numerous inactive pits throughout the southern portion of the map area. Peat extraction is active east of Seddon's Corner.

Previous investigations of the Quaternary geology of the area include the work of McPherson (1968; 1970), Lebedin (1978), Matile (1984; 1994), Matile and Conley (1980), and Matile and Groom (1983; 1987). Soils of the area were mapped by Smith and Ehrlich (1967).

Carbonate rocks rise to within 2 m of the surface in the vicinity of Garson and Tyndall. There are extensive areas of Precambrian outcrops north of the Winnipeg river, some of which have been streamlined into roches moutonnées by glacial action. Only a few Precambrian outcrops occur between the Winnipeg River and the Phanerozoic limit. Due to surface weathering, glacial striations were observed at only 10 sites. These range in orientation from 225° to 257°.

Mapping, data collection and sediment sampling were conducted by A. Burt and assistant from May 26 to August 8, 1997 and from May 25 to August 28, 1998. Road access, which diminishes from southwest to the north and east, includes grid roads in the agricultural southwest, recreational trails and logging roads on the moraine complexes, and logging roads north of the Winnipeg River. All-terrain vehicles were used along power lines on Milner Ridge. Ground-penetrating radar surveys were conducted on the Belair and Milner Ridge moraine complexes. Exposures of the upper Quaternary sequence are located along the shore of Lake Winnipeg, the banks of the Winnipeg River, and in gravel pits in the Milner Ridge, Belair and Birds Hill complexes.

Near-surface sediments were examined by augering to a depth of 1 m at over 2000 sites. Along section roads, one randomly selected site was examined per 1.6 km of road; however, sites were recorded at 0.8 km or 0.4 km intervals where access was limited. Map units were tentatively assigned in the field using surface observations such as landforms and boulder frequency, and subsurface data to a depth of 1 m, including unit thickness, texture, structure, colour and reaction to HCl. Near-surface and outcropping till was sampled at a depth of 1 m at a 10 km spacing. Fine-grained glaciolacustrine sediments were sampled at depths of 0.3 and 1.0 m in the southern portion of the map area and at 1.0 m in the northern portion. A total of 42 till samples and 74 fine-grained sediment samples were obtained. Geological contacts are being plotted on air photos dating from 1989 to 1994 and ranging in scale from 1:51 000 to 1:56 000.

South of the Winnipeg River, silt till contains abundant carbonate gravel clasts. These till deposits outcrop along the margins of the Belair, Milner Ridge and Birds Hill moraine complexes, on the Paleozoic bedrock high near Garson, adjacent to Precambrian bedrock outcrops, in small topographic highs in the Selkirk area, and in flute ridges in the Beausejour area. In the northeastern part of the area, there is an abrupt transition to a discontinuous gravelly sand diamict, also generally considered till, derived from Precambrian bedrock. This unit is most commonly observed adjacent to bedrock outcrops. Large ice contact glaciofluvial and subaqueous outwash deposits form the core of the Belair, Milner Ridge and Birds Hill complexes. The texture of these sediments varies from bouldery cobble gravel to sand and the lithology is varies from Precambrian-rich to Paleozoic-rich. These glaciofluvial sediments are commonly deposited as debris flows. Small eskers, several km in length, occur in the clay/till plain.

Throughout much of the area, till has been draped with glacial Lake Agassiz sediments. Clay and silt are dominant, and littoral sand occurs adjacent to moraine complexes. Glacial lake shoreline features include discontinuous large and small beaches, spits, and wave cut scarps that surround the moraines. Iceberg scours are evident in fine-grained sediments as subtle ridges and slight depressions in till south of the Winnipeg River. In some cases, scours can be traced under organic deposits.

Postglacial alluvial sediments are present in Netley Marsh, and along the Red and Brokenhead rivers. These deposits consist of clay and silt with minor sand. The presence of shells and organic material and a friable structure are useful diagnostic indicators. Large shoreline deposits, as well as features related to shoreline erosion, are present on Lake Winnipeg. The largest depositional feature is a large, destructive wave-dominated delta system at the mouth of the Red River, supplied by the longshore drift of coastal sediments and fluvial sediments. In addition, there are a series of barrier islands and barrier beaches with associated back swamps, most of which are located along the east shore, south of Elk Island. Eolian reworking of sand deposits in the Belair and Milner Ridge moraine complexes has resulted in the formation of small stabilized dunes, generally 1 - 2 m high. South of the Winnipeg River, organic deposits are most extensive at the margins of the Belair and Milner Ridge moraine complexes. These deposits range from hundreds of meters to kilometres in lateral extent and may be related to groundwater discharge. North of the Winnipeg River, extensive organic deposits have formed due to poor drainage and slow rates of decomposition. Teardrop shaped islands and water flow patterns are evident in many organic deposits.

Pinawa/Nopiming Area

In the Pinawa and Nopiming map areas, the physiography is dominated by that of the Canadian Shield, where local topography is characterized by irregular and hummocky exposures of bedrock. Bedrock exposure, with scattered glacially transported boulders, is present in the entire field area, with extent of outcrop being controlled by the amount and type of sediment cover. Bedrock exposure, as well as lakes, are less extensive in the west than in the east, due to the infilling of intervening bedrock depressions by a relatively continuous blanket of glaciolacustrine sediments and organic deposits. At higher elevations, however, bedrock exposure may have been enhanced by the erosive action of Lake Agassiz.

Archean granite and granodiorite, as well as metamorphosed intrusive rocks dominate the bedrock geology. The northern two-thirds of the study area also includes greenstone belts in the Bird River and Manigotagan River areas, comprised of metavolcanic and metasedimentary rocks (Manitoba Mineral Resources Division, 1979).

Industrial mineral extraction is limited to a few small pits, as well as one large sand and gravel quarry west of Pinawa.

The surficial geology of the study area has been previously addressed by Nielsen (1980). Mapping of Quaternary sediments in adjacent Ontario has been carried out by Zoltai (1961) and Morris, (1993a, 1993b). In Manitoba, Henderson (1993; 1994a; 1994b; 1994c; 1996; 1998), Henderson etal. (1993) as well as Henderson and Way Nee (in press) mapped the surficial geology bordering the northwest half of the study area.

Fieldwork by J. Mann and assistant was carried out from June to late August, 1998. Road access is satisfactory in the southwestern corner of the field area near Lac du Bonnet, where mapping sites were randomly located within the 1.6 km grid formed by the road system. In the rest of the study area access is limited to active logging roads, such as the east/west Trans-license road, the main paved and gravel roads to Pinawa (Highway 211), Pointe du Bois (Highway 313), the Whiteshell (Highways 307 and 309) and Nopiming Parks (Highway 314), and to Bird River and Werner Lake (Highway 315). In the eastern and northern part of the area, there are few roads, as many former logging roads are overgrown and in disrepair. In this area, descriptive data were collected at 0.4 km intervals. In a few cases, the spacing was doubled where little change was seen in several consecutive sites. In order to obtain map data and sediment samples in the intervening areas between the roads, access by all terrain vehicle was utilized for two weeks, and access by a fixed-wing aircraft equipped with floats was used for three days.

At a total of 1475 collection sites, sediments were excavated by auger or shovel to 1 m depth, and were described in detail. A total of 51 till samples were obtained, at a spacing of 10 km, where access and presence of till permitted. Till sample pits were dug to a minimum depth of 1 meter and 11-litre samples were taken from below the ~30 to 40 cm thick A and B soil horizons. Till samples were preferentially recovered from beneath fine-grained glaciolacustrine sediment in order to minimize the role of weathering on sediment composition. In borrow pits or road-cuts, the sediments were excavated to expose undisturbed material before sampling. At 49 sites, fine-grained glaciolacustrine samples, 0.2 litres in size, were recovered from depths of 0.3 and 1.0 m. Air photos being used for preparation of geological maps are at 1:50 000 scale, and date from 1984, 1989 and 1992.

Ice flow direction indicators on exposed bedrock most commonly are present as striae, although chattermarks and grooves also are present. Striations were measured at over 100 sites, and all record one ice advance from the northeast. Crossing striae indicate local reflections of ice flow by 30 to 40°, likely related to bedrock topography.

In the extreme southwest corner of the study area, calcareous silt till, deposited by ice flow from the northwest, is present. The eastern limit of this calcareous till, first mapped by Nielsen (1980), impinges on the extreme southwest corner of the area (NTS 52L/4). East of the limit, laterally discontinuous sand till of northeast provenance and glaciolacustrine cover occur among extensive bedrock outcrop, and sharp change in relief between bedrock and drift cover can be observed. West of the calcareous drift limit, bedrock outcrop is less extensive, and the change in relief between bedrock and sediment is obscured by the thicker cover of calcareous drift and glaciolacustrine clay.

The calcareous till is very silty, with a gravel fraction making up about 20% of the sediment. Underlying Precambrian rocks are reflected by a gravel fraction that is a varied mix of Paleozoic and Precambrian. Sand till and associated sediments, found everywhere east of the calcareous till limit as a discontinuous cover, preferentially occur on the lee flanks of bedrock knobs. These sediments contain abundant medium to coarse sand. In some cases, perhaps reflecting provenance from metasedimentary and metavolcanic terranes, the fine fraction of sand diamict is much siltier, although the pebble fraction, like other areas, consists of angular to subangular granitoid rocks. At one site, where sand diamict was observed on the stoss side of a bedrock high, the very consolidated sediment included clear horizontal partings, and was overlain by a poorly sorted, matrix to framework supported, ablation till, or flow till. Based on similar observations of an overconsolidated sand till made east of the study area (Morris, 1993a), this diamict seems likely to be a lodgement till, or a subglacial flow till. Sand diamict in at least one site was also deposited subaqueously as multiple density underflows. This unit contains horizontal silt lenses and laminae, and was observed in association with sand and gravel from a glaciolacustrine outwash deposit.

Proximal glaciofluvial sediments occur as morphologically featureless disjunct deposits of massive to poorly stratified, bouldery sand and gravel, deposited as fills in bedrock depressions. In some cases, these deposits drape the flanks of the bedrock depressions that contain them, and in places proximal glaciofluvial deposits consist of framework-supported cobble and boulder gravels. Subaqueous outwash commonly occurs as planar- to trough-cross bedded, fine- to medium-grained sand and gravelly sand deposits that from place to place contain cobble to boulder-sized dropstones commonly draped by overlying sand laminae. Subaqueous outwash also grades from coarser ice proximal to finer ice distal sediments. The subaqueous outwash deposits are more extensive than ice proximal glaciofluvial deposits, and not only occur in bedrock depressions, but commonly fill and overtop depressions, and bury the bedrock to form a continuous deposit. Toward the margins of large outwash sand bodies, sand sporadically occurs above clay, implying reworking by Lake Agassiz. In several localities, subaqueous outwash consists of complex assemblages of rhythmically planar bedded, fine- to medium-sand and silty fine sand, each bed 0.5 - 5 cm in thickness. In some cases, sand beds within a rhythmic sequence have rippled upper surfaces and exhibit draping laminae and trough cross bedding. These features indicate traction currents in density underflows. In places, glaciolacustrine silt and clay overlie subaqueous outwash deposits and thus indicate a receding sediment source, or possibly increasing water depths.

Thick accumulations of laterally continuous glaciolacustrine silt and clay occur only in the extreme southwestern corner of the study area. These deposits are used as agricultural land, and cultivated fields commonly reveal intersecting arcuate iceberg scours. On the exposed shield, glaciolacustrine fines occur as discontinuous cover in topographic lows between bedrock highs that acted as sediment traps. The largest and most extensive of these traps, where glaciolacustrine clay is commonly located, is the chain of lakes that comprise the Winnipeg River system. The distribution of fine-grained glaciolacustrine sediments is likely a function of elevation. Silty clay is by far the most common fine-grained glaciolacustrine deposit in the study area, and it varies from massive to laminated. These clays also commonly contain silt clasts, and very fine sand lenses and laminae. In all cases, the silt portion of a laminated silty clay is extremely reactive to HCl, where as massive silty clays and clayey silts were moderately reactive. At four locations, sequences recording about 20 to 40 glaciolacustrine silt and silty clay couplets of possible annual origin were observed. Couplet thicknesses varies from 0.3 to 2 cm.

Organic deposits are ubiquitous in the study region, and are commonly contained in low-lying, poorly drained depressions between bedrock outcrops, or perched atop relatively large and topographically high bedrock exposures.

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REFERENCES

Betcher, R. N.
1986: Groundwater Availability Map Series: Selkirk Area (62I); Manitoba Natural Resources, Water Resources, 1:250 000.

David, P.P.
1971: The Brookdale road section and it's significance in the chronological studies of dunes in the Brandon Sand Hills of Manitoba; **in** Turnock, A.C. (ed.), Geoscience Studies in Manitoba; Geological Association of Canada, Special Paper No. 9, p. 293-299.

Day, M. J.
1977: Analysis of Movement and Hydrochemistry of Groundwater in the Fractured Clay and Till Deposits of the Winnipeg Area, Manitoba; M.Sc. thesis, University of Waterloo, Waterloo, Ontario, 209 p.

Fenton, M. M., Moran, S. R., Teller, J. T. and Clayton, L.
1983: Quaternary Stratigraphy and History in the Southern Part of the Lake Agassiz Basin; **in** Teller, J. T. and Clayton, L., (eds.), Glacial Lake Agassiz: Geological Association of Canada Special paper 26, p. 49-74.

Goff, K. J.
1971: Hydrology and Chemistry of the Shoal Lakes Basin, Interlake Area, Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 117 p.

Groom, H. D.
1985: Surficial Geology and Aggregate Resources of the Fisher Branch Area: Local Government District of Fisher and Rural Municipality of Bifrost; Manitoba Energy and Mines, Aggregate Report AR84-2, 33 p.

Henderson, P.J.
1993: Quaternary geology of the Bissett area, southeastern Manitoba: applications to drift prospecting; **in** Current Research, Part B; Geological Survey of Canada Paper 93-1B, p. 63-69.

1994a: Glacial Dispersal and drift composition, Rice Lake greenstone belt, southeastern Manitoba; **in** Current Research 1994-C; Geological Survey of Canada, p. 205-214.

1994b: Surficial geology and drift composition of the Bissett-English Brook area, Rice Lake greenstone belt, southeastern Manitoba; Geological Survey of Canada, Open File 2910, 190 p.

1994c: Quaternary geological investigations related to drift prospecting, Rice Lake greenstone belt, Manitoba (Parts of NTS 62P/1, 52M/4, 52M/3 and 52L/14); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, p. 170-171.

1996: Kimberlite indicator mineral data from the Bissett-English Brook-Wallace Lake area (NTS 62P/1, 52 M/3, 52 M/4, 52 L/14), Rice Lake Greenstone Belt, southeastern Manitoba; Geological Survey of Canada, Open file 3367, 23 p.

1998: Quaternary geology of the English Brook area, Manitoba (NTS 62P/1); Geology Survey of Canada Map 1898A, scale 1:50 000.

Henderson, P. J., Dunn, C. E. and Coker, W. B.
1993: Quaternary studies related to drift prospecting, Rice Lake greenstone belt and Bernic Lake area, southeastern Manitoba; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1993, p. 153-154.

Henderson, P. J. and Way Nee, V.
In press: Quaternary geology of the Bissett area, Manitoba (NTS 52M/4); Geology Survey of Canada, A-series map, scale 1:50 000 (map).

Last, W. M.
1974: Clay mineralogy and stratigraphy of offshore Lake Agassiz sediments in southern Manitoba; M. Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 183 p.

Lebedin, J.
1978: Groundwater resources of the Beausejour area; Canada Department of Regional Economic Expansion, Prairie Farm Rehabilitation Administration, Engineering Services, Regina, 25 p.

Manitoba Energy and Mines.
1990: Winnipeg /NTS 62H; Bedrock Geology Compilation Map Series, scale 1: 250 000.

Manitoba Mineral Resources Division.
1979: Geological Map of Manitoba; Manitoba Mines, Natural Resources and Environment, Geological Map 79-2, 1:1 000 000.

Matile, G. L. D.
1984: Quaternary geology map of the Birds Hill area; Manitoba Energy and Mines, Mines Branch, Map AR84-5, 1: 20 000.

1994: Aggregate Resources Inventory in the L. G. D. of Reynolds; Manitoba Energy and Mines, Mines Branch, Aggregate Report AR89-2, 178 p.

Matile, G. L. D. and Betcher, B.
1998: Observations on selenite distribution within the Lake Agassiz clay plain; Manitoba Energy and Mines, Geological Services Branch, Open file Report OF 98-6, 6 p.

Matile, G. L. D. and Conley, G.
1980: Quaternary Geology and Sand and Gravel Resources of the Rural Municipality of Springfield; Manitoba Energy and Mines, Mines Branch, Aggregate Map AR80-1, 1:50 000.

Matile, G. L. D. and Groom, H.
1983: Aggregate Resources in the L. G. D. of Alexander and the R. M. of Lac du Bonnet; **in** Manitoba Energy and Mines, Report of Field Activities, 1983, p. 155-158.

1987: Late Wisconsinan Stratigraphy and Sand and Gravel Resources in the Rural Municipality of Lac du Bonnet and Local Government District of Alexander; Manitoba Energy and Mines, Mines Branch, Aggregate Report AR85-2, 44 p.

Matile, G. L. D. and Thorleifson, L. H..
1995: Surficial geology, Whitemouth Lake area, Manitoba, Ontario, and Minnesota; Geological Survey of Canada Open File 2993, Manitoba Energy and Mines Open File 95-1, Scale 1: 100 000.

1996a: Surficial geology, Falcon Lake area, Manitoba and Ontario; Geological Survey of Canada Open File 3030, Manitoba Energy and Mines Open File 95-2, Scale 1: 100 000.

1996b: Surficial geology, Steinbach area, Manitoba; Geological Survey of Canada Open File 3270, Manitoba Energy and Mines Open File 96-6, Scale 1: 100 000.

1996c: Surficial geology, St. Malo area, Manitoba; Geological Survey of Canada Open File 3327, Manitoba Energy and Mines Open File 96-9, Scale 1: 100 000.

McPherson, R. A.
1968: Pleistocene Stratigraphy of the Winnipeg River in the Pine-Falls-Seven Sisters Area; M. Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 61 p.

1970: Pleistocene Geology of the Beausejour Area; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 153 p.

Mishtak, J.
1961: Proposed Greater Winnipeg Floodway Soil Mechanics Investigations; unpublished report, Department of Agriculture and Conservation.

Mkumba, J. T. K.
1983: d34S and d18O Variations in Aqueous Sulfates in Groundwater Systems of Winnipeg and Kitchener-Waterloo; M.Sc. thesis, University of Waterloo, Waterloo, Ontario, 169 p.

Morris, T. F.
1993a: Quaternary geology of the Separation Lake area, northwestern Ontario; **in** Summary of Field Work and Other Activities 1992, Ontario Geological Survey, Miscellaneous Paper 160, p.141-143.

1993b: Quaternary geology, Umfreville Lake area; Ontario Geological Survey, Preliminary Map P.3234, scale 1:50 000.

Nielsen, E.
1980: Quaternary geology of a part of southeastern Manitoba; Manitoba Department of Energy and Mines, Publication GR 80-6, 2 maps, 1:100 000.

1989: Quaternary Stratigraphy and Overburden Geochemistry in the Phanerozoic Terrane of Southern Manitoba; Manitoba Energy and Mines, Geological Paper GP87-1, 78 p.

Nielsen, E. and Matile, G. L. D.
1982: Till stratigraphy and proglacial lacustrine deposits in the Winnipeg area; Field Trip Guidebook 1, Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 17-19, 1982, 22 p.

Pach, J. A.
1994: Hydraulic and solute transport characteristics of a fractured glaciolacustrine clay, Winnipeg, Manitoba; M.Sc. thesis, University of Waterloo, Waterloo, Ontario, 197 p.

Pratt, L. E., Ehrlich, W. A., Leclaire, F. P., and Barr, J. A.
1961: Report of Detailed-Reconnaissance Soil Survey of Fisher and Teulon Map Sheet Areas; Manitoba Soil Survey, Report No. 12, 78 p.

Rannie, W. F., Thorleifson, L. H. and Teller, J. T.
1989: Holocene evolution of the Assiniboine River paleochannels and Portage la Prairie fan; Canadian Journal of Earth Sciences, v. 26, p. 1834-1841.

Reid, Crowther and Partners Limited
1972: Inventory of existing urban geology for Winnipeg, Manitoba; Report submitted to Geological Survey of Canada, 30 p.

Smith, R. E. and Ehrlich, W. A.
1967: Soils of the Lac du Bonnet area; Manitoba Soil Survey Report No. 15, 118 p.

St-Onge, M. R.
1990: NATMAP: Canada's National Geoscience Mapping Program; Geological Survey of Canada Open File 2256. 83 p.

Teller, J. T.
1976: Lake Agassiz deposits in the main offshore basin of southern Manitoba; Canadian Journal of Earth Sciences, v. 13, p. 27-43.

Teller, J.T. and Fenton, M.M.
1980: Late Wisconsinan glacial stratigraphy and history of southeastern Manitoba; Canadian Journal of Earth Sciences, v. 17, p. 19-35.

Teller, J. T., Bannatyne, B. B., Large, P. and Ringrose, S.
1976: Quaternary sediment, bedrock topography and geology of southern Manitoba, Surficial map series, 76-1 to 76-4; Department of Mines, Resources and Environmental Management, Mineral Resources Division, 1:500 000.

Teller, J. T., Thorleifson, L. H., Matile, G. L. D. and Brisbin, W. C.
1996: Sedimentology, Geomorphology and History of the central Lake Agassiz basin; Field Trip Guidebook B2; Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 27-29, 1996, 101 p.

Thorleifson, L. H. and Matile, G. L. D.
1993: Till geochemical and indicator mineral reconnaissance of southeastern Manitoba; Geological Survey of Canada Open File 2750, 1 diskette.

Wicks, F. J.
1965: Differential Thermal Analysis of the Sediments of the Lake Agassiz Basin in Metro Winnipeg: M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 232 p.

Woodsworth-Lynas, C. M. T. and Guigne, J. Y.
1990: Iceberg scours in the geological record: examples from glacial Lake Agassiz; **in** Dowdeswell, J. A. and Scourse, J. D.; (eds.), Glacimarine Environments: Processes and Sediments, Geological Society Special Publication 53, p. 217-223.

Zoltai, S. C.
1961: Glacial history of part of northwestern Ontario; Proceedings of the Geological Association of Canada, v.13, p. 61-83.