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The Quaternary Stratigraphy Of A Portion Of Southeastern Manitoba, Canada

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THE QUATERNARY STRATIGRAPHY
OF A PORTION OF
SOUTHEASTERN MANITOBA
CANADA

by

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ABSTRACT

The purposes of this investigation are to study the Quaternary Stratigraphy of the area (7770 sq. km.), to correlate any identifiable stratigraphic units with those in the surrounding region, and to reconstruct the Quaternary history of the area.

The surface deposits were mapped (1:250,000 scale) by field examination combined with air photo interpretation and the subsurface sediments studied by examination of stratigraphic sections and the drilling of 101 power auger holes (depth 3 m. to 33 m.). Laboratory analyses, mainly on the till samples, consisted of (1) matrix textural analyses (-2 mm.), (2) pebble counts (8 to 4 mm.), (3) lithologic composition of the very coarse sand (2 to 1 mm.), (4) mineralogical composition of the fine sand (0.250 to 0.125 mm.), and the fine matrix carbonate (-0.063 mm.).

Within the study area the bedrock surface dips gently westward and southwestward, and is covered by sediments ranging in thickness from about 12 m. in the northwest to about 120 m. in the southeast.

The Quaternary sediments can be divided into the following units, starting with the oldest: the Rosa Formation (T - till); W/Ra Stratified Drift; Woodmore Formation (T); St. Malo Formation (S - stratified sediment); Stuartburn Formation (T); Tolstoi Formation (T); Vita Formation (S); Senkiw Formation (T); Bedford Formation (S), which includes

the Sandilands Sand Member; Roseau Formation (T); Grunthal Formation (S); Marchand Formation (T); and the Hazel Formation, which is divided into the lower member (S), Steinbach Member (T), and upper member (S).

The till units are differentiated mainly by stratigraphic position, matrix texture, very coarse sand lithology, clast fabric, and fine carbonate content. The other units generally are differentiated only by their stratigraphic position.

The till units are correlated with others recognized in northwestern and southwestern Minnesota; northeastern North Dakota; southwestern Manitoba; the Beausejour area, north of the study area; the Portage La Prairie area, northwest of the study area; southern Saskatchewan; and southern Ontario.

The pre-Senkiw units, and likely the Senkiw itself, are more than 40,000 years old. The Rosa, Woodmore, Stuartburn, and Tolstoi Formations were deposited by glaciers advancing generally from the northwest. The W/Ra Stratified Drift, St. Malo, and Vita sediments record periods of ice retreat, and the St. Malo and Vita periods of subaerial exposure and vegetation growth. A major ice advance from the northeast formed the Senkiw till and as the ice retreated the Sandilands Member of the Bedford Formation was deposited in the east and southwestern part of the area subaerially exposed. The Roseau till was deposited by a major ice advance from the northwest, probably between 25,000 and 15,000 years B.P. Subsequently glacial Lake Koochiching and later glacial Lake Agassiz submerged the area and the Grunthal and Hazel stratified sediments were deposited in them. The Marchand and Steinbach tills were formed by minor ice advances into these lakes. Lake Agassiz permanently drained from the area about 8,500 years ago.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

Location and Access

The research area is in southeastern Manitoba between latitudes 49° and 50° north and longitudes 96° and 97° west (Figure 1). It covers 7770 square kilometers (3000 sq. mi.) and includes all of townships 1 to 11 and the shouthern part of township 12 between ranges 4 to the western part of range 11 east of the Principal Meridian. Steinbach, located north-west of the centre of the area, is the largest settlement.

Access is good in the western half with many gravel and paved roads but it is restricted in the eastern half, because of extensive peat cover, to a few major roads and some trails.

Purpose of the Investigation

The purposes of this study were (1) to determine the Quaternary stratigraphy of the area, (2) to determine the surface and subsurface distribution of any identifiable stratigraphic units, (3) to correlate the stratigraphy with that of the surrounding regions, and (4) to use this stratigraphic information to interpret the Quaternary history of the area.

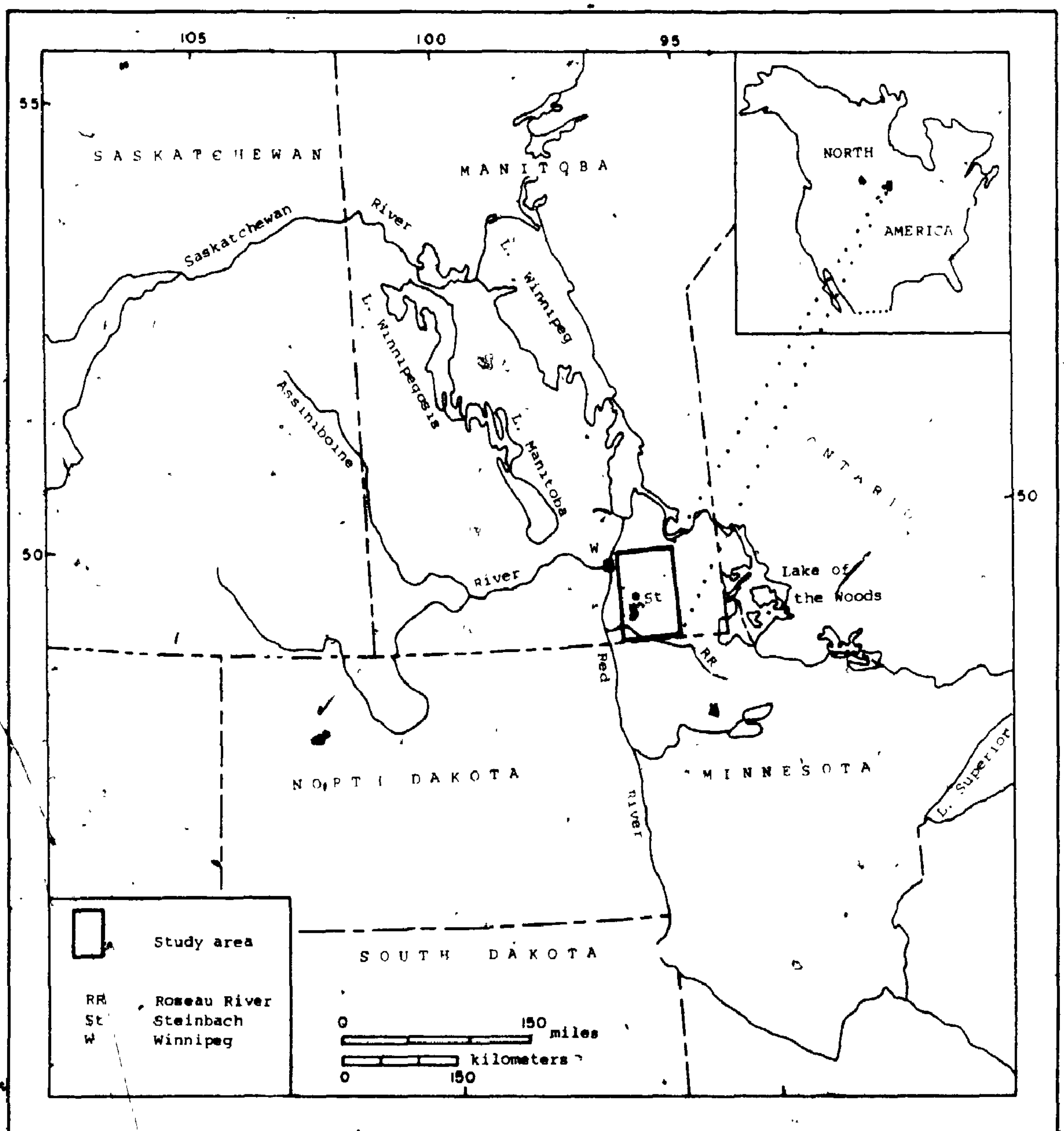


Figure 1. Location of the study area.

Previous Work

Previous to this study little work had been done in the area. In the surrounding region much of the research, until very recently, has been concerned with glacial Lake Agassiz, a large lake that formed as the last major ice sheet melted.

Within the study area the first recorded European explorer was La Jemeraye, who in 1736 descended the Roseau River to the Red River (Morton, 1970, p.28). General descriptions of the surface deposits were made by Hind (1859, 1860), S.J. Dawson (1859), G.M. Dawson (1875), and Upham (1890, 1895) for portions of the area. G.M. Dawson (1875) was the only person to describe wood-bearing stratified deposits overlying boulder clay along the downstream part of the Roseau River.

In 1915 the eastern one third of the area was included in a study by Johnston (1921), which was intended primarily to describe the character of the surface deposits in the region west of Lake of the Woods and their usefulness to future settlers. He identified two tills: (1) a sandy till which contained a low proportion of carbonate material, that he interpreted as being deposited by ice advancing from the northeast, and (2) a finer textured till, which contained considerably more calcareous material, that he believed was deposited by ice advancing from the northwest and was younger than the sandy till. He also interpreted that portion of the Bedford Hills (Figure 3) higher than 1150 feet (345 m.) above sea level as a "drift plateau" formed at the margin of the northeastern ice and reported that "borings" in the west and southwest revealed the upper till was underlain by stratified drift containing organic material. Johnston showed the history of Lake Agassiz consisted of two high water periods separated by a low water interval. Johnston (1934), in connection with a groundwater study, published a surficial geology map covering the southern part of Manitoba including the study area.

Soils maps covering portions of the area were published by Ehrlich et al. (1953) and Smith et al. (1964, 1967).

Studies of the Quaternary deposits in the surrounding region have been summarized by Elson (1961, 1967). The stratigraphy north of the study area was discussed by McPherson (1971) and that to the northwest by Fenton (1970, 1971). South of the area in northwestern Minnesota and northeastern North Dakota the stratigraphy has been described by Harris (1973), Harris et al. (1974), and Salomon (in press).

Method of Study

The field work consisted of the following: (a) mapping the surficial deposits at a scale of 1:250,000, (b) outlining the subsurface geology by examining the few available geologic sections and drilling 101 test holes with a truck-mounted power auger, (c) collecting samples from near surface excavations, geologic sections, and test holes for later laboratory analyses, and (d) measuring a number of till fabrics. (See also Appendices A and B.) Each test hole is identified by the letters FW followed by a number and each section by the letters FWS and a number. The location-numbering system used, based on north-south ranges and east-west townships, is shown in Figure 2. Wherever possible the location of each section or test hole was determined to the nearest one quarter legal subdivision (L.S.D.)

The laboratory analyses included the following: (1) textural analyses (-2 mm. fraction), (2) pebble counts (8 to 4 mm. fraction), (3) lithologic composition of the very coarse sand (2 to 1 mm.), (4) mineralogical composition of the fine sand (0.250 to 0.125 mm.), and (5) carbonate analyses (-0.063 mm. fraction). Most of the samples analysed were till. The textural analyses were done by the hydrometer method using a modified form of the American Society for Testing and Materials procedure (1964). The carbonate analyses, to determine the amount of calcite and dolomite in a sample, were done by the gasometric method of Dreimanis (1962). The coarse sand analyses consisted of, in most cases, determining the percentage of limestone, dolostone, and crystalline (igneous + metamorphic) rock fragments, which usually included more than 98 percent of a sample. A detailed determination of the mineralogical composition of both light and heavy mineral fractions was done for the fine sand. All the till fabrics were plotted as mirror image and some as dip-sensitive rose diagrams. A more detailed description and discussion of each method can be found in Appendices B to H.

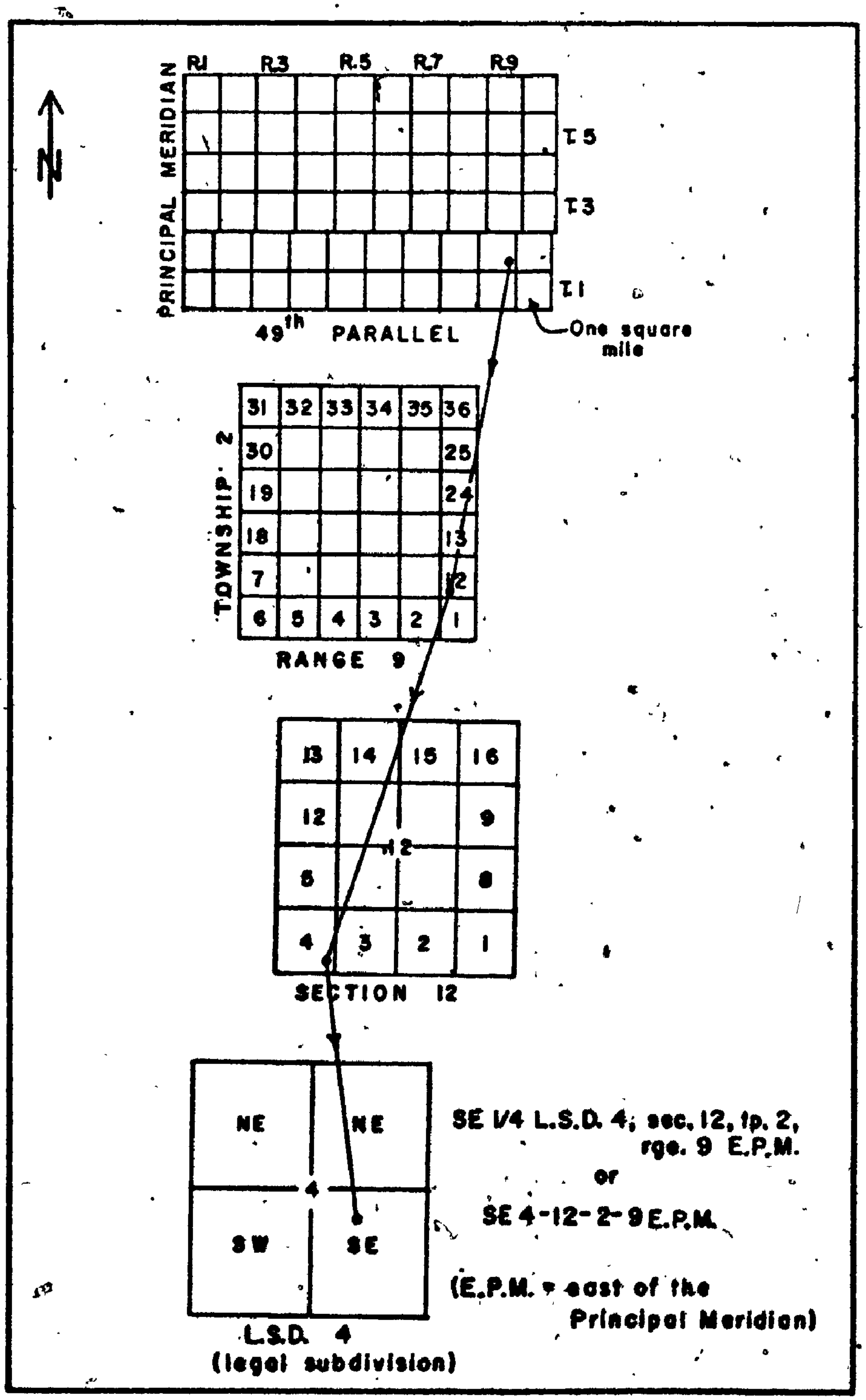


Figure 2. Location-numbering system.

Physiography

The study area is part of the Manitoba Plain which is that subdivision of the Interior Plains located between the Precambrian Shield and the Manitoba Escarpment (Bostock, 1970). The area can be subdivided into the Red River Plain, the South-Eastern Lake Terrace Plain, and the Bedford Hills (Figure 3).

The Red River Plain, located in the northwestern portion of the area, is flat, poorly drained, and about 240 m. (800 ft.) above sea level (Figure 4). The native vegetation consists of prairie and meadow grasses although now the major portion is agricultural crops (Ehrlich et al., 1953, Smith et al., 1964).

The South-Eastern Lake Terrace Plain has low relief and slopes downward from an elevation of about 315 m. (1050 ft.) in the east to about 255 m. (850 ft.) in the west. It is composed of a complex of landforms which have resulted from the modification of till and glaciofluvial deposits by Lake Agassiz. Wave-eroded till occupies many of the high sites and lacustrine sediments and peat are present in the low sites. The native vegetation on the better drained ground is typical of the Boreal mixed forest and patches of black spruce and tamarack with intervening sage and shrub meadows occupy the lower, wetter sites (Smith et al., 1964, 1967).

The Bedford Hills form a generally scarp-bordered upland in the southeast (Figure 4) which rises to an elevation of

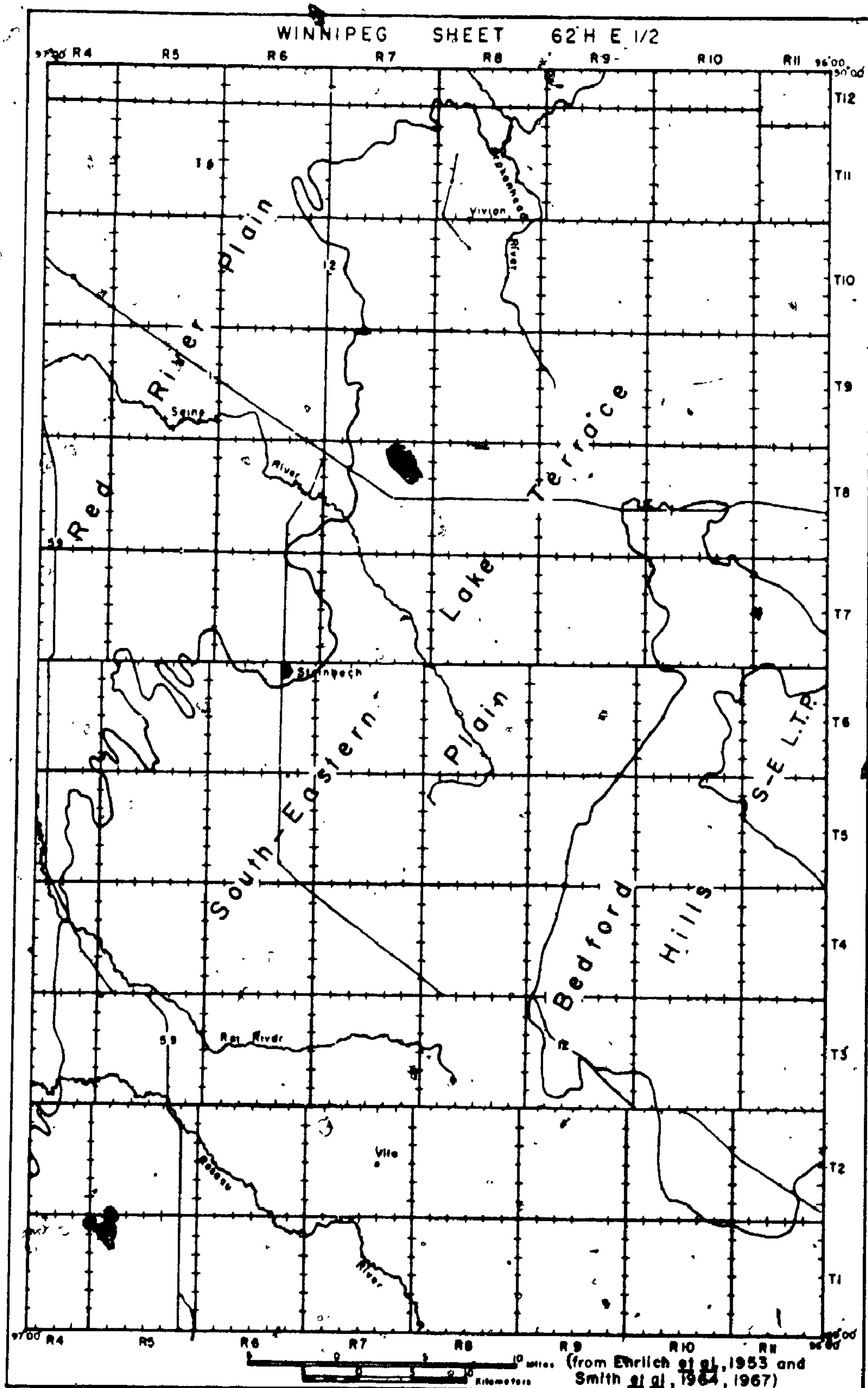


Figure 3. Physiographic map of study area.

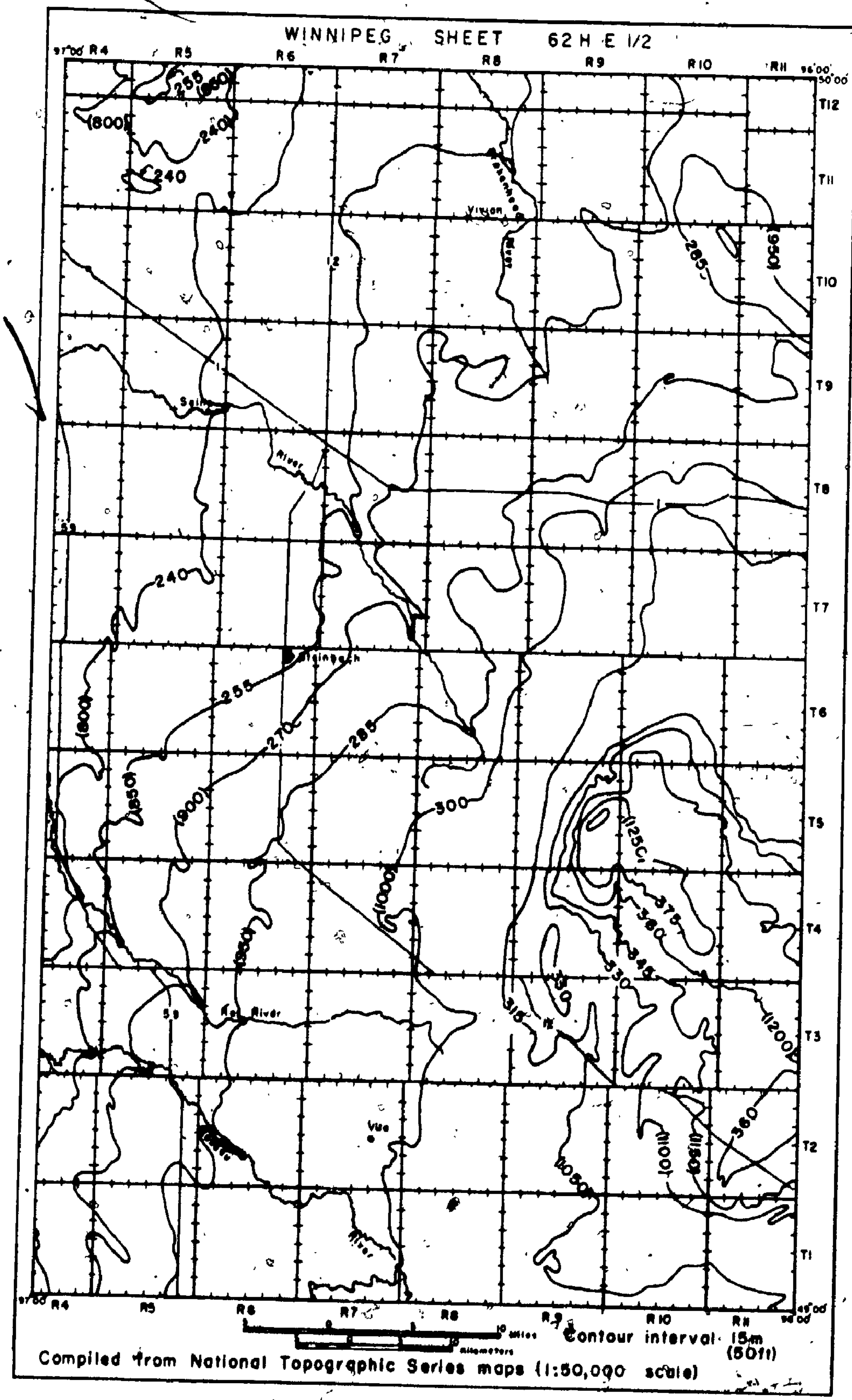


Figure 4. Topographic map of study area.

about 390 m. (1300 ft.). The surface varies from flat to irregular or subparallel hills. The Hills are mostly sand and are therefore very well drained. The native vegetation consists of jackpine with mixed hardwoods and softwoods on the lower flanks (Smith et al., 1964).

Bedrock Geology

The bedrock of the surrounding region includes rocks of Precambrian to Tertiary age (Figure 5). Recent descriptions include those of Davies (1962), Bannatyne (1970, 1971), and McCabe (1971). For the purpose of this study the bedrock can be divided into six lithologic units (Figure 5): (1) predominantly granitic, Precambrian rocks to the east and north, (2) a narrow sandstone and shale unit, the Winnipeg Formation, to the north, (3) a limestone and dolomitic limestone unit, the Red River Formation, to the north and north-northwest, (4) a dolostone unit, including the Stonewall and the Stoney Mountain Formations and the Interlake and Elk Point Groups, to the west and northwest, (5) a limestone unit, the Manitoba Group, further to the northwest, and (6) a predominantly shale unit to the west and extreme northwest. This last unit can be subdivided into the rock units which outcrop on the Manitoba Plain, the Amaranth, Melita, and Reston Formations (Figure 5, unit 5), and the Swan River Group and Ashville Formation (Figure 5, unit 6), and those which form the eastward-facing Manitoba Escarpment (Figure 5, unit 7). Creta-

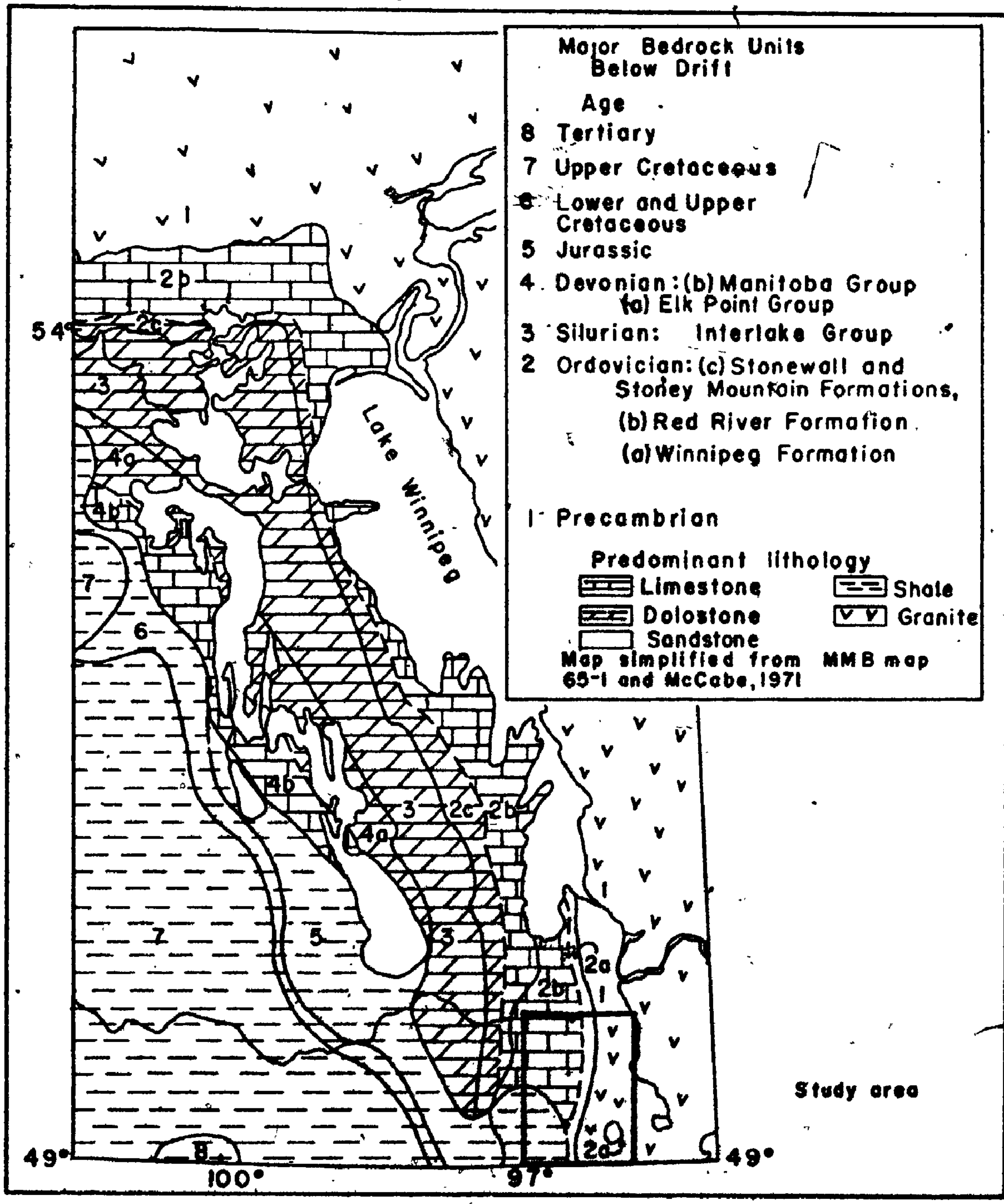


Figure 5. Bedrock geology map of southern Manitoba.

ceous outliers, composed of shale, sandstone, and lignite, have been recognized filling small pre-Cretaceous channels west and slightly southwest of Lake Winnipeg (B. B. Bannatyne, oral com., 1971; McCabe, 1971).

Within the study area four bedrock units are believed to be present. These are undivided Precambrian granitic rock, the Ordovician Winnipeg Formation consisting of sandstone and shale (McCabe, 1971, Vigrass, 1971), the Ordovician Red River Formation, limestone and dolomitic limestone (McCabe, 1971, Bannatyne, 1971), and the Jurassic Amaranth Formation, dolomitic red shale and siltstone with minor gypsum and anhydrite (Bannatyne, 1959, 1971, and Water Resources Branch test holes). The distribution of these units (Figure 6) is determined from water well logs and a number of test hole logs supplied to the author by the Manitoba Water Resources Branch. Because of sparse settlement and an increase in drift thickness little bedrock information is available in the eastern part or the area and the position of the contacts is largely conjectural.

Bedrock Topography

The bedrock topography map (Figure 6) was constructed using (1) water well and test hole logs to obtain drift thickness, and (2) National Topography System maps, with a contour interval of 25 feet, for surface topographic control. The relief on the bedrock surface is less than 60 m. (200 ft.) The elevation of the bedrock surface decreases from more than

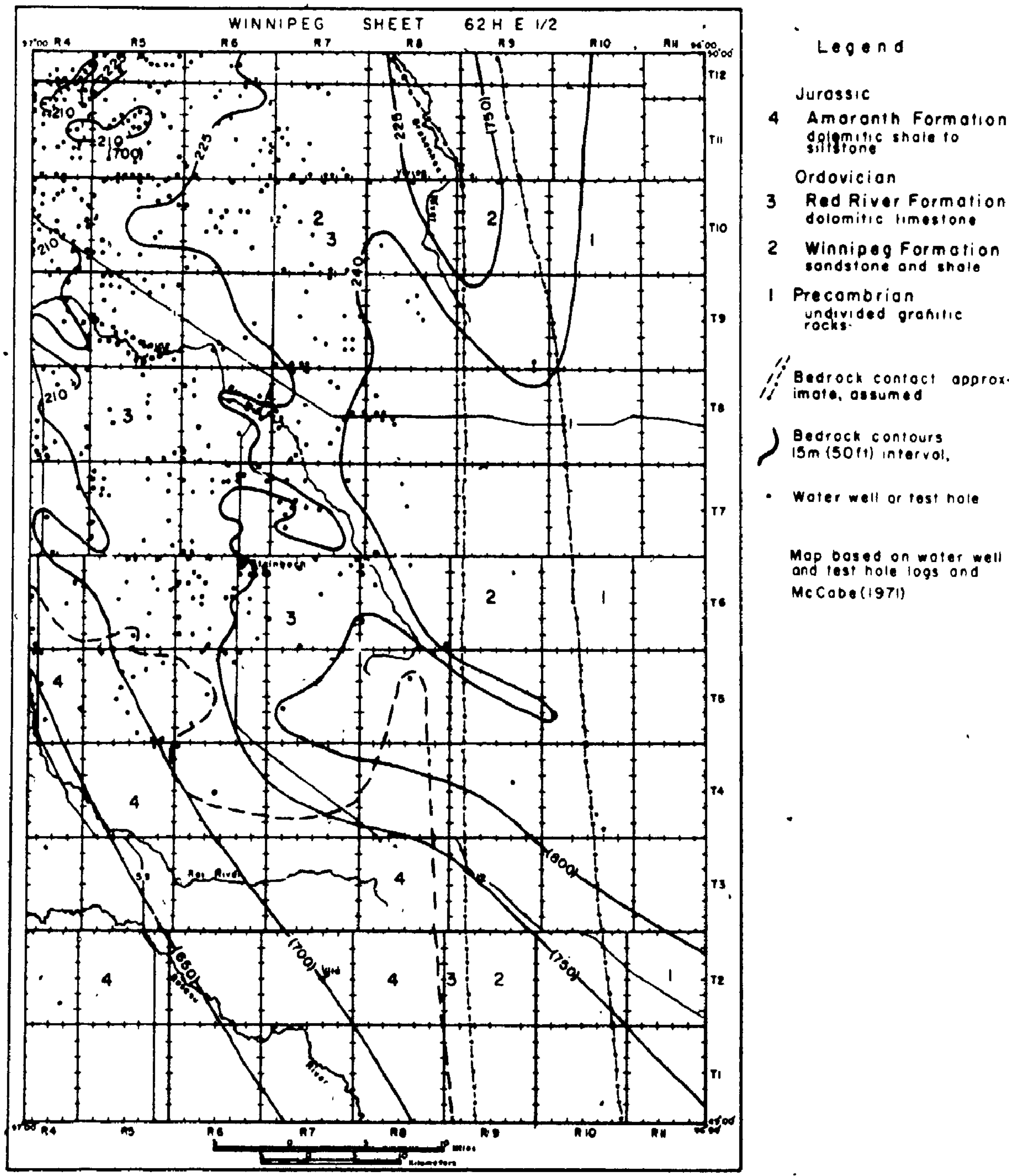


Figure 6. Map of the bedrock geology and topography of the study area.

240 m. (800 ft.) above sea level in the southeast to less than 210 m. (700 ft.) in the west and 195 m. (650 ft.) in the southwest. Two shallow depressions occur in the northwestern corner. Deflections of the contours suggest a narrow bedrock valley extending from township 9, range 4 southeastward, possibly as far as township 5, range 10. No data are available to confirm or deny the presence of a bedrock valley, postulated by Klassen, *et al*. (1970), below the Roseau River in township 3, ranges 4 and 5. McPherson (1970) described a bedrock low north of the study area trending southeastward in the vicinity of the Brokenhead River. The data indicate this feature extends into the area (Figure 6, tps. 8 to 12, rges. 8 to 10).

CHAPTER 2

QUATERNARY GEOLOGY

Glacial drift completely covers the study area. It varies from about 12 m. (40 ft.) thick in the northwest (tp. 11, rge. 6) to over 120 m. (400 ft.) in the southeast (Figure 7) and includes both till and stratified material.

Part 2.1 Surficial Geology

The areal distribution of the surficial deposits is shown on the Quaternary geology map (Figure 8) which was produced from field examination combined with airphoto interpretation. The main purpose of the map is to show the sediment to be expected in about the upper 2 meters (6 ft.). The only exception to this is the shallow organic subunit (8a, Figure 8) which refers to only the upper meter. The primary map units are genetic: the glacial, glaciofluvial, lacustrine, organic, and alluvial units. Where possible these units are subdivided on the basis of lithology. If more than one primary unit is present in the upper 2 meters the more continuous unit is chosen as the main one. The best example of this is in the till (unit 3, Figure 8). This map unit is partially covered by lacustrine sediment and is subdivided to show the proportion and composition of this cover.

A description of these units follows and additional information on some of them can be found in Section 2.2

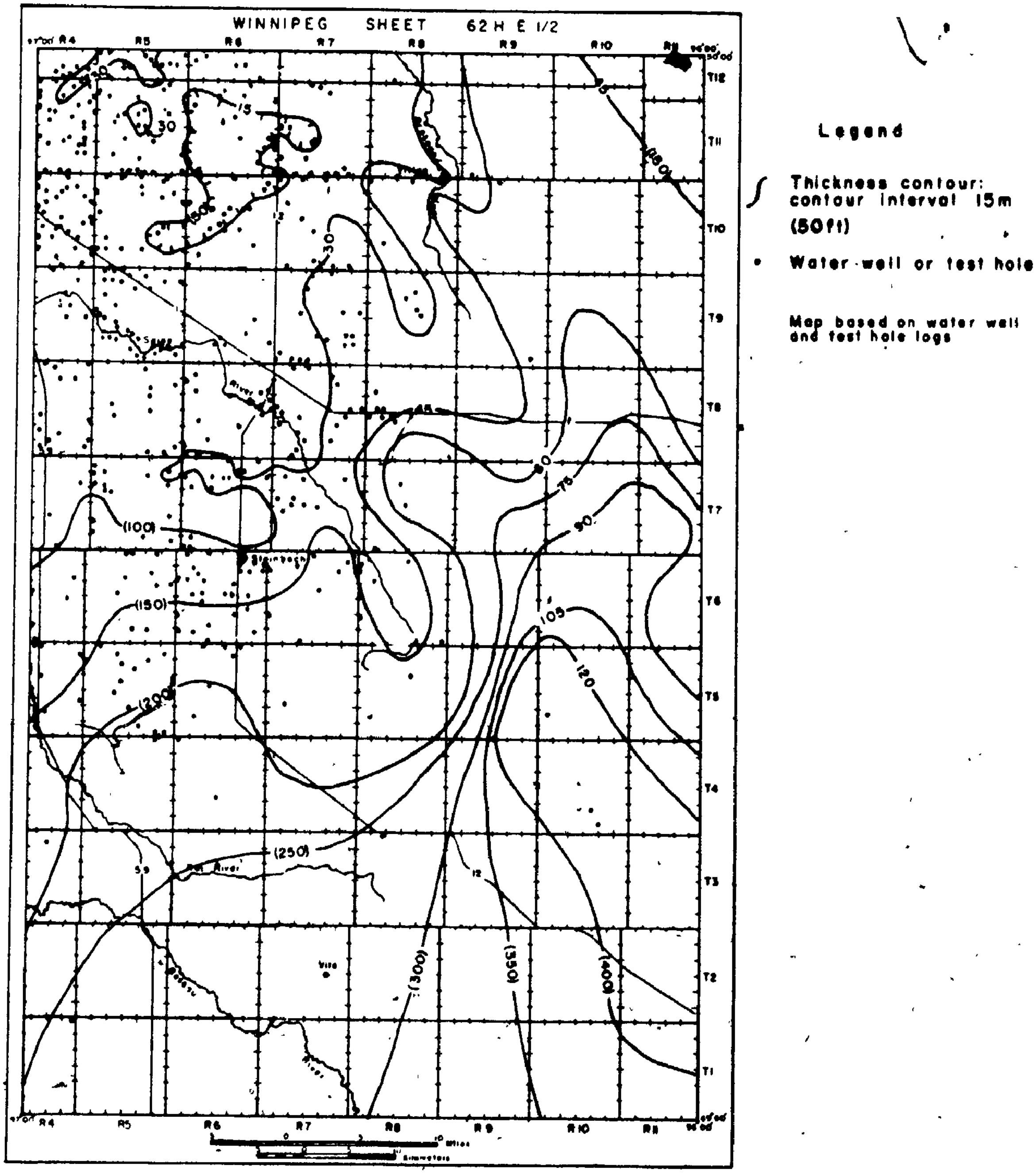


Figure 7. Drift thickness map of the study area.

describing the Quaternary Stratigraphy.

Glaciofluvial Sand Unit

This unit is present in the eastern portion of the area and includes the Bedford Hills and much of townships 7 and 8, ranges 10 and 11, and township 10, range 10. It can be divided into two mappable subunits; wave-washed material (1a) and wave-eroded material (1b, figure 8).

The wave-washed unit is composed of fine to medium grained sand and is present on the Bedford Hills above about 330 m. (1100 ft.). The topography is generally flat to slightly rolling with relief less than 4 m. (12 ft.). Locally the topography may be hummocky (tp. 5, rge. 9) or a series of subparallel northeast trending ridges (tp. 2, rge. 11). The native vegetation is predominantly jackpine. This subunit is bordered on the northwest and the southwest by scarps 6 to 16 m. (20 to 50 ft.) high. Till, lacustrine sand, and/or peat form the eastern and western boundaries in the central part. Locally the subunit is overlain by till (sec. 23, tp. 5, rge. 10; sec. 19, tp. 4, rge. 10; and sec. 29, tp. 3, rge. 11). Fine lacustrine sediment overlies this subunit in and adjacent to section 36, township 4, range 9.

The wave-eroded subunit is present to the north and southwest of the main part of the Bedford Hills between the elevations of 330 m. (1100 ft.) and 270 m. (900 ft.) above sea level. The topography is flat to slightly rolling with relief of less than 4 m. (12 ft.). The subunit consists of fine to medium grained sand and commonly has a concentration of boulders on its surface, particularly in townships 7 and 8, ranges 10 and 11. It is distinguished from the wave-washed unit by the boulder concentration and its lower elevation.

Glaciofluvial Sand and Gravel Unit

The majority of the deposits forming this unit (Figure 8, unit 2) are situated on the western margin of the Lake Terrace Plain (Figure 3) and the others in townships 8 and 9 range 9, and in the northwest (tps. 11 and 12, rges. 4 and 5). These deposits form isolated hills or irregular ridges with a relief of 3.6 to 9 m. (12 to 30 ft.). The examination of a number of gravel pits indicates they are composed of mainly stratified sand and gravel with the relative proportions varying with the position in the deposit. Based on (1) the small number and the small size of the gravel pits and (2) one test hole (sec. 6, tp. 11, rge. 8) the deposits consist predominantly of sand. Some of these deposits are overlain by one to two meters (3 to 6 ft.) of till and/or lacustrine sediment.

The deposits placed in this unit are thought to be kame-deltas deposited in a proglacial lake by streams flowing generally eastward off a westward retreating glacier.

Till

Till (Figure 8, unit 3) is present at or near the surface over most of the area not covered by glaciofluvial, organic, or thick lacustrine deposits. It forms the major unit in the southwest and north centre and is also present in the northeast and southeast. The topography is a flat to undulating plain sloping westward and northwestward at 0.7 to 1.4 m./km. (3 to 6 ft./mi.) with the local relief generally less than 2 m. (6 ft.). The till is predominantly silty loam north of township 5 and east of range 10 and loam south of township 5 west of range 10. A sandy loam till is exposed in some places south of township 4, west of range 9.

This unit can be divided into four mappable subunits: (3a) till more than 90% covered by sand, (3b) 50 to 90% covered, (3c) less than 50% covered, and (3d) more than 90% clay covered Figure 8). The sand is fine to medium grained and a gravel-rich layer is often present at its base or on the exposed till. In 3a and 3b clay may be present between the sand and the till. The sediment in 3d consists mainly of a silty clay with minor clayey silt. The thickness of the sediment overlying the till is generally less than 2m. (6 ft.) but in portions of townships 3, 4, and 5, ranges 6, 7, and 8 subunit 3a is between 3 and 5 m. (9 and 15 ft.) thick. A more detailed description of the till can be found in section 2.2 describing the Quaternary Stratigraphy.

Lacustrine Units

As the last glacier to cover the area melted, a large proglacial lake named Lake Agassiz (Upham, 1880) submerged the study area. The lacustrine deposits were laid down in and at the margin of this lake. These deposits include: (a) the discontinuous veneer of sand and/or clay over the till, described in the preceding subsection; (b) sand and clay deposits over 2 m. (6 ft.) thick; and (c) sand and gravel.

The lacustrine sand (Figure 8, unit 4) occurs mainly in the east (tps. 1 to 6, rges. 8 to 11, and tps. 8 to 12, rges. 9 to 11) commonly adjacent to, but at a lower elevation than, the glaciofluvial sand unit. The topography is predominantly a flat to undulating, partly dune-covered plain. Where the unit has been dissected by later erosion, however, the surface is more irregular (tps, 2 and 3, rges, 10 and 11). The sand is generally fine to medium grained.

The lacustrine clay (Figure 8, unit 5) is present in the northwestern quarter of the area. It forms a flat westward sloping (0.8 m./km., 4 ft./mi.) plain with less than 1 m. (3 ft.) of relief. The unit is composed of silty clay.

In some areas the surface of the lacustrine clay includes low-relief ridges and grooves. Within the Red River Plain these lineations are 65 to 100 m. (200 to 300 ft.) wide, less than 1 m. (3 ft.) deep and extend in some cases for more than 9 km. (5 mi.; Figure 9, Plate 1). They are either straight or curved, the former being more common, and may intersect or run parallel. Similar but smaller lineations also

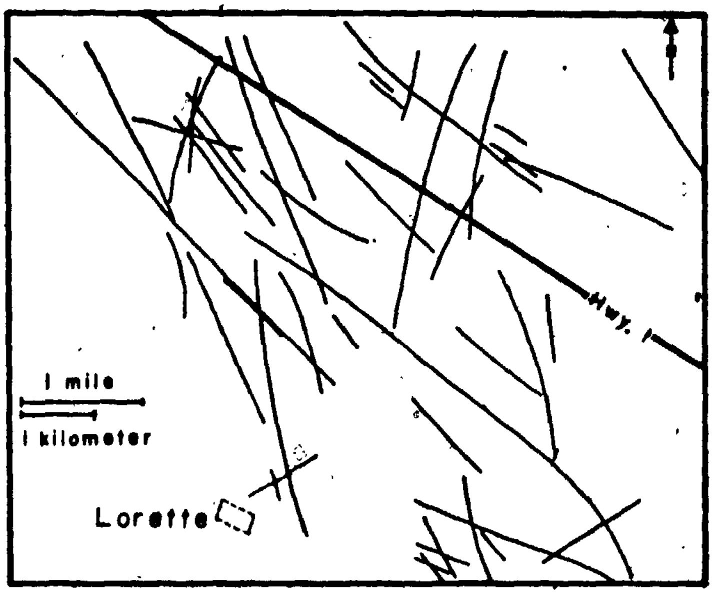


Figure 9. Lineations on the Red River Plain near Lorette (tp. 9, rge. 5).

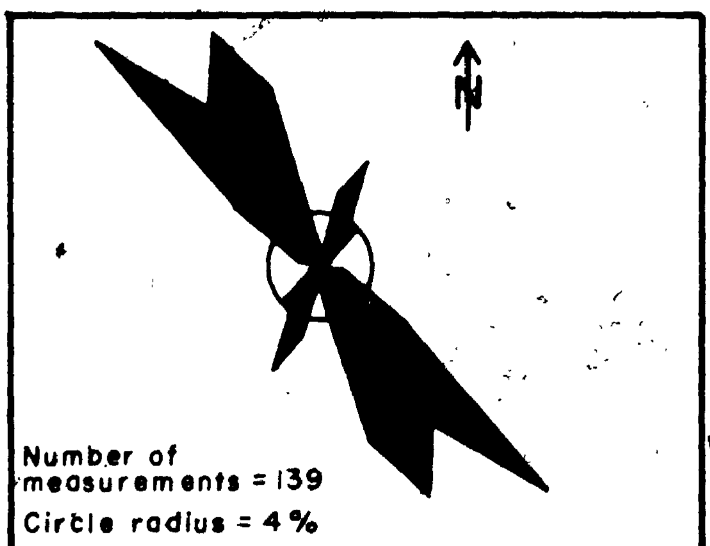


Figure 10. Rose diagram showing the orientation of the lineations.

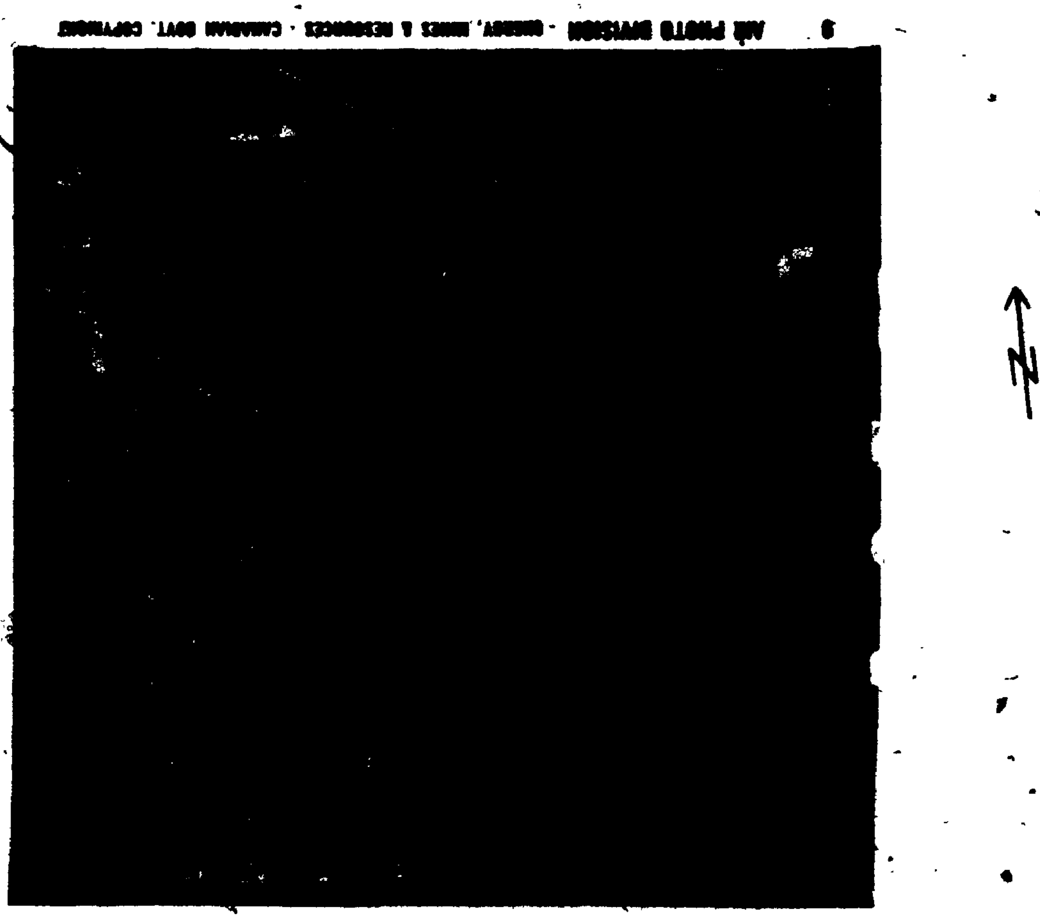


Plate 1. Lineations on the Red River Plain near Lorette.

occur in the partly clay veneered till in the northeast (tp. 10, rge. 7; and tp. 9 and 10, rge. 9). These are generally 33 to 66 m. (100 to 200 ft.) wide by 1.6 km. (1 mi.) or less in length and the curved lineations are more abundant than on the Red River Plain.

The lineations on the Plain have been discussed by a number of workers including Horberg (1951), Nikiforoff, (1952), Mollard, (1957), Elson (1961 and 1967), Clayton et al., (1965), McPherson, (1970), and Bluemle, (1973). These lineations have been interpreted by Clayton et al., (1965) and many later writers as drag marks formed by wind-driven ice impinging on the bottom of Lake Agassiz. Similar ice drag features, though of slightly different scales, have been described by numerous authors including Tyrrell (1892) along the margin of Lake Winnipegosis (Figure 1), Weber (1958) in Great Slave Lake, Dionne (1969, a and b) in the Gulf of St. Lawrence, Berkson and Clay (1973) in Lake Superior, and Taylor (1974) near Somerset Island, District of Franklin.

Lacustrine Sand and Gravel Unit

This unit includes depositional features such as beaches, bars, and spits, and erosional features such as scarps. They have developed on till, glaciofluvial, and other lacustrine deposits. The depositional features include single ridges, generally less than 4 m. (12 ft.) in height (Figure 8, unit 7), and series of smaller subparallel ridges 2 to 3

m. (6 to 9 ft.) in height. The latter are shown as lineaments on map units 7 and 1b. The ridges range from asymmetric, with a steeper lakeward flank, to symmetrical. Where exposed they are composed of beds of sand, sand and gravel, and open framework gravel. Many of the beds are well sorted and a few show graded bedding. The ridges include both beaches, such as those in township 6, range 6, and bars and spits, such as those in the southeast (tps. 3 and 4, rge, 9, and tps. 6 and 7, rgs. 10 and 11). The scarps are up to 15 m. (50 ft.) high. They may grade laterally into beach deposits (sec. 3, tp. 2, rge. 10, and secs. 35 and 36, tp. 1, rge. 10).

Relationship of Strandlines to Lake Agassiz Waterplanes

Proglacial Lake Agassiz formed and completely submerged the area as the last ice sheet melted. The lake fell in stages as the northward retreat of the ice uncovered successively lower outlets and as it fell, beaches, scarps and other related features formed at many of these lake levels. The disappearance of the great weight of ice resulted in uplift, or isostatic rebound, of the region during and after the ice retreat (Kupsch, 1967, Elson, 1967). The amount of rebound increased northward resulting in a tilting of the strandline features. These strandlines have been studied in detail by Upham (1895) and Johnston (1946). Their work included determination of the geographic position and elevation together with naming of many of the strandlines.

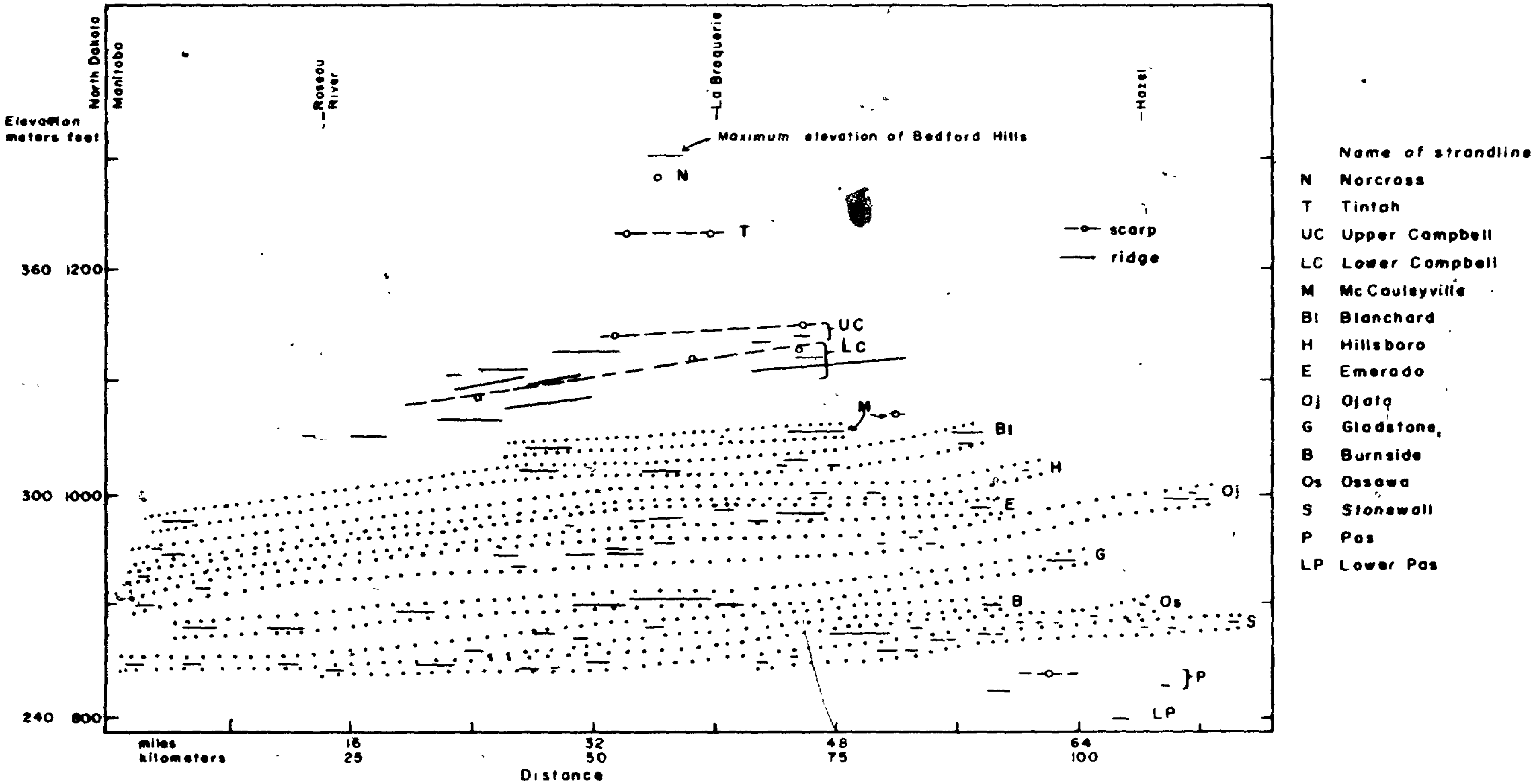
Errors associated with this early work resulted from attempting to correlate strandline segments that are separated by small vertical distances over large horizontal distances, and the overlooking of some of the strandline segments. The recent work of Bluemle (1974) has revealed four previously unrecognized strandlines in southeastern North Dakota for example. Later attempts to correlate with this early work have inherited some of these original errors.

A detailed study of the strandline features in the area is beyond the scope of this project. An attempt was made, however, to group the strandline features, hereafter referred to as segments, according to the waterplane they were formed at and to relate the segments to the beach levels determined by Johnston (1946). The first part was accomplished by estimating the elevations of these features, using topographic maps with a 25 foot (8 m.) contour interval, and projecting the location and elevation of these features onto a line of maximum uplift drawn northeastward through the area. The line of maximum uplift was chosen prependicular to isobase six of Johnston (1946) because this isobase passes through the area. The second part consisted of plotting the location of each segment on the profile diagram of Johnston (1946) and noting the closest beach. Each segment plotted required its estimated elevation and its perpendicular distance from isobase six. Isobase six was drawn on the Quaternary geology map to obtain these distances.

The following factors were considered in relating the strandline segments to the previously determined Lake Agassiz beach profiles: (1) the relationship between the origin of a segment and the water level at the time of its formation: for example a bar often lies below water but the crest of a beach lies above the mean water level, a factor recognized by Upham (1895, p.277), (2) the topographic control available to estimate the segment elevations, (3) that some vertical variation should be allowed in the elevation of the beach profiles to take into account factors such as the above, and variation caused by different workers measuring "strandline elevations" at different positions on the same type of feature. The variation has been estimated at 10 ft. (3 m.) (Kupsch, 1967); 10 to 20 ft. (3 to 7m.) (Elson, 1967); and 20 to 30 ft. (7 to 10 m.) (McPherson, 1970).

A plot of estimated segment elevation against location is shown in Figure 11. The distance between each pair of lines bounding groups of strandline segments probably related to the same water level is generally 3 to 5 m. (10 to 15 ft.). If the allowable variation in segment elevation is raised to 7 to 10 m. (20 to 30 ft.) many of the previously separated segment groups would merge.

A map showing the strandline segments in the area related to the beach profiles of Johnston (1946) is shown in figure 12. The segments of the Bedford Hills have not been previously studied in detail and will be described briefly.



Strandline features projected onto a northeast trending line drawn perpendicular to isobase number 6 of Johnston (1946). Elevation of the features was estimated from NTS maps with a 25 foot (7.5 m) contour interval.

Figure 11. Plot of the estimated elevations versus the location for the strandline segments in the area.

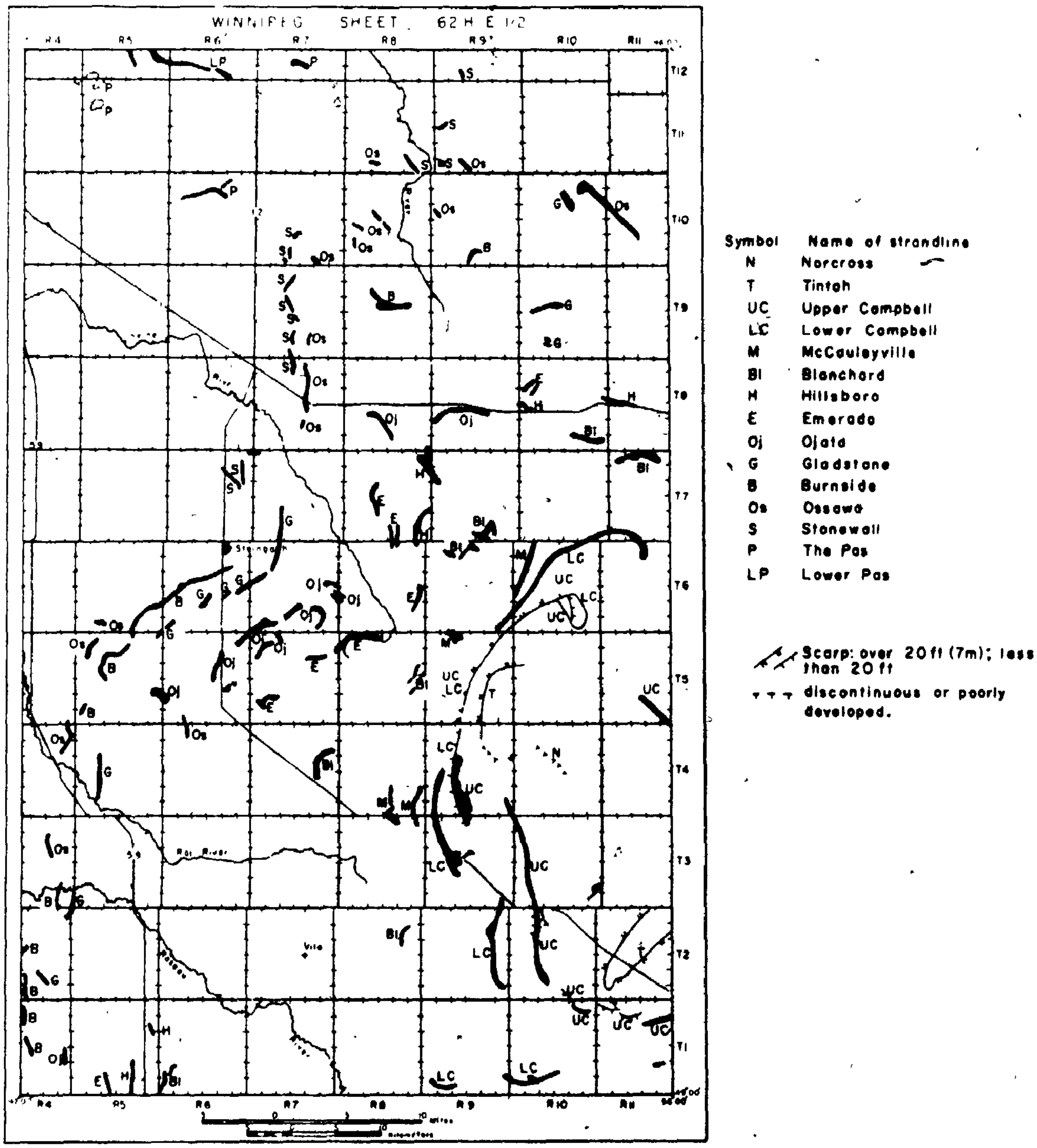


Figure 12. Map showing one possible matching of the strandline segments in the study area to the Lake Agassiz beach profiles of Johnston (1946).

The highest point on the Hills plots midway between the Herman and Norcross waterplanes of Johnston (1946). This point falls only about 3 m. (10 ft.) below the northward projection of the Herman waterplane determined by Moran and Clayton (manuscript, received 1972) at Fertile, northwestern Minnesota. The low subparallel ridges in township 7, range 11, are likely a product of a slight reworking of the glaciofluvial deposits when Lake Agassiz stood at this waterplane. The uppermost recognizable segment is a poorly developed scarp (tp. 4, rge. 10) which plots near the Norcross waterplane. A scarp extending from section 20, township 4, range 10, to section 24, township 5, range 9 occurs below this and may be related to the Tintah waterplane. The toe of a high scarp (sec. 33, tp. 3, rge, 9 to tp. 6, rge. 10) plots at the Lower Campbell waterplane while two slightly higher scarps which join it (sec. 24, tp. 4, rge. 9 and sec. 15, tp. 6, rge. 10) are near the Upper Campbell waterplane. Well developed beaches and spits are also associated with these scarps.

Organic Unit

This unit covers about one half of the eastern portion of the area. The unit has been subdivided into shallow peat (Figure 8, 8a), generally less than 1 m. (3 ft.) deep and deep peat (Figure 8, 8b) more than 1 m. (3 ft.) deep. These deposits generally form level to slightly sloping (0.8-1.6 m./km., 4-8 ft./mi.) plains though the shallow deposits may also fill small depressions. The composition of the units has been described by Ehrlich et al. (1953) and Smith et al. (1964, 1967). The shallow subunit consists of a fibrous to mucky; sphagnum to sedge to reed peat. It may be treeless or support a few clumps of willow and larch. The deep peat is composed of fibrous, sedge to sphagnum peat. It often supports black spruce and tamarack stands though small portions may be covered by string bogs (Zoltai, 1971). Smith et al. (1964) state that these bogs consist of alternating subparallel mossy ridges and sedge filled swales and that the peat is usually 1 to 3.5 m. (3 to 12 ft.) thick. Where exposed in ditches the sediment underlying the peat consists of dark gray clay containing a few molluscs (tp. 8, rge. 9) or gray sand (tp. 8, rge. 10; tp. 10, rges. 9 and 10).

Alluvial Unit

This unit (Figure 8, unit 9) covers a very small portion of the area, being confined to the main waterways. The deposits consist of stratified, moderately to poorly sorted gravel, sand, silt and clay with some layers and lenses which contain abundant organic material. The unit consists of river and flood plain deposits.

Eolian Sand

These deposits form a discontinuous veneer over minor portions of the glaciofluvial and lacustrine sand deposits in the east. Their morphology is generally irregular hummocks, less than 2 m. (6 ft.) high. Well formed dunes are rare. The majority of the hummocks are stabilized though a few blowouts are present (tp. 5, rge. 10). The texture is fine to medium sand.

Part 2.2 Quaternary Stratigraphy

The Quaternary sediment can be divided into a number of stratigraphic units (Table 1). The main units are a number of tills which can be distinguished by the following parameters: (1) texture of the matrix (-2 mm.), (2) lithology of the very coarse sand fraction (2-1 mm.), (3) stratigraphic position, (4) carbonate content of the fine matrix (-0.63 mm.), (5) clast fabric, and (6) pebble (8-4mm.) lithology and concentration. To aid in the description of these units the following compilations have been prepared: (1) geological cross sections (Figures 13, 14 and 15), (2) maps showing the locations of the geologic sections, test holes, and cross sections (Figure 16, a and b), (3) a summary of the properties of the different tills (Table 2), (4) diagrams showing, for each till, the changes in the mean value of each property between the different cross sections (Figures 17, 18 and 19), (5) the available data on pebble composition and concentration (Figure 20). In calculating the mean values for each till within a section the results of all samples on and near the line of section where grouped together. Data from stratigraphic sections and test holes in which the values of a particular property varied notice-

	upper member
Hazel Formation	Steinbach Member (T)
	lower member
Marchand Formation (T)	
Grunthal Formation	
Roseau Formation (T)	
Bedford Formation	Sandilands Sand Member
Senkiw Formation (T)	
Vita Formation	
Tolstoi Formation (T)	
Stuartburn Formation (T)	
St. Malo Formation	
Woodmore Formation (T)	
W/Ra Stratified Drift	
Rosa Formation (T)	
	T = till

Table 1. Quaternary stratigraphy of the study area

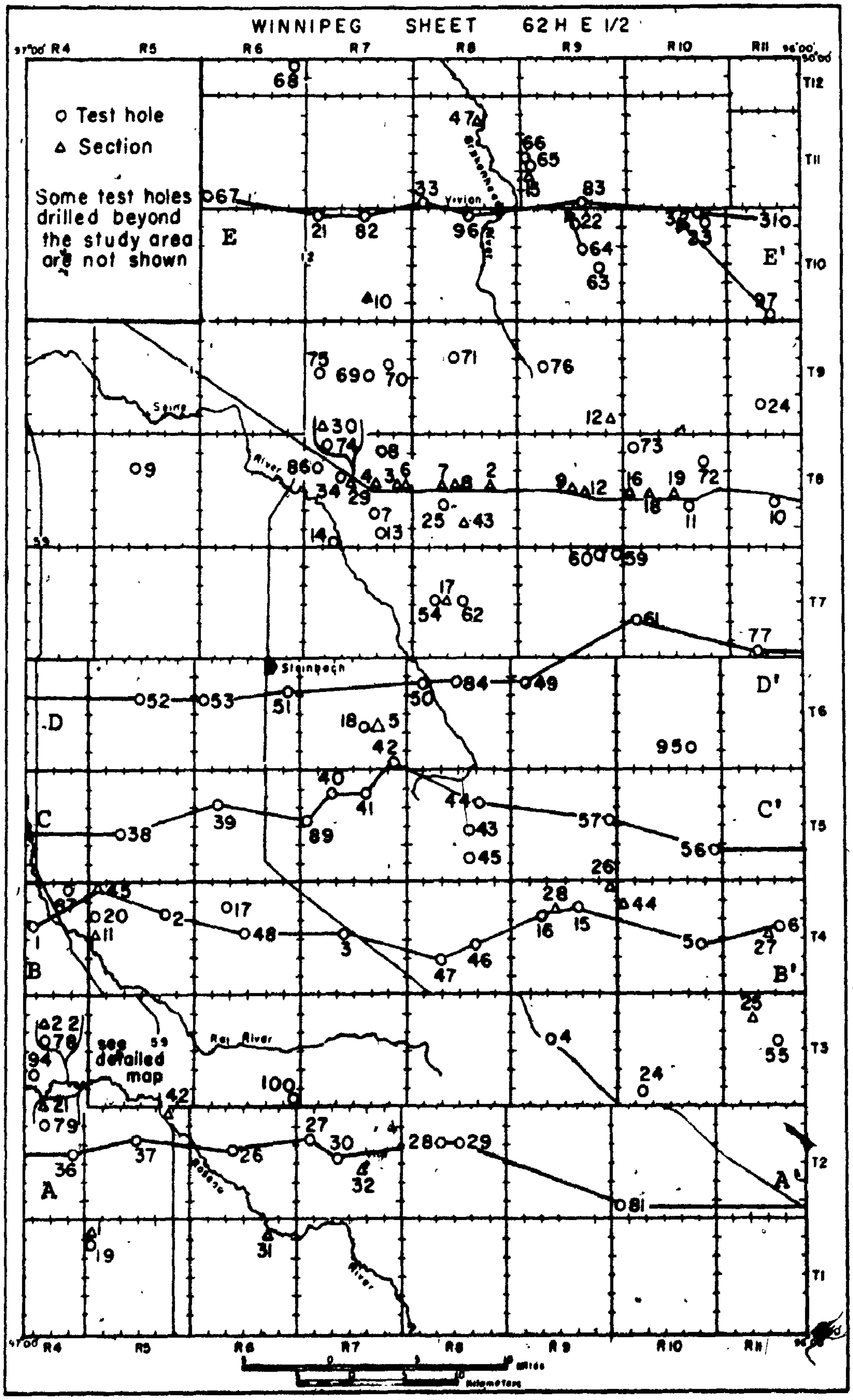


Figure 16(a). Map showing the locations of test holes, geologic sections, and cross sections in the study area.

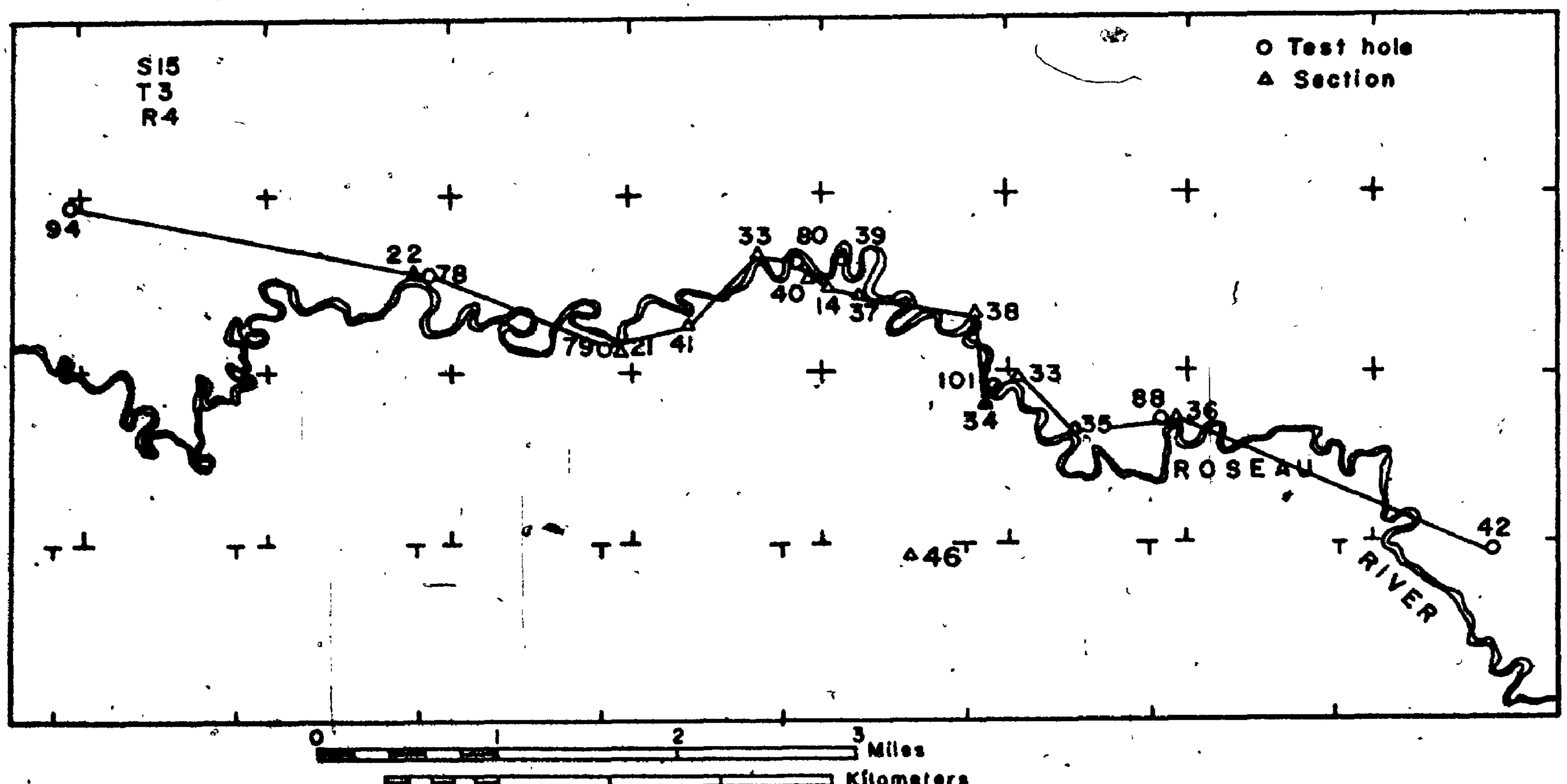


Figure 16(b). Map showing the geologic sections, test holes, and stratigraphic sections near the Roseau River.

TILL	TEXTURE (1) Matrix -2.0mm % Sand Silt Clay	(2) 8-4mm No./L	MATRIX COMPOSITION (2) Pebble (8-4mm) Cr Ls Ds Cb Cr/Cb Ls/Ds	V C Sand (2-1mm) Cr Ls Ds Cb Cr/Cb Ls/Ds	(2) (3) Fine sand Fel Aqz Rqz	-0.063mm Cc Do Cb C/D	FABRIC	COLOUR
Steinbach Member	31 52 17 N=66	204 N=1	18 55 27 82 0.24 2.7 N=4	31 27 42 69 0.45 0.99 N=34	33 62 4 N=8	23 35 58 0.68 N=39	NW-SE	Oxidized: grayish brown, 2.5Y 5/2 wet Unoxidized: olive gray, 5Y 4/2 wet
Marchand Formation	42 43 15 N=82		16 32 52 84 0.19 0.63 N=3	41 16 43 59 0.72 0.41	29 66 4 N=2	15 38 53 0.40 N=70		Oxidized: grayish brown, 2.5Y 5/2 wet Unoxidized: olive gray, 5Y 4/2 wet
Roseau Formation	32 50 18 N=67	181 N=1	16 43 40 83 0.19 1.1 N=1	34 26 40 66. 0.52 0.67 N=35	33 62 4 N=5	17 37 54 0.52 N=43	NW-SE	Oxidized: grayish brown, 2.5Y 5/2 wet Unoxidized: olive gray, 5Y 5/2 wet
Senkiw Formation	60 29 11 N=103	47 N=4	35 47 18 65. 0.59 2.7 N=5	east 70 12 18 30. 2.5 0.74 N=17 west 50. 21. 29 50 1.0 0.81 N=39	32 62 4 N=10	11 27 38 0.44 N=95	NE-SW	Oxidized: light brownish gray, 2.5Y 6/2 wet Unoxidized: dark gray, 5Y 4/2 wet
Tolstoi Formation	25 53 22 N=7	159 N=1	21 21 58 79. 0.26 0.36 N=1	28 8 64 72. 0.40 0.12 N=5		11 44 55 0.25		Oxidized: light yellowish brown, 2.5Y 6/4 wet
Stuartburn Formation	41 45 14 N=7	215 N=3	20 26 53 79 0.25 0049 N=3	41 16 43 59. 0.70 0.37 N=32	37 57 4 N=6	11 39 50 0.30 N=29	WNW-ESE	Oxidized: very dark grayish brown, 2.5Y 3/2 wet Unoxidized: dark olive gray, 5Y 3/2 wet
Woodmore Formation	29 49 22 N=7			27 17 56 73. 0.38 0.30 N=6	27 68 4 N=8	13 48 61 0.29 N=7		Oxidized: grayish brown 2.5Y 5/2 wet Unoxidized: olive gray, 5Y 5/2 wet
Rosa Formation	29 50 21 N=27			42 13 45 58. 0.78 0.29 N=19		12 37 49 0.31 N=17		Unoxidized: dark gray, 5Y N4/ wet

(1) Sand=2.-0.063 mm, Silt=0.063-0.002 mm, Clay=-0.002 mm.
(2) small number of samples, data may not be representative
(3) 0.250-0.125 mm fraction

Cr=crystalline, Ls=limestone, Ds=dolostone, Cb=total carbonate, Fel=feldspar, Aqz=angular quartz, Rqz=rounded quartz, Cc=calcite, Do=dolomite, N=number of samples
NO./L=number of pebbles per liter of till

Table 2. Summary of the properties of the till units.

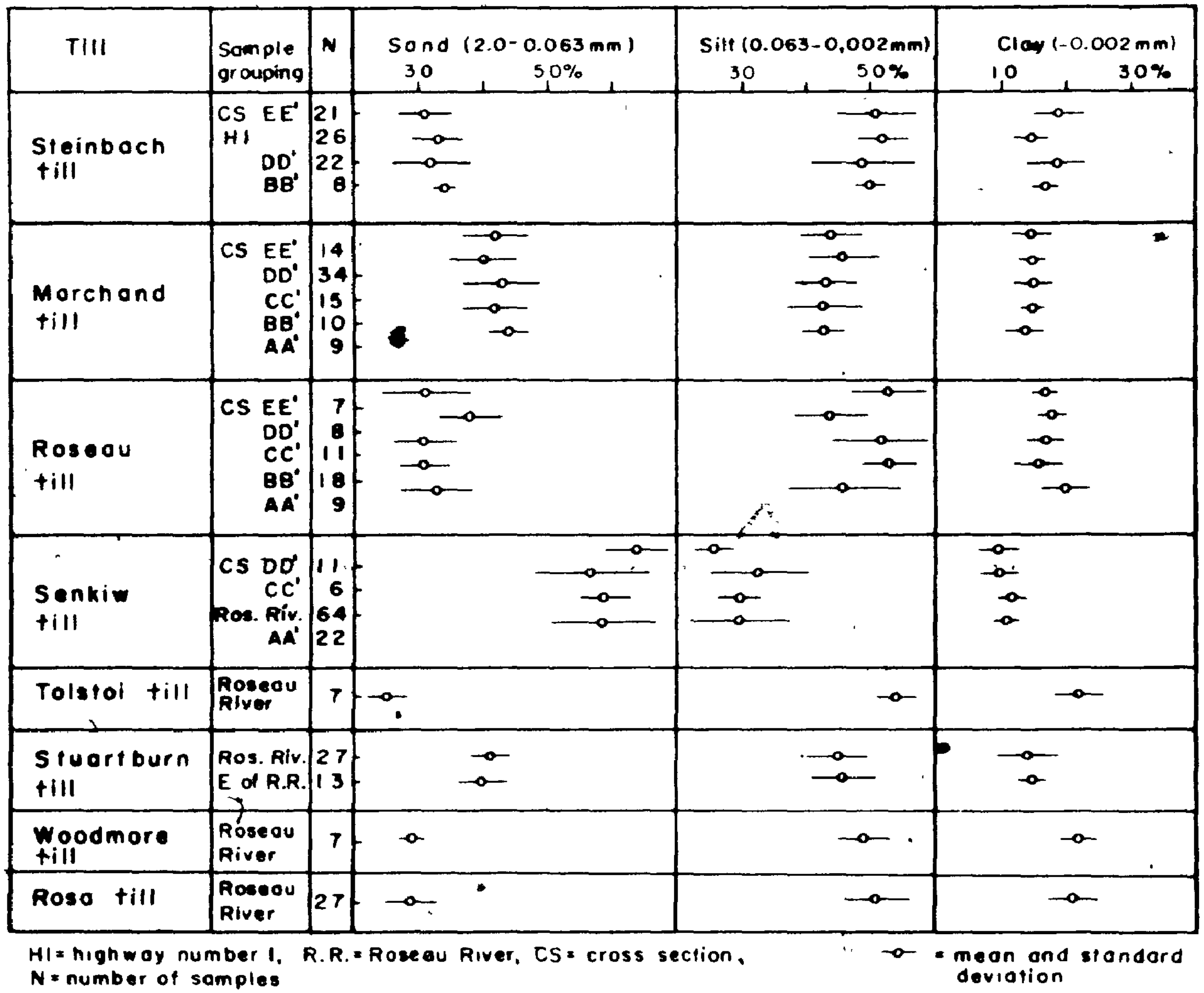


Figure 17. Matrix texture of each till unit within each cross section.

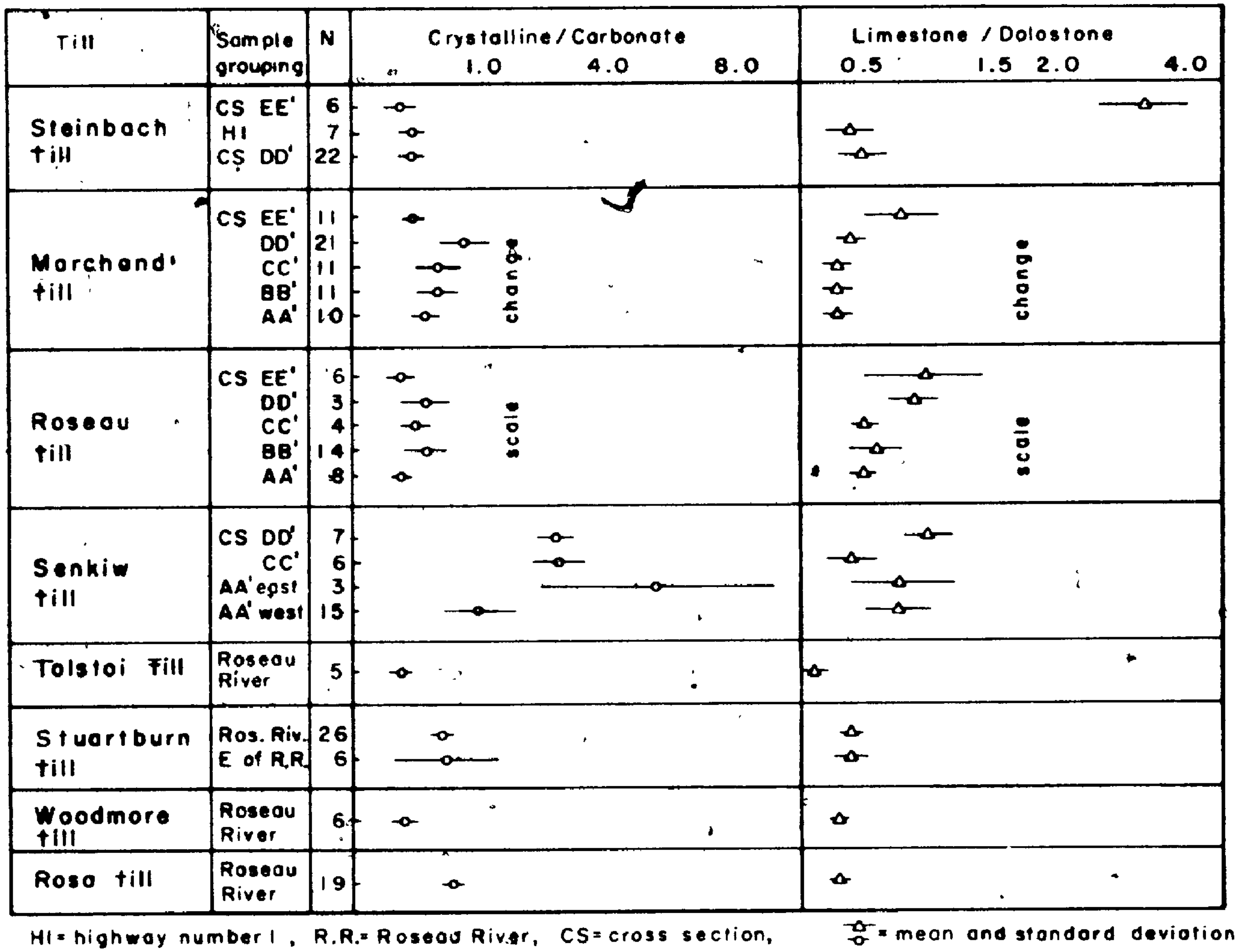


Figure 18. Ratios of the major lithologic components of the very coarse sand fraction of each till unit within each cross section.

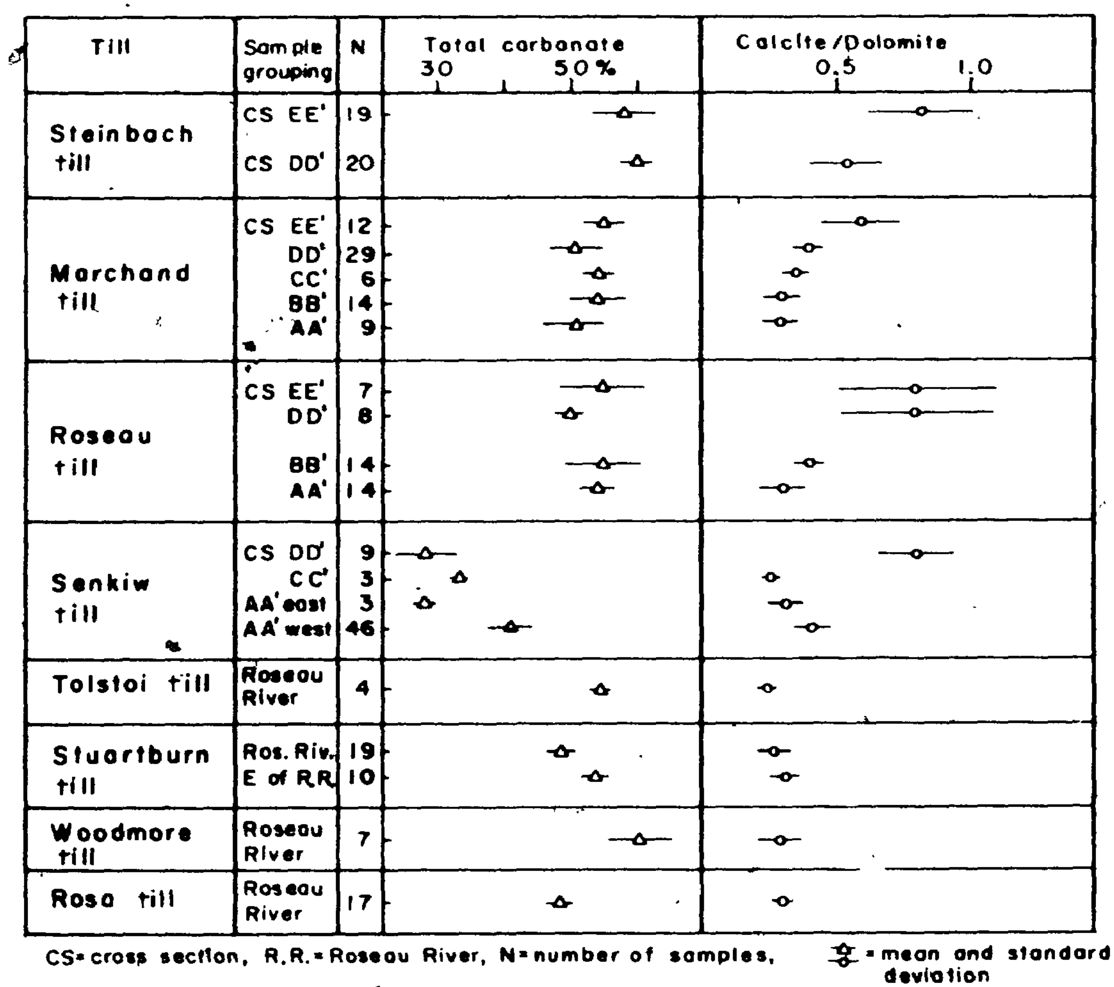


Figure 19. The fine matrix carbonate content of each till unit within each cross section.

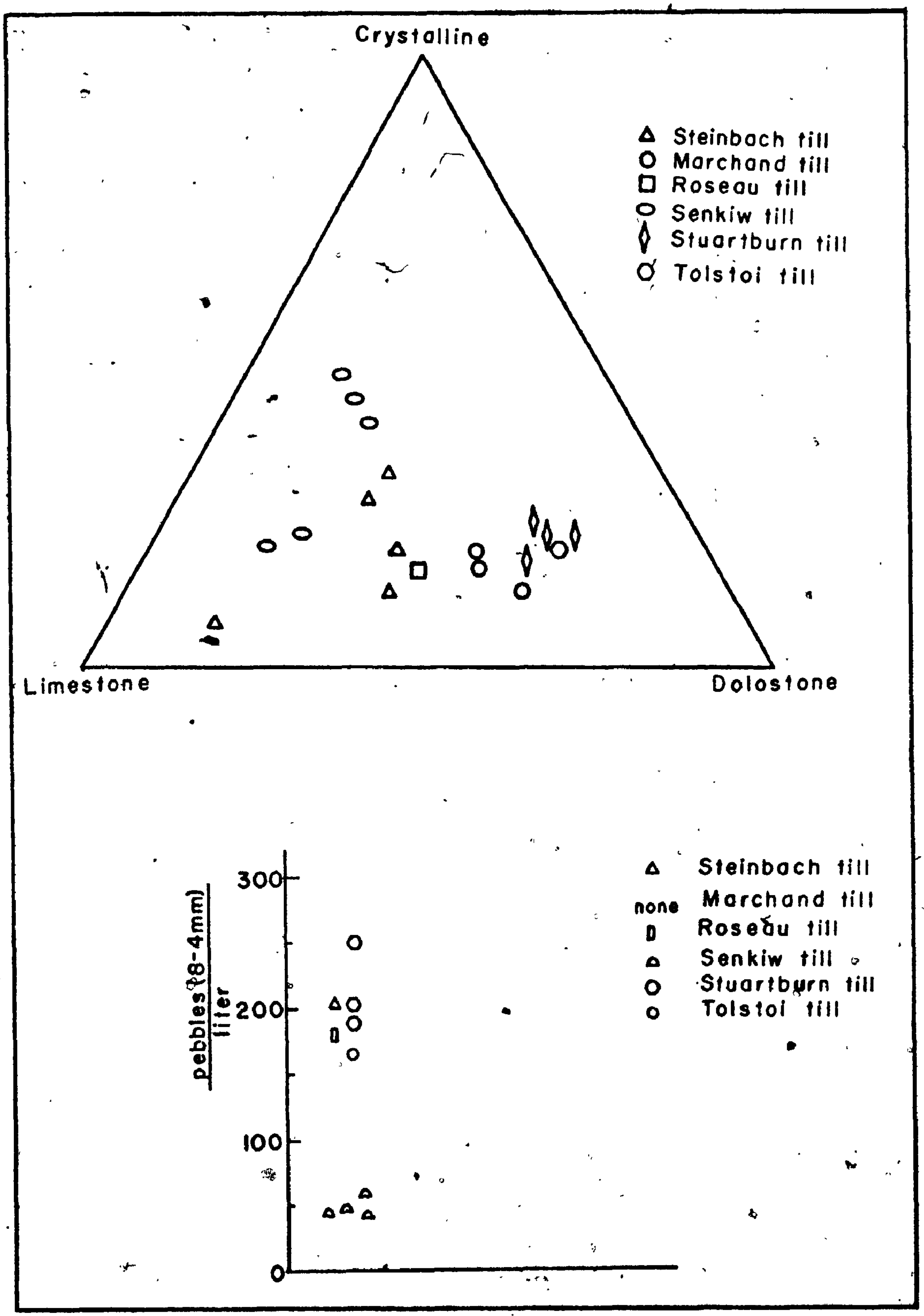


Figure 20. Diagrams showing the data on pebble (8-4 mm) composition and concentration in the till units.

ably and consistently from the cross section mean were not included in the final calculations and are discussed separately. The value of the mean and standard deviation for the grouped samples and the samples within each group are listed in Appendix J. Additional comment on some of the units can be found in chapter 3.

Rosa Formation

The Rosa Formation derives its name from the Rosa Post Office (sec. 27, tp. 3, rge. 5) located north of the Roseau River where this till was first recognized. No type section is designated at this time because of the lower contact of this till has not been reached. Reference sections include test holes FW79, FW80 (Figure 16(b)), and FW101 (tp. 3, rge. 6 Figure 16(a), Appendix H).

The Rosa Formation is a silty sand till (Figure 21) or a loam to silty loam (the latter textural designation and similar ones in the following text are based on the United States Department of Agriculture soil classification, 1951) with a mean texture of 29 percent sand, 51 percent silt, and 21 percent clay (Table 2). The mean composition of the very coarse sand fraction is 42 percent crystalline, 13 percent limestone, and 45 percent dolostone grains, and that of the fine matrix 12 percent calcite, 37 percent dolomite and 49 percent total carbonate. The colour is dark gray (5Y N4; this and all other colour codes refer to the Munsell Soil Colour Chart, 1954) when wet and unoxidized.

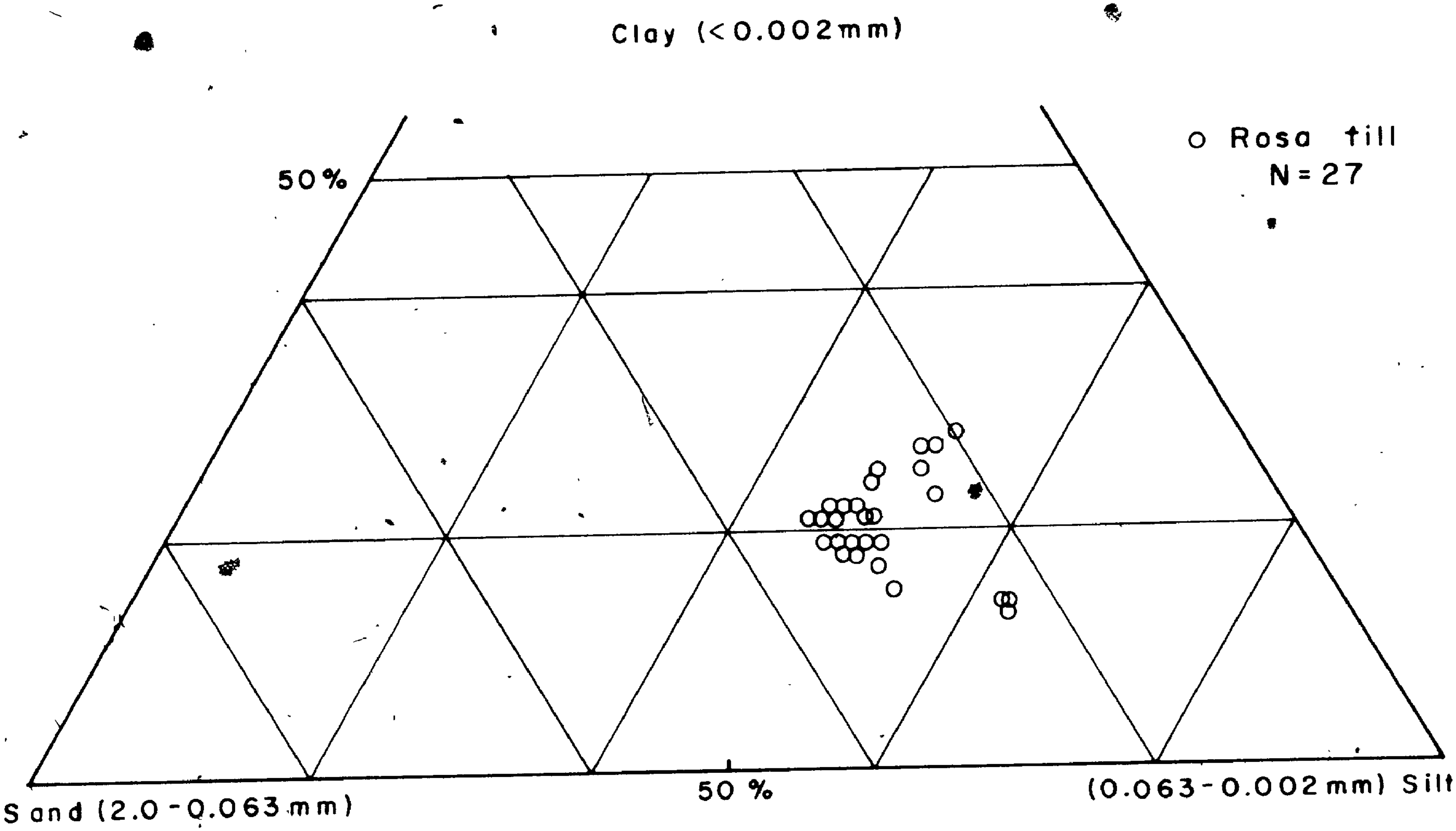


Figure 21. Ternary plot of the texture of the Rosa till matrix samples.

This till is generally harder and slower-drilling than the overlying Woodmore Formation.

The upper contact is sharp where overlain by stratified drift (Figure 15, FW80) but where covered by the Woodmore Formation (Figure 15, FW79) the analyses indicate some incorporation of the Rosa till into the Woodmore till. The lower contact has not been reached.

The Rosa Formation has been recognized in the deep test hole drilled near the Roseau River (Figure 22) where it has a minimum thickness varying from about 5 m. (15 ft.) to 15 m. (50 ft.). Two ground water test holes drilled about 8 km. (5 mi.) north and 9.6 km. (6 mi.) south of this portion of the River suggest there is about 30 m. (100 ft.) of drift below the lowest depth reached. At least a portion of this is the Rosa Formation. Tentatively this unit has also been recognized in northwestern Minnesota (test hole FW91).

The Rosa till is distinguished from the overlying tills mainly by its texture and very coarse sand composition (Table 2). This is finer-grained than the Stuartburn Formation (Figure 23) and has a larger porportion of crystalline grains in the very coarse fraction (about 15%, Table 2) than the texturally similar Woodmore and Tolstoi Formations.

Information concerning the source of this unit is limited to textural and compositional data. The small limestone to dolostone ratio and the fine texture suggest that this till was deposited by ice advancing over the predominantly dolostone bedrock west and northwest of the area.

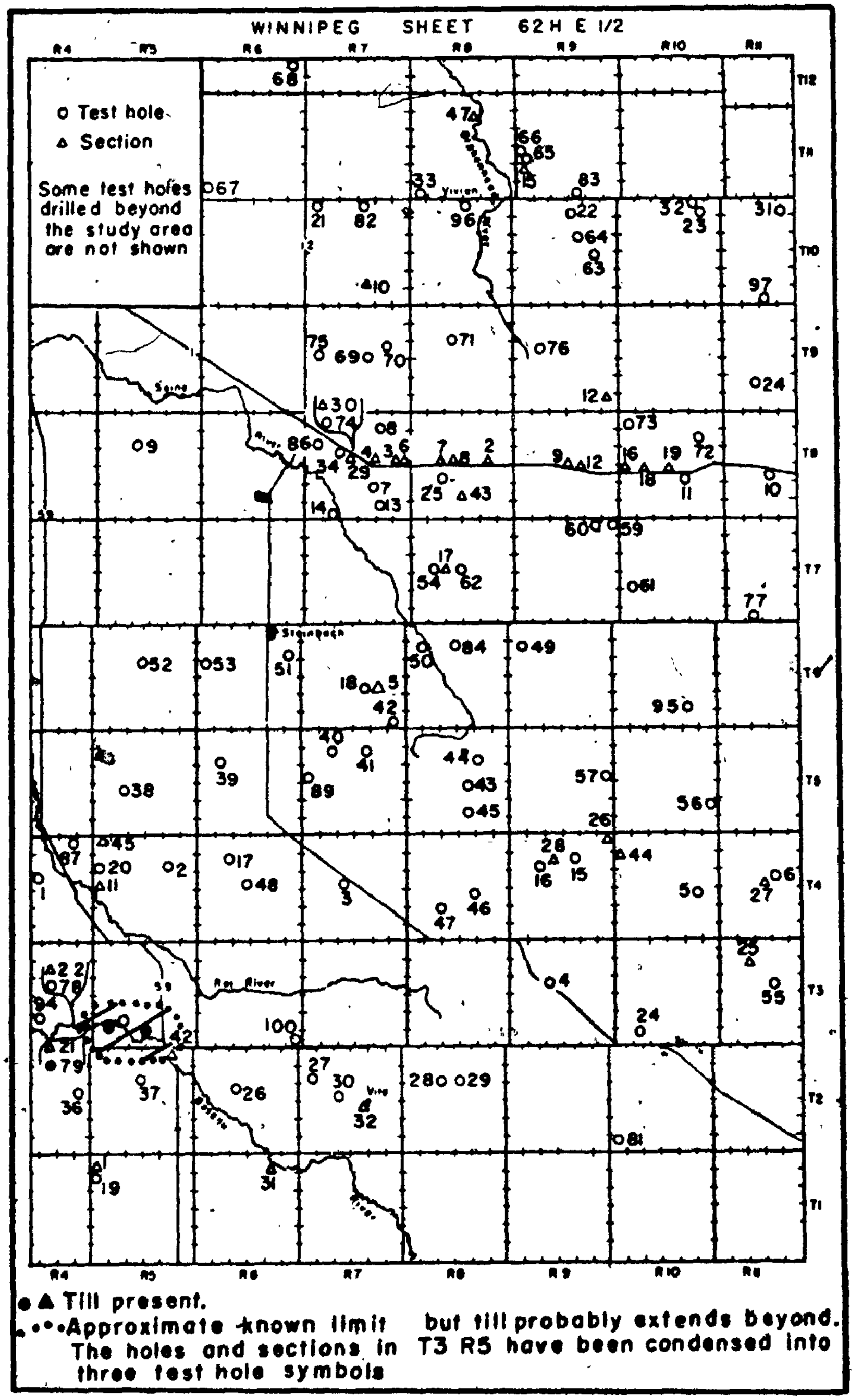


Figure 22. Map showing the distribution of the Rosa till.

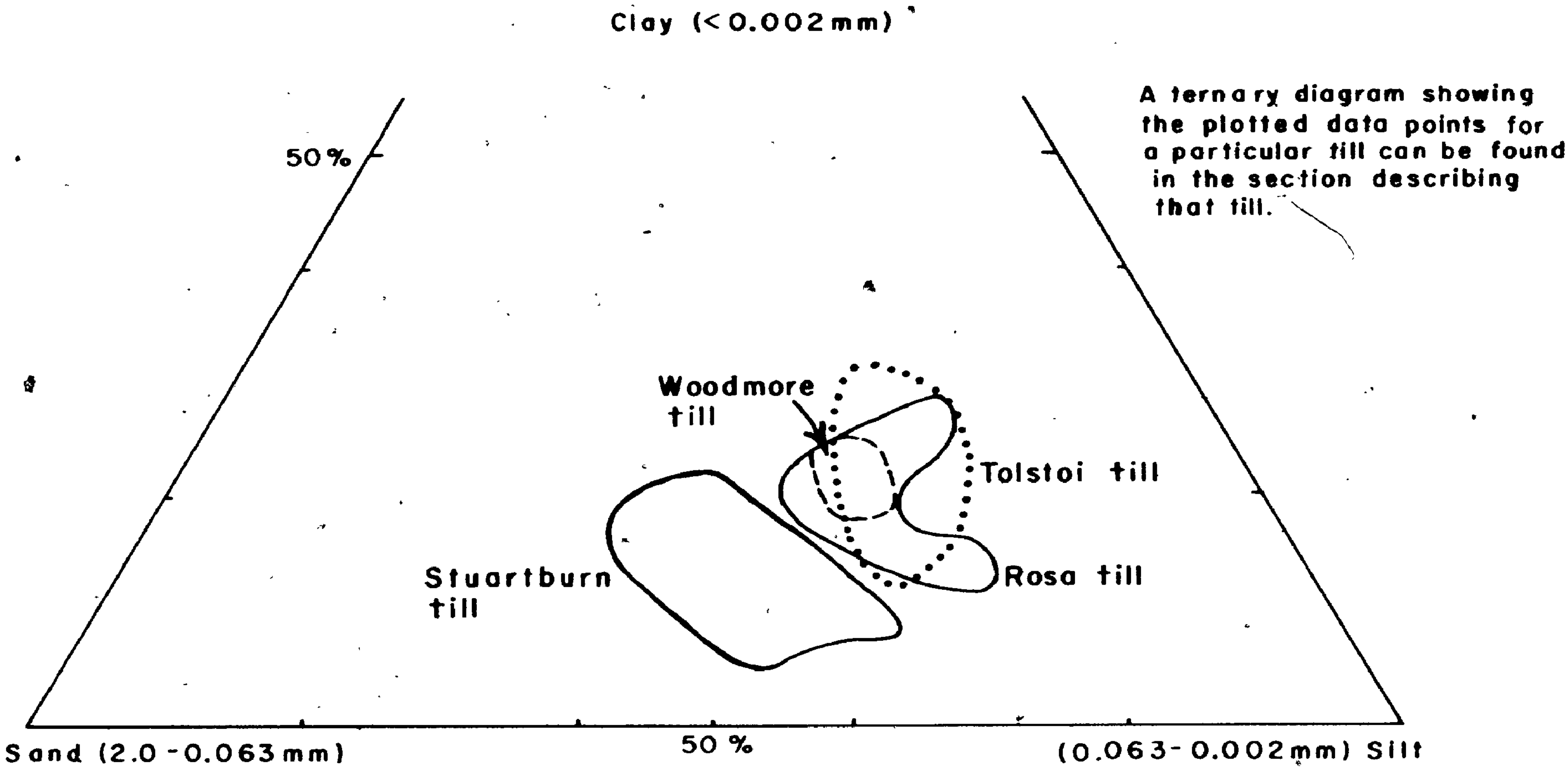


Figure 23. Textural comparison of the Rosa, Woodmore, Stuartburn, and Tolstoi tills.

W/Ra Stratified Drift

This informal unit includes all the stratified drift between the Woodmore and Rosa Formations. This unit has been found only in test hole FW80 (Figure 15) where it consists of about 5 m. (15 ft.) of clayey silt underlain by about a meter (3 ft.) of fine to medium grained sand.

Woodmore Formation

The source of the name is the Woodmore Post Office (sec. 17, tp. 2, rge. 5) located south of the Roseau River along which the unit is exposed. The type section is test hole FW80 (C L.S.D. 9, sec. 7, tp. 3, rge. 5). Reference sections are FWS14, FWS39, and FW79 (Figure 16(b), Appendix H).

The Woodmore Till is a silty sand till (Figure 24) or a loam to silty loam (USDA, 1951) with a mean texture of 29 percent sand, 49 percent silt, and 22 percent clay. The very coarse sand fraction consists of 27 percent crystalline grains, 17 percent limestone grains and 56 percent dolostone grains and the fine matrix contains 13 percent calcite, 48 percent dolomite and 61 percent total carbonate (Table 2). The till is grayish brown (2.5Y 5/2 wet) when oxidized and olive gray (5Y 5/2 wet) when unoxidized.

The upper surface is exposed only in sections FWS14, and FWS39, where it forms a sharp contact with the overlying St. Malo Formation. The lower contact is either with stratified drift (Figure 15, FW80) or with the Rosa till (Figure

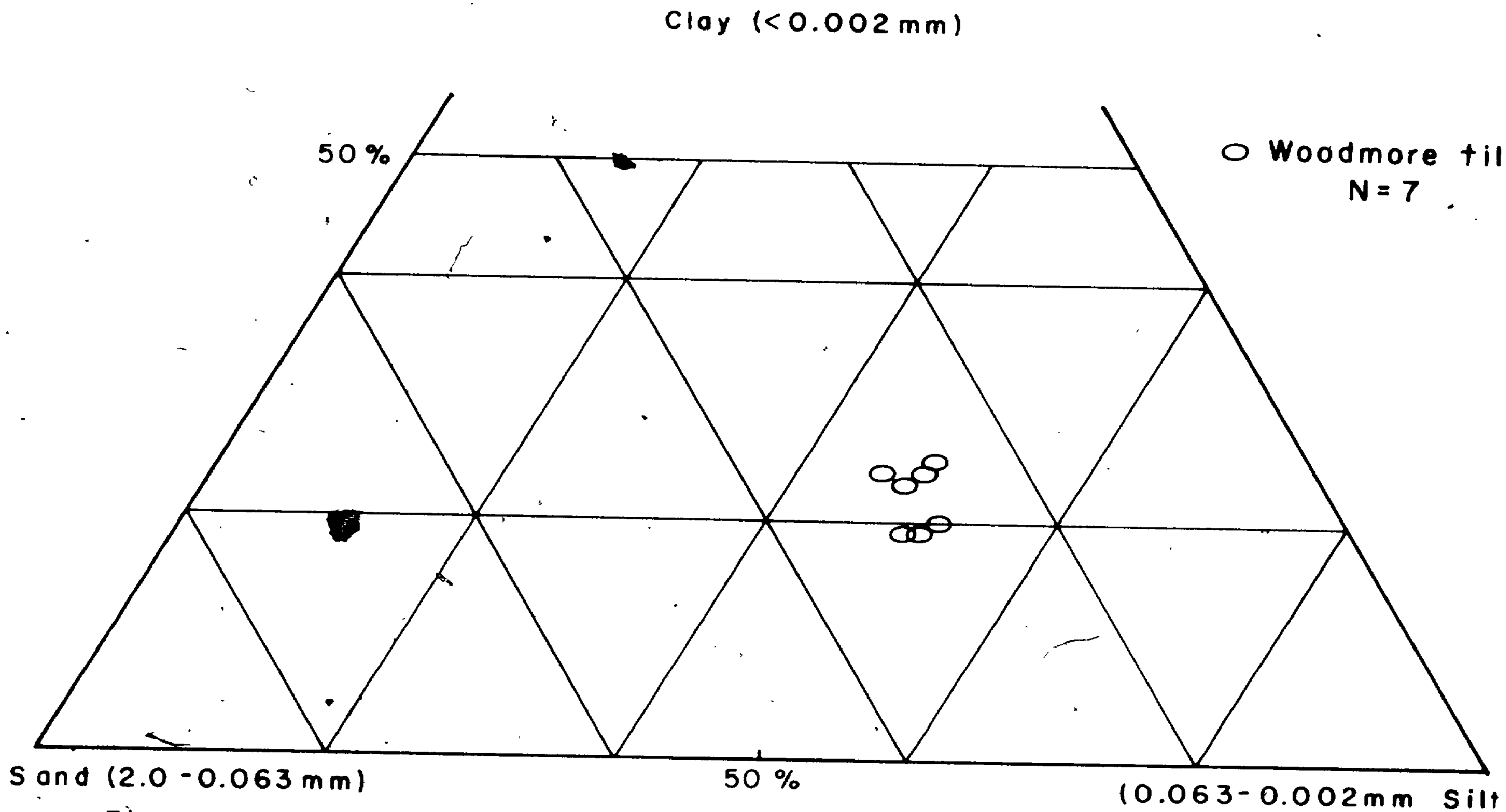


Figure 24. Ternary plot of the texture of the Woodmore till matrix samples.

15, FW79) and in both cases analyses show incorporation of the underlying sediment into the base of the Woodmore till.

This unit has been recognized near the Roseau River and tentatively east of it (Figures 15 and 25). The thickness is about 3 m. (15 ft.).

The Woodmore till is distinguished from the Rosa till by having a smaller proportion of crystalline grains (15%) in the very coarse sand fraction (Table 2) and from the Stuartburn Formation (till) by a finer texture (Figure 23) and a smaller proportion of crystalline grains (14%, Table 2). This till has a larger limestone to dolostone ratio (very coarse sand) than the Tolstoi Formation (till) (0.30 to 0.12, Table 2).

The high proportion of dolostone (VCS) and dolomite (fine matrix) and the fine texture suggests the till was deposited by ice moving over the dolostone-rich bedrock to the west and northwest of the area. The absence of W/Ra Stratified Drift on the west side of the area (Figure 15) also indicates erosion by ice advancing from the west.

St. Malo Formation

The St. Malo Formation includes all the stratified sediment above the Woodmore Formation and below the Stuartburn Formation (till). The source of the name is the town of St. Malo (sec. 23, tp. 4, rge. 4) situated north of the type section. The type section is the Circus Section (FWS14, NE1/4 L.S.D. 5, sec. 8, tp. 3, rge. 5) Refer-

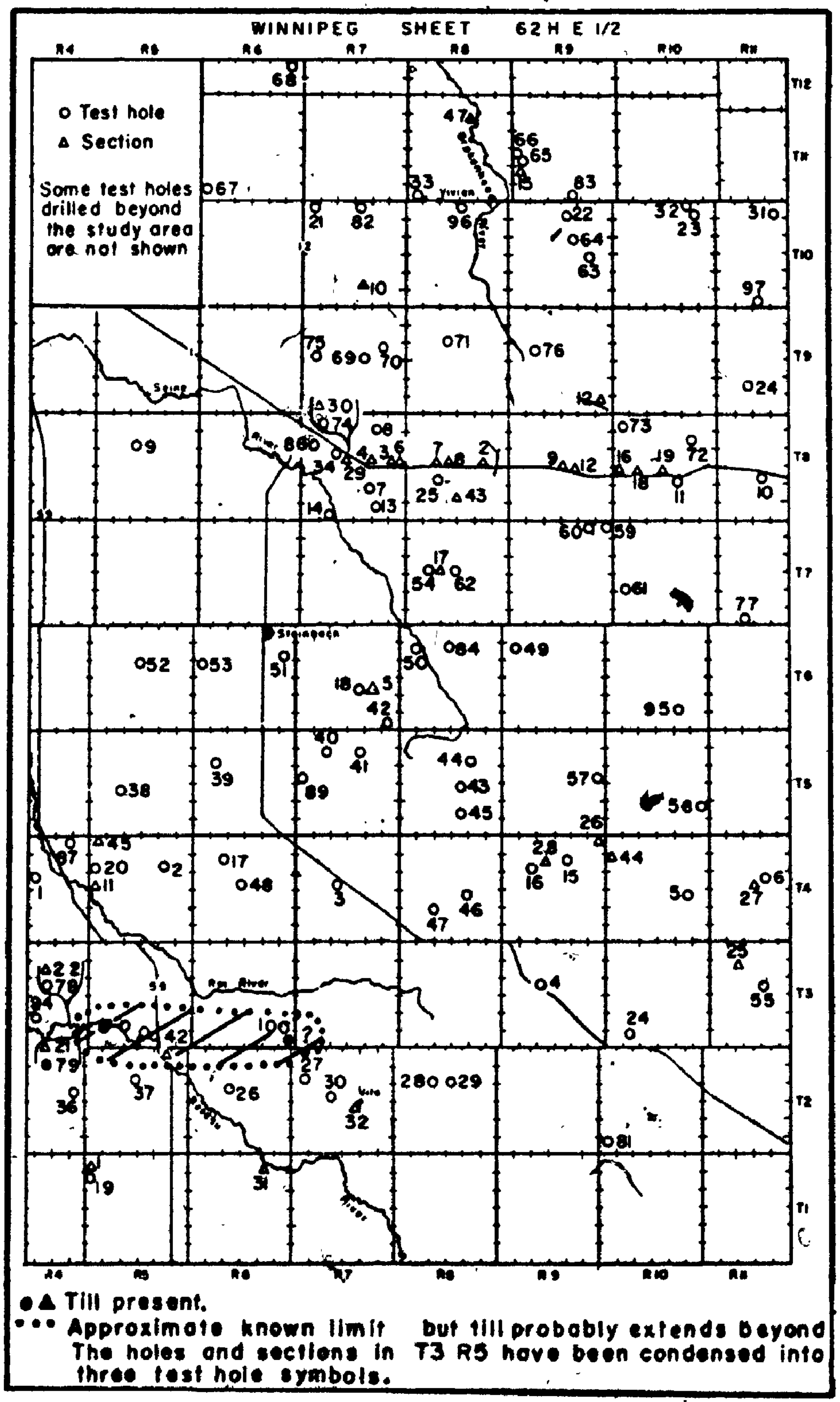


Figure 25. Map showing the distribution of the Woodmore till.

ence sections are FWS39 and FW80 (Figure 16(b), Appendix H).

The drift is thin, consisting of, in upward succession, about 5 cm. (2 in.) of sandy granules, 5 cm. (2 in.) of fine grained compressed plant material, and 1 m. (3 ft.) of fine sand and minor silty clay (Circus Section, Figure 15). One sample of the organic material yielded an uncorrected radiocarbon age of greater than 38,000 years B.P. (GSC 1465, unpublished) and one of 25,517±342 B.P. (BGS49, Brock Univ.). The second date is too young. The results of the palynological analyses of a sample are shown in Appendix K. R. J. Mott (written com., 1972) states that the pollen and the spore content is low and the pollen assemblage shows "a clear resemblance to late glacial or early Holocene spectra from southern Manitoba and adjacent Minnesota" and "similar assemblages have been interpreted as indicating a closed coniferous forest of spruce (both *Picea glauca* and *P. mariana* present) probably associated with *Larix* (tamarack), *Populus* (poplar and aspen), and birch and various other shrubs and herbs". No faunal remains were noted when the disaggregated organic material was examined under a microscope.

The contacts with both the Stuartburn and Woodmore tills are sharp. The unit is differentiated from the other stratified units by its stratigraphic position.

Stuartburn Formation

The name is taken from the settlement of Stuartburn (sec. 18, tp. 2, rge.6) situated southeast of the type section. The type section is FWS14 (Circus Section, NE 1/4 L.S.D. 5, sec. 8, tp. 3, rge. 6. Figures 15 and 16(b)). Reference sections include FWS38, FWS39, FWS40, and FWS41 (Figure 16(b) and Appendix H).

The Stuartburn Formation is a silty sand till (Figure 26) or a loam to silty loam (USDA, 1951) with a mean texture of 41 percent sand, 45 percent silt, and 14 percent clay. The very coarse sand fraction is composed of 41 percent crystalline, 16 percent limestone, and 43 percent dolostone grains and the fine matrix contains 11 percent calcite, 39 percent dolomite, and 50 percent total carbonate (Table 2). The pebble fraction is high in dolostone (20% crystalline, 26% limestone, and 53% dolostone; Figure 20). The clast fabric is west-northwest-east-southeast (Figure 27).

All but the upper part of the Stuartburn till is massive and cut by closely spaced and, in some sections reddish brown, horizontal and vertical joints. In section FWS40 the author dug 2 m. (6 ft.) into the till and beyond that depth the staining disappeared and the joints could no longer be detected. The till is very dark grayish brown (2.5Y 3/2) when wet and oxidized and olive gray (5Y 3/2) when wet and unoxidized.

In many places the upper part of this unit consists of a sequence of interbedded till and stratified drift. The

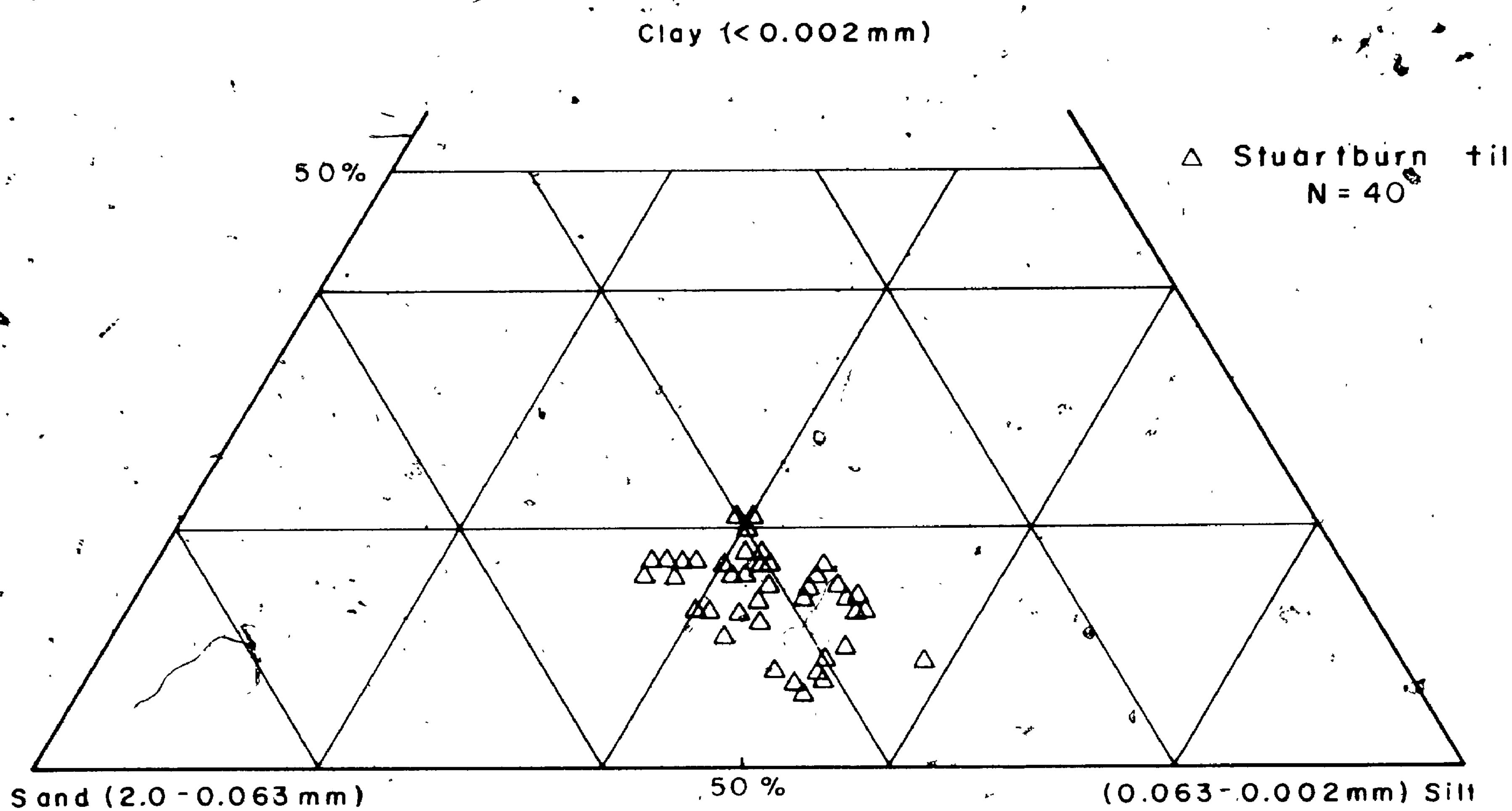


Figure 26. Ternary plot of the texture of the Stuartburn till matrix samples.

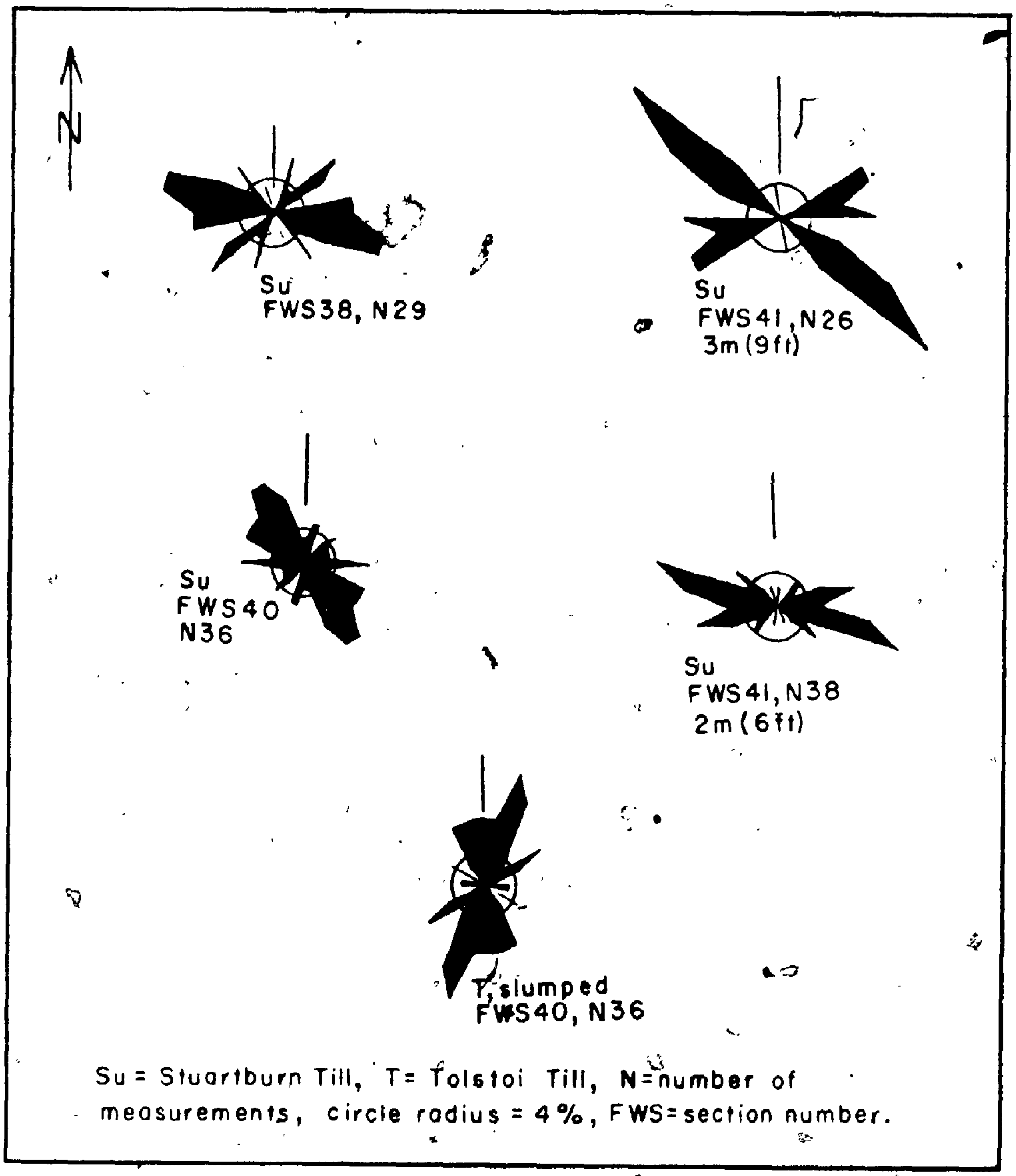


Figure 27 . Clast fabrics of the Stuartburn Till and Tolstoi Till.

degree of development of the layering and the composition of the layers varies with depth and from section to section. In general however, the layering becomes better developed higher in the section with a change from wavy, discontinuous layers of variable thickness near the base to continuous, nearly parallel ones in the upper part. There is also an upward change from till interbedded with till-like, poorly sorted, clayey, silty, sand to interbedded well sorted sand and silt near the top. In sections FWS38 and FWS40 (Figure 16(b)) the overlying Tolstoi Formation (till) is interbedded with the upper part of this stratified sequence and in others this sequence is overlain by the Vita Formation (Stratified sediment).

Where examined, the lower contact of this till is sharp and with the St. Malo Formation.

The Stuartburn till has been recognized along the Roseau River (Figure 15), east of it (Figures 13 and 28) and in northwestern Minnesota (test hole FW91, Appendix H).

The base of the till is covered in many sections but the known thickness varies from a total of a few meters to about 3 m. (9 ft.) of massive till overlain by about 2 m. (6 ft.) of interbedded till and stratified drift (FWS38). East of the Roseau River it varies from about 5 m. (15 ft.) to about 10 m. (30 ft.).

The Stuartburn till is differentiated from the till above and below it mainly by the texture (Figure 23) and the very coarse sand composition (Table 2). This till has more sand

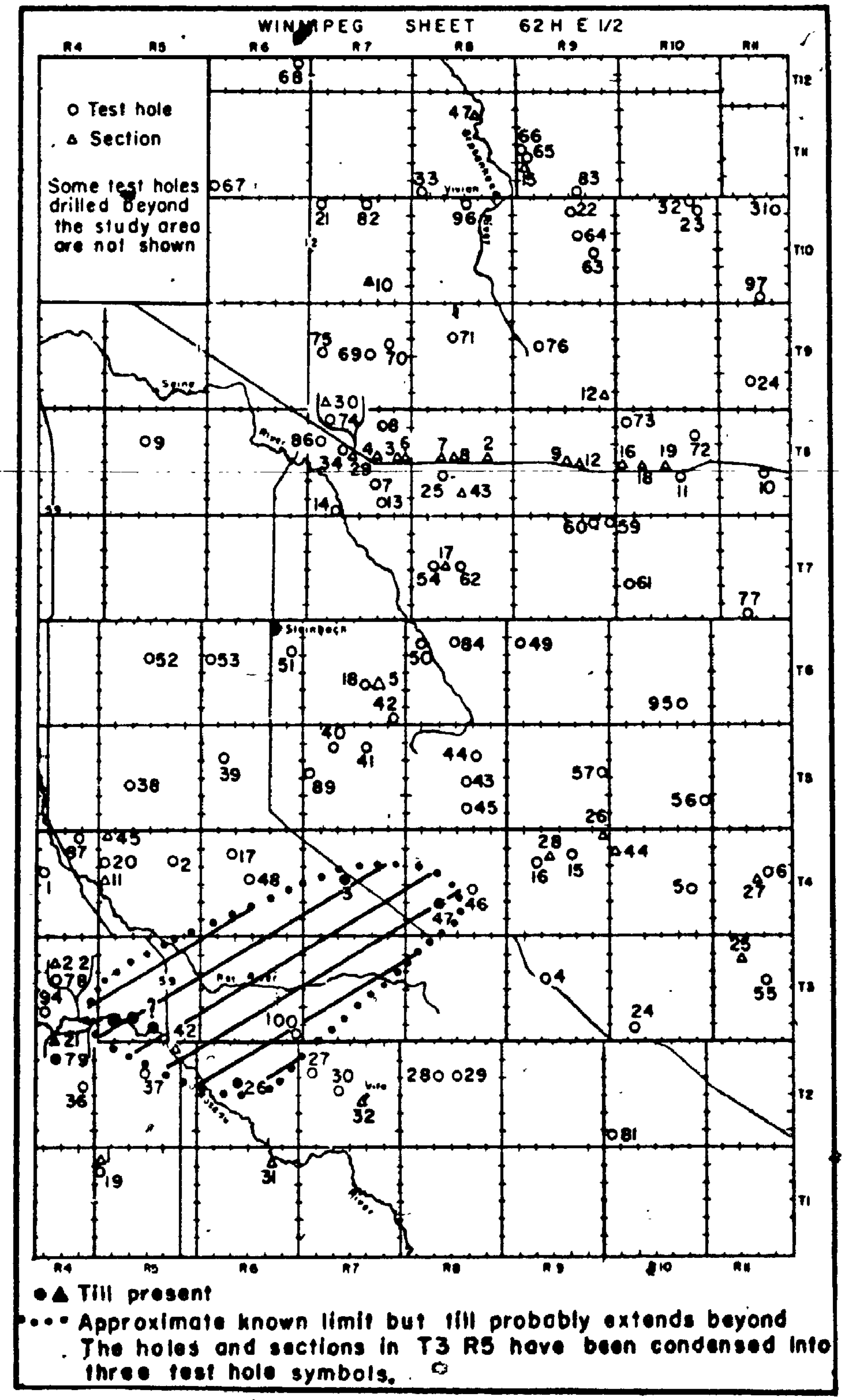


Figure 28. Map showing the distribution of the Stuartburn till.

(about 14%) and crystalline grains (14%) than the Tolstoi and Woodmore tills, more sand (13%) than the Rosa till, and less sand (19%) and less crystalline grains (10 to 30%) than the Senkiw Formation (till). The small limestone to dolostone ratio (very coarse sand and pebble fractions) also helps separate it from the Senkiw and younger tills (Figure 18, Table 2).

This till was likely deposited by ice advancing over the dolostone bedrock west and northwest of the area. This is suggested by (1) the WNW-ESE fabric and (2) the high proportion of dolostone and dolomite in the till.

Tolstoi Formation

The source of this name is the settlement of Tolstoi (sec. 36, tp. 1, rge. 5) southeast of the type section. The type section is FWS38 (Silence Section: SW1/4 L.S.D. 8, sec. 8, tp. 3, rge. 5). Reference sections are FWS39 and FWS40 (Figure 16(b), Appendix H).

The Tolstoi Formation is a silt till (Figure 29) or a silty loam (USDA. 1951) with a mean composition of 25 percent sand, 53 percent silt, and 22 percent clay. The very coarse sand fraction consists of 28 percent crystalline, 8 percent limestone, and 64 percent dolostone grains while the fine matrix contains 11 percent calcite, 44 percent dolomite and 55 percent total carbonate (Table 2). The pebble count indicates a predominance of dolostone (21% crystalline,

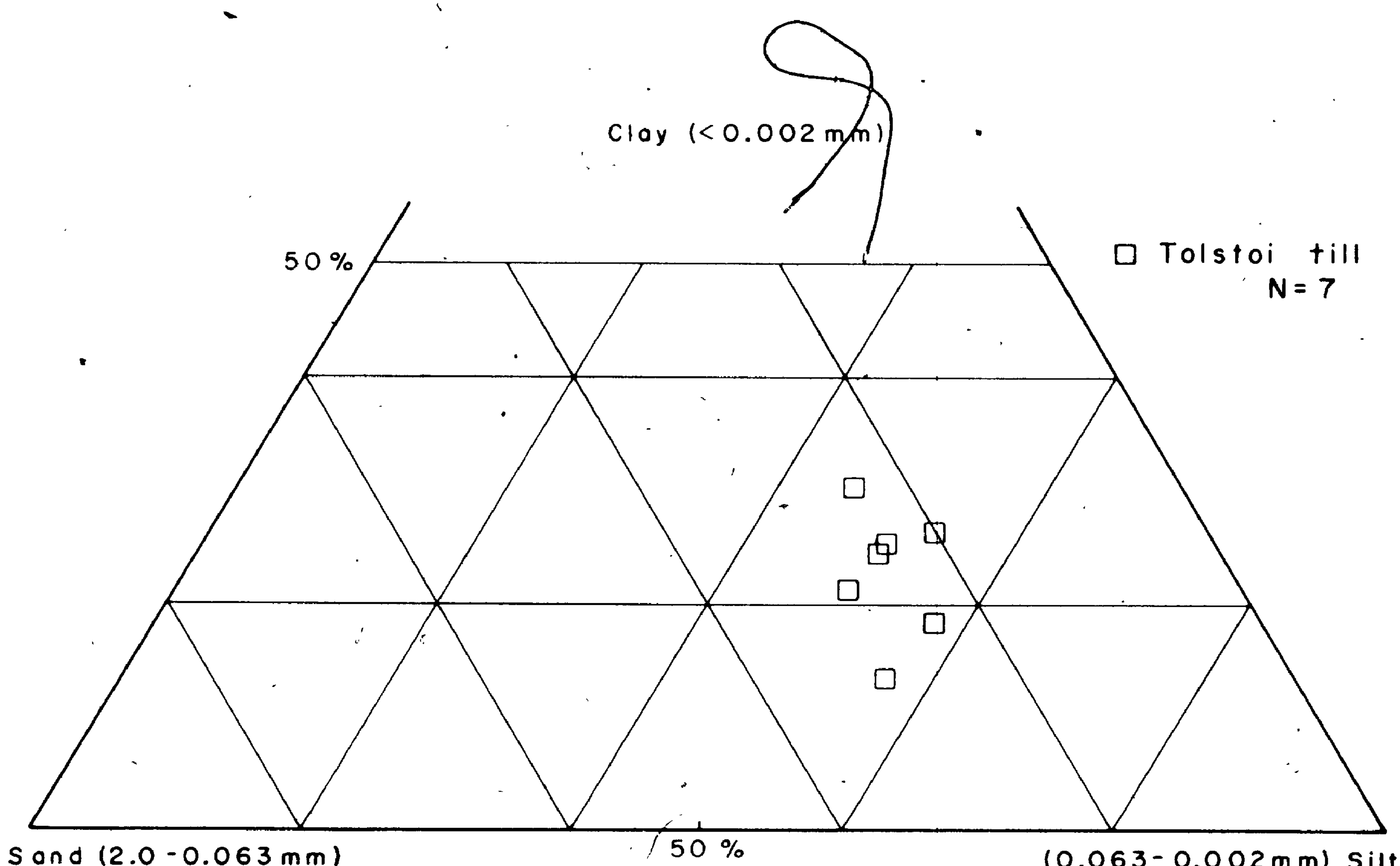


Figure 29. Ternary plot of the texture of the Tolstoi till matrix samples.

21% limestone, and 58% dolostone). The only clast fabric measured is east-northeast - west-southwest.

The exact nature of the unit, changing from section to section, varies from one to three layers each about 30 cm. (1 ft.) thick, which are underlain by, overlain by, and, where applicable, interbedded with sand or silt. Near the surface the till contains many horizontal, reddish brown stained joints. In section FWS40 (Figure 16(b)) excavation revealed that both the joints and staining could not be detected beyond about 2 m. (6 ft.) into the unit. Till is light yellowish brown (2.5Y 6/4) when wet and oxidized and in most sections at least one of the layers has a characteristic "pinkish tint" when viewed in sunlight. The contact between this till and the overlying Vita Formation is sharp. In sections FWS38 and FWS40 the Tolstoi till is interbedded with stratified sediment which is indistinguishable from the underlying stratified drift near the top of the Stuartburn till.

This till has been recognized in sections FWS14, FWS37, FWS38, and FWS40 (Figures 15 and 30). It is generally less than 1 m. (3 ft.) thick.

The Tolstoi till is differentiated from the other tills mainly by its fine texture (Figure 17 and 23; mean sand, $\bar{T}$ 25% others 29 to 60%) and the high dolostone content in the very coarse sand fraction (Figure 18, Table 2; mean DS, $\bar{T}$ 64% others 18 to 56%).

The high dolostone content together with the fine grained texture of this till suggests it was deposited by

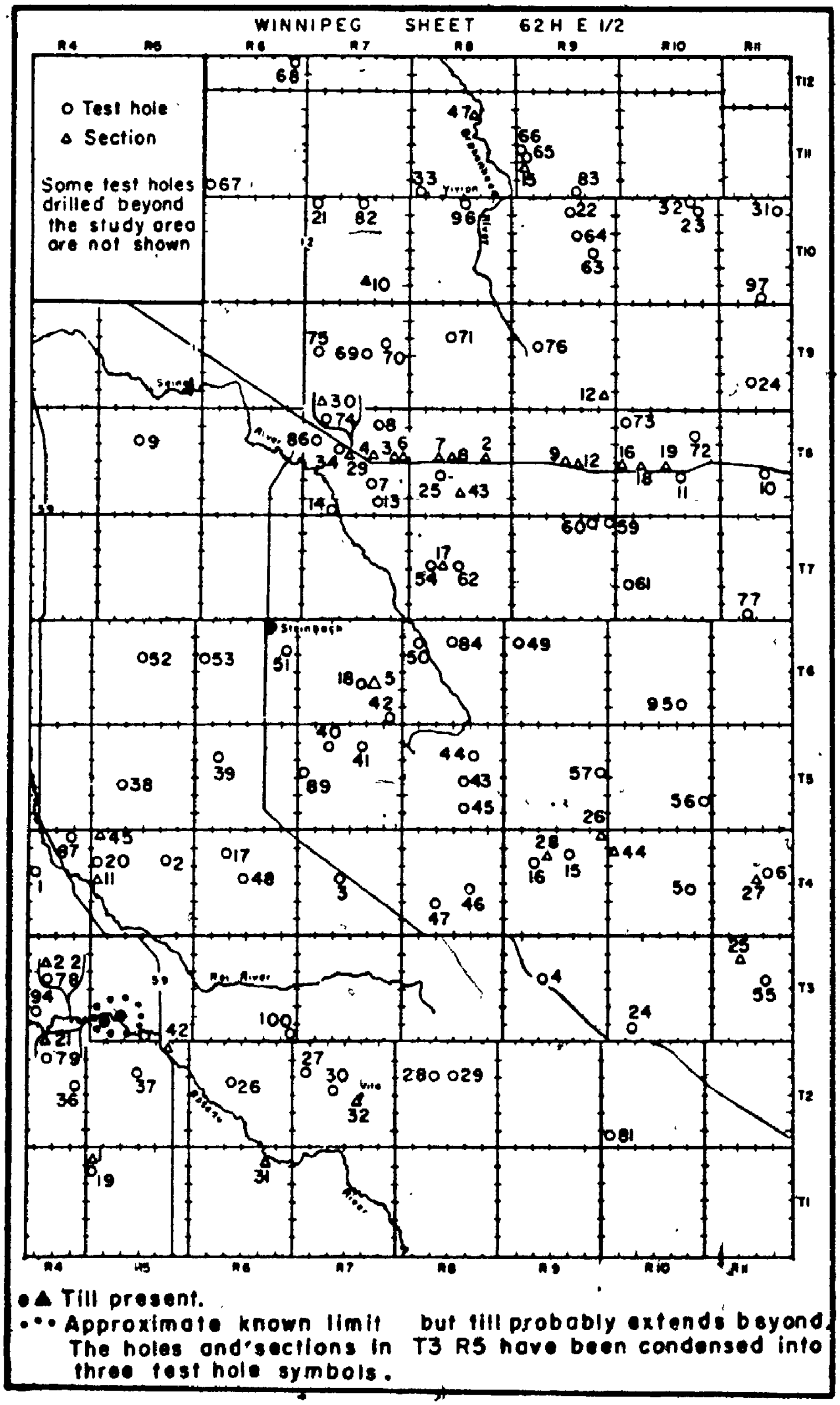


Figure 30. Map showing the distribution of the Tolstoi till.

ice advancing over the predominantly dolostone bedrock west and northwest of the area. The one fabric measured (Figure 27) could be a transverse fabric, a frequent occurrence in thin tills such as this, but is probably a slump fabric because it parallels the fabric measured in the slumped till below it.

Vita Formation

The Vita Formation comprises all the stratified sediment above the Tolstoi Formation and below the Senkiw Formation. The name is derived from the settlement of Vita (sec. 23, tp. 2, rge. 7). The type section is the Circus Section (FWS14, NE1/4 L.S.D. 5, sec. 8, tp. 3, rge. 5). Reference sections are FWS38 and FWS41, (Figure 16(b), Appendix H).

This formation is exposed in a number of sections along the Roseau River (Figure 15). For the purposes of description this unit can be subdivided into the lower contorted gravel and sand, the middle pond and flood plain deposits, and the upper sand and silt.

The contorted sand and gravel consists of an obscurely bedded sandy gravel in the upper part and grades downward into sand. The deposit, particularly the upper part, is highly stained and oxidized, and in section FWS38 analyses of the VCS show the upper part contains more crystalline and less limestone grains than the lower part (upper 50% crystalline, 6% limestone, and 43% dolostone; lower 37%

crystalline, 16% limestone, 46% dolostone). The thickness ranges from about 30 to 60 cm. (1-2 ft.). The contortions often involve the lower part of the floodplain deposit and also, in some sections, the upper part of the underlying interbedded till and stratified drift. The contortion zone is generally about 1 m. (3 ft.) thick. One structure which resembles a fossil ice wedge was found in section FWS40. This contorted sand and gravel layer has not been recognized west of section FWS41 (Figure 16(b)).

The pond and floodplain deposits are a slightly clayey silt containing a few pebbles. They are massive to obscurely bedded and in some places contain discontinuous, wavy black streaks. Where freshly exposed or below the water table the colour is dark gray (N4 wet) and where oxidized it is grayish brown (2.5Y 5/2 wet).

These deposits contain abundant organic material including ostracodes, molluscs, plant material, and insects. Samples from FWS34, FWS38, FWS40, and FWS41 (Figure 16(b)) were examined by L.D. Delorme and L.L. Kalus, Canada Center for Inland Waters and the results from the individual samples (Delorme, written com., 1974) are recorded in Appendix K. The molluscs included both terrestrial and aquatic species. They indicate deposition in oxbow lakes or extant muddy stream bank locations in an open, slightly moist, grassland or tundra environment which perhaps merged with a dwarf coniferous forest containing some broadleaf trees. Brush or trees were present on or near the floodplain. The climate was cooler than the present. The ostracodes, present only in the samples from section FWS34, indicate deposition in "an intermittent stream located within a mixed forest association". The mean annual temperature was "about 1.19°C (range -9.5 to 6.6°C) and the total annual precipitation was 17.7 inches (range 9.1 to 39.6 inches)." (Delorme, written com., 1974). This is cooler and dryer than the present with a mean annual temperature of about 1.8°C and mean annual precipitation of about 20.5 inches (Smith et al., 1964). Palynological analysis of a sample from an organic layer in Section FWS41 suggests a botanical assemblage similar to the late glacial or early Holocene assemblages from southern Manitoba and adjacent Minnesota indicating a closed coniferous forest with spruce declining as pine moved into the region (R.J. Mott, written com., 1972). The contact with the overlying sand and silt is sharp.

The upper sand and silt subdivision is present in many of the sections and test holes along the Roseau River (Figure 15) and is generally a fine to medium grained sand with a few silt layers. In sections FWS14, FWS40, and FWS41 (Figure 16(b)), where this subdivision is well exposed, there is an irregular alternation between (1) thicker layers of horizontally bedded sand and (2) thinner layers of interlaminated sand and silt, which are sometimes deformed. In section FWS40 there is also gravel near the base of the sequence.

In section FWS21 (Figure 16(b)) some of the thinly laminated layers are much thicker, up to 1 m. (3 ft.), and throughout the section they show evidence of current erosion with portions of individual layers being totally removed in some places and partly fragmented in others. Some of the sand layers are horizontally laminated while others show well developed cross bedding and climbing ripples. The cross bedding, in this particular section, dips generally southeastward (mean 141°, N=10). Logs up to 10 cm. (4 in.) in diameter are present throughout this subdivision in section FWS21, particularly near the contacts of the sand and interlaminated silt and sand layers. One log (Picea sp.; R.J. Mott, written com., 1972) yielded an uncorrected radiacarbon age of >41,000 years BP (GSC 1663, unpublished). The log was likely buried shortly after falling into the water because it still included the bark and had many thin, projecting twigs when collected.

In section FWS38 (Figure 15) the pond and floodplain deposit is overlain by a generally massive silt (81% silt) containing a few gastropods. A water-worn log found in the sandy upper part of this sediment in section FWS35 yielded a corrected radiocarbon age of >43,000 years BP (GSC 1801, unpublished).

Where recently exposed or below the water table this sediment is unoxidized with a gray colour (N5 to N6 wet). Where exposed the sand is a light yellowish brown colour with reddish brown staining along some of the bedding planes.

The silt is a light grayish brown colour.

The contact with the underlying flood plain deposit is sharp. In section FWS21 where the flood plain and contorted sand and gravel deposits have not been recognized there is no sharp contact with the underlying interbedded till and stratified sequence, merely a disappearance of the till layers.

The Vita Formation is also present in some of the test holes drilled in other parts of the area. In FW94, drilled west of the Roseau River sections (Figure 16(b)), the unit consists of about 12 m. (40 ft.) of silty clay, the lower two thirds of which contains small clasts of silty and, in some cases, till-like sediment. This drift is present in test hole FW26 (Figure 13, cross sec. AA'; Figure 16(a)) and is likely the sediment underlying the Senkiw till in FW36, (Figure 13, cross sec. AA') and FW42 (Figure 14, cross sec. CC'). The known thickness ranges from about 4 m. (12 ft.) to 17 m. (55 ft.). The thick stratified deposits that many of the water well logs report lying below the upper few tills (Figure 13 and 14) may be, at least in part, equivalent to this unit. If this is the case the maximum thickness of this drift is much greater than mentioned above.

This unit is differentiated from the other stratified units by its position between the Senkiw till and the Tolstoi till, or where the latter is absent the Stuartburn till.

Lower Drift in the Northeast

This includes all the drift in the northeastern portion of the area lying below the Roseau Formation or the Sandilands Sand Member of the Bedford Formation. This drift has been recognized in only a few places (Figure 14, cross sec. EE' and FW77 cross sec. DD') and is neither well understood nor defined. It can be split into as many as three tills (Table 3) and some stratified drift. Stratified drift has not been found between till A and till B so the possibility that till A is the lower part of B with a large amount of incorporated sand cannot be excluded. Till C contains a lower proportion of crystalline grains (30%, Table 3) in the very coarse sand fraction.

The lack of stratigraphic information at depth between the northeastern and southern parts of the area precludes any correlation of the lower tills in the northeast. The properties of even the upper three tills in the north (Figure 14, cross sec. EE') noticeably from those of the same tills farther south (Figures 17, 18, and 19).

Senkiw Formation

The source of the name is the Senkiw Post Office (sec. 17, tp. 3, rge. 5). No type section is designated at this time. Reference sections are FWS34, FWS36, FWS41, and FW94 (Figure 16(b) and Appendix H).

The Senkiw Formation is a slightly pebbly silty sand (Figure 31) or a sandy loam (USDA, 1951) with a mean matrix

Till	Matrix (-2.0mm)			VC Sand (2-1mm)				-0.063 mm				Colour
	Sand	Silt	Clay	Cr	Ls	Ds	Cb	Cc	Do	Cb	Cc/Do	
				Cr/Cb		Ls/Ds						
		%			%				%			
C	28	50	22	30	25	44	69	20	32	52	0.60	Grayish brown,
	N=7			0.45		0.66		N=3				10YR 4/2 wet
				N=7								
B	27	50	23	69	21	9	30	24	19	43	1.30	Dark gray,
	N=9			3.0		3.9						5Y 4/1 wet
				N=8								
A	72	24	4	63	26	11	37	9	26	35	0.74	Gray
	N=3			2.7		3.5		N=3				5Y 5/1 wet
				N=2								

Cr=crystalline, Ls=limestone, Ds=dolostone, Cb=total carbonate, Cc=calcite, Do=dolomite
N=number of samples used to obtain mean.

Table 3. Properties of the lower tills in the northeast.

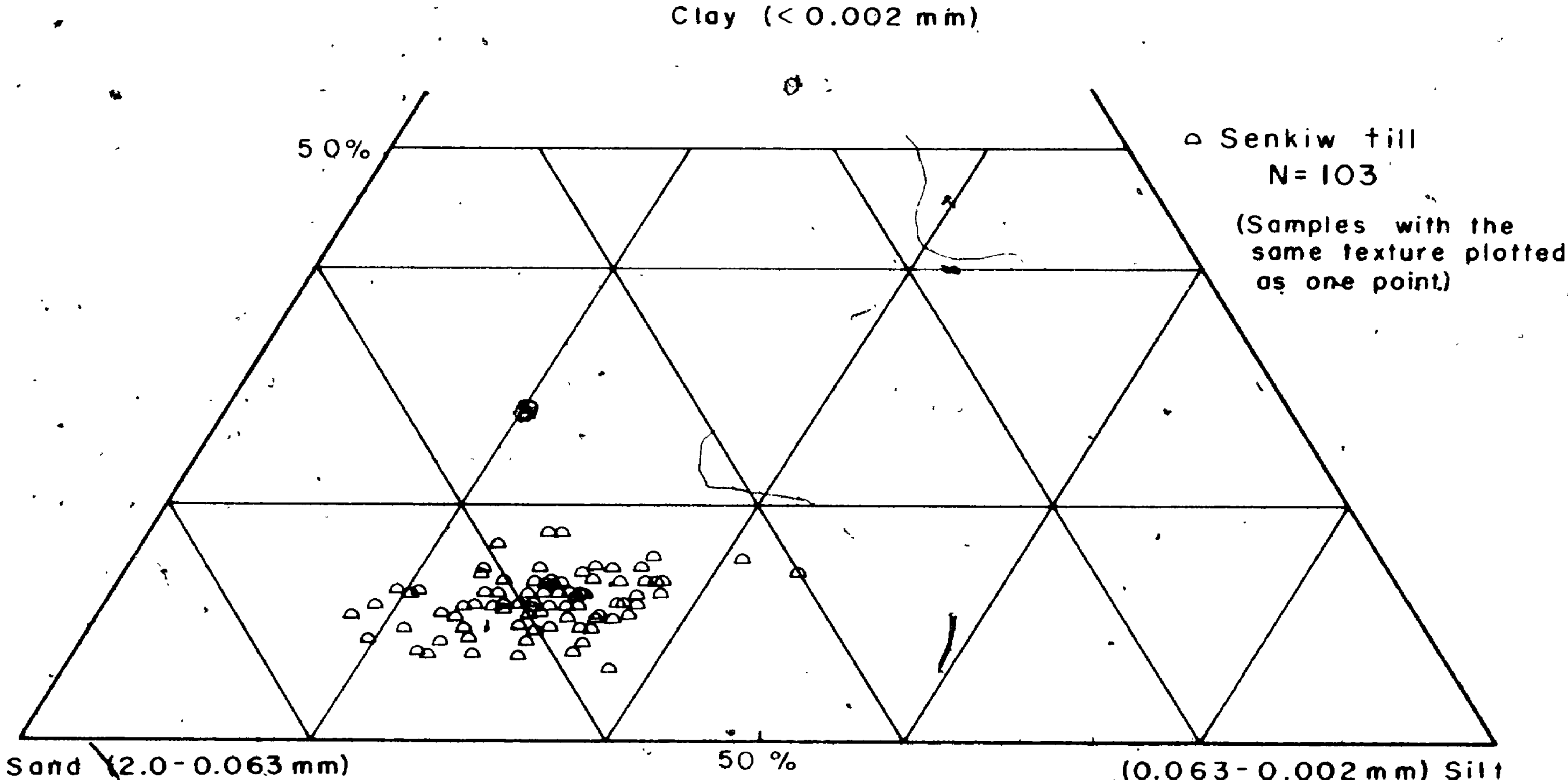


Figure 31. Ternary plot of the texture of the Senkiw till matrix sampls.

texture of 60 percent sand, 20 percent silt, and 11 percent clay (Table 2). The mean composition of the very coarse sand is, in the west, 50 percent crystalline, 21 percent limestone, and 29 percent dolostone grains, and in the east, 70 percent crystalline, 12 percent limestone, and 18 percent dolostone grains. The fine matrix carbonate has a mean composition of 11 percent calcite, 27 percent dolomite, and 38 percent total carbonate. The mean pebble composition is 35 percent crystalline, 47 percent limestone, and 18 percent dolostone clasts. Some lignite fragments are present in all size fractions examined. The clast fabric is generally northeast-southwest (Figure 32; see chapter 3 for a discussion of the fabric). Along the Roseau River, the only place where it is naturally exposed, (tp. 3, rges. 4 and 5) the Senkiw till is usually massive and forms near vertical, comparatively joint free, cliffs capping many of the sections. The clast content is low (47 pebbles/liter, Table 2). It is hard and resistant when dry but disintigrates easily when immersed in water. A few discontinuous sand layers are present in some sections and in FWS36 the till is interbedded with at least three layers of stratified drift up to 3 m. (9 ft.) thick. Drag folds developed near the upper surface of one layer, in FWS36, indicate a generally westward movement of the immediately overlying Senkiw till. The only exposure in the north (FWS17, tp. 7, rge. 8, Figure 16(a)) is massive and typical of the unit.

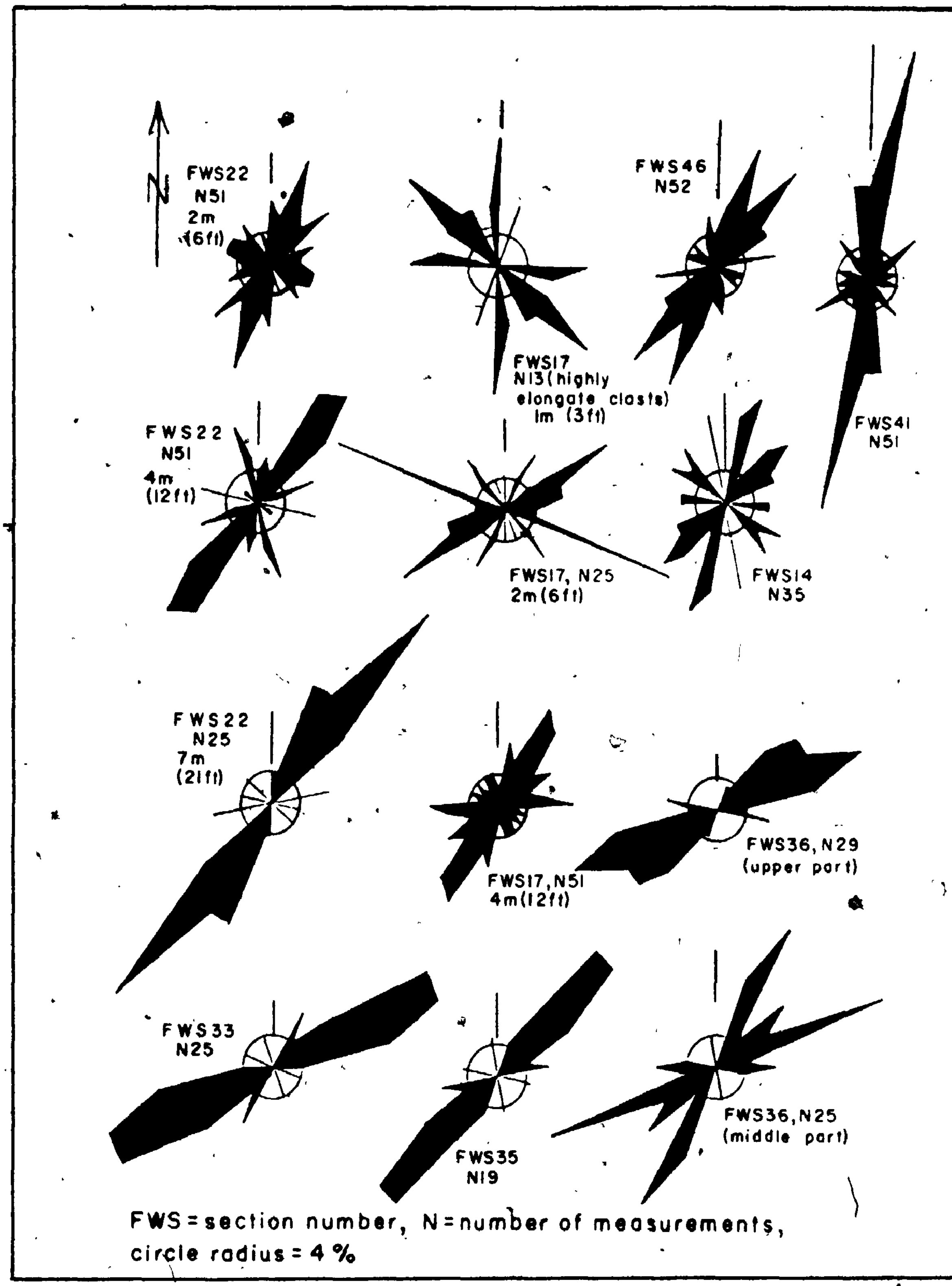


Figure 32. Clast fabrics of the Senkiw Till.

The colour is light brownish gray (2.5Y 6/2) when wet and oxidized and dark gray (5Y 4/2) when wet and unoxidized.

The texture is fairly constant throughout the area (Figure 17). The greatest local variation is shown by the composition of the very coarse sand with samples collected in the eastern half of the area containing a much larger proportion of crystalline grains than those from the south-west (Figure 18). The total carbonate in the fine matrix is higher in the west (Figure 19). Both the very coarse sand and the fine matrix carbonate have a large calcite (Ls) to dolomite (Ds) ratio along cross section DD' and this ratio decreases in the south (Figures 18, 19).

The Senkiw Formation forms the uppermost unit in many of the Roseau River sections and in these places is overlain by only a thin sand layer. Where covered directly by the Roseau Formation (till) the contact is sharp, and in FWS46 (tp. 2, rge. 5, Figure 16(a)) a few boulders are present at the contact. The lower contact is always with stratified sediment. It is generally sharp but in section FWS35 a mass of stratified sediment has been sheared up into the till and in section FWS36 three layers of stratified drift have been incorporated into the till (see chapter 3 for additional comments on this incorporation.)

The Roseau River sections and some other exposures show that the Senkiw till is a very discontinuous unit and in some sections the till covers only a portion of the length of the exposure (150-300 m., 500-1000 ft.). The unit has.

been recognized in the central and southern portion of the area west of the Bedford Hills (Figure 33). Also test holes drilled by the Manitoba Water Resources Branch record thick deposits of "very sandy till" in the southeast (Figure 13, cross sec. AA', holes W19 and W20). Test holes drilled along the Roseau River reveal the thickness of the Senkiw to range from 0 to at least 47 m. (140 ft.). However it is generally less than 20 m. (60 ft.) thick (Figures 13 and 14).

The Senkiw till is distinquished from the other tills by (1) a large sand content (Figure 34, Table 2, mean Se 60% others 29-41%), (2) a large proportion of crystalline grains in the very coarse sand fraction (Figure 18, Se 50-70% others 28 to 42%), (3) a small proportion of carbonates in the fine matrix (Figure 19, Se 38% others 49-61%), (4) a large proportion of crystalline pebbles and a low concentration (Figure 20), and (5) a northeast-southwest fabric.

A northeastern source for the Senkiw till is indicated by (1) the large amount of sand in the till (Figure 17, Table 2), (2) the large proportion of crystalline grains and the large limestone to dolostone ratio in the VCS fraction (Figure 18, Table 2), (3) the small proportion of carbonate, its westward increase shown by the VCS and fine matrix fractions (Figures 18 and 19), (4) the northeast southwest clast fabric, and (5) drag folds (FWS36) and larger deformational features (FWS35) which both indicate a generally westward to southwestward glacier motion.

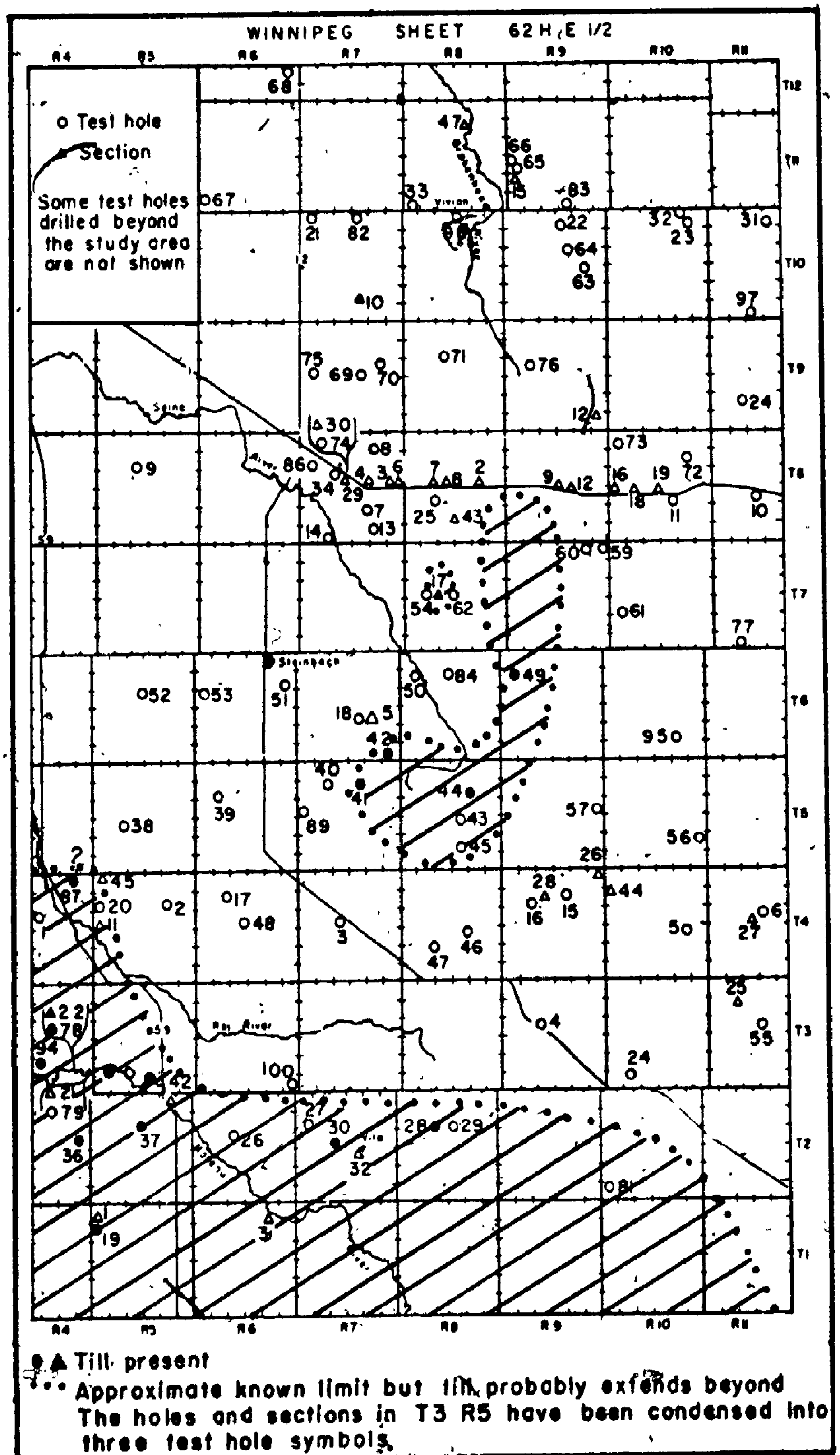


Figure 33. Map showing the distribution of the Senkiw till.

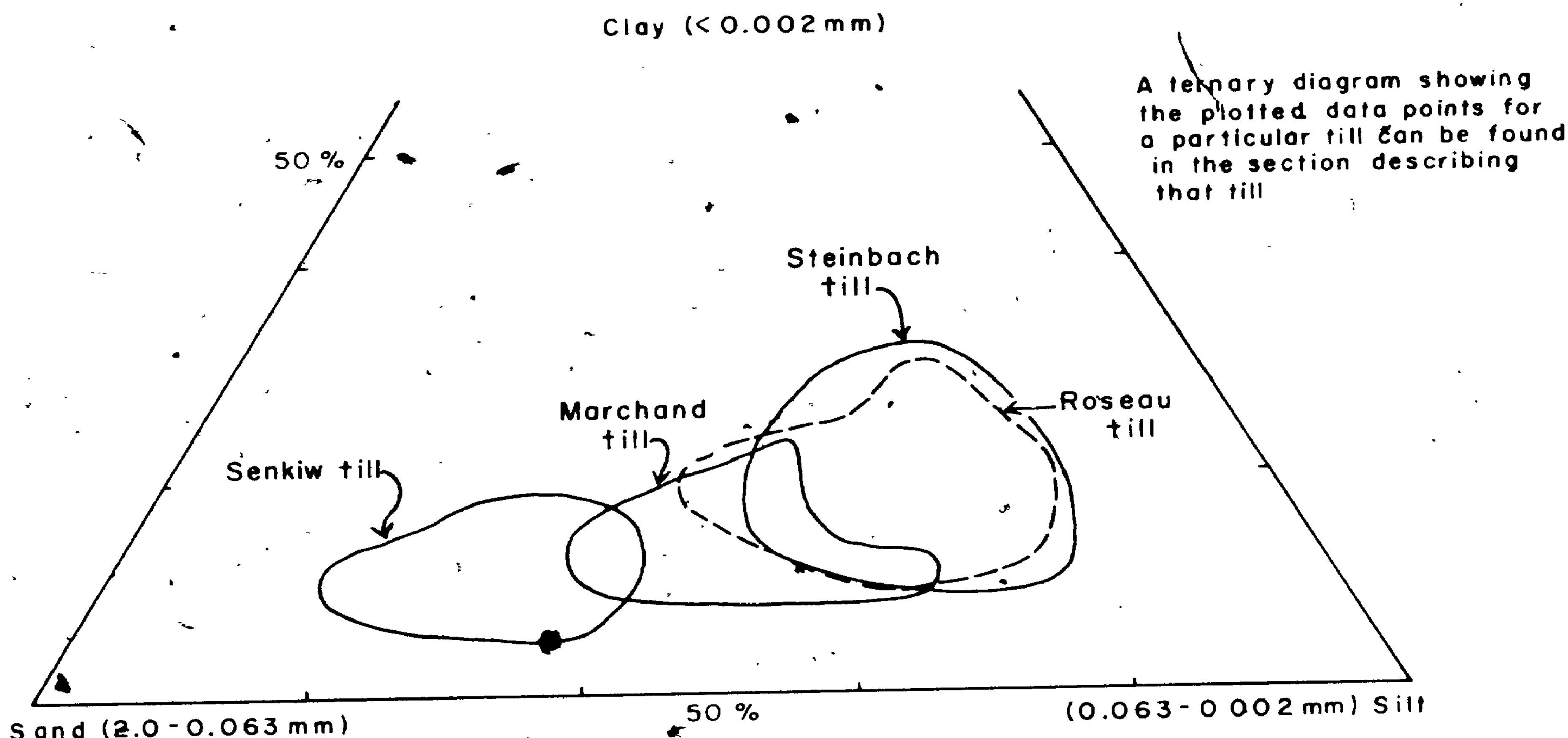


Figure 34. Textural comparison of the Senkiw, Roseau, Marchand, and Steinbach tills.

Bedford Formation

The Bedford Formation comprises all the stratified sediment above the Senkiw Formation and below the Roseau Formation. The name is derived from Bedford (sec. 9, tp. 5, rge. 9) on the Canadian National Railway. No type section is designated at this time. Reference sections include FW41 (tp. 5, rge. 7, Figure 16(a)), FW64 (tp. 10, rge. 9), and FW97 (tp. 10, rge. 11).

The Bedford Formation is divided into two members (1) an unnamed member which comprises the generally fine grained sediment in the western part of the area and (2) the Sandiland Sand Member which comprises all the sand in the Formation in the eastern third of the area. Part of this second member forms the Sandiland Forest Reserve.

The unnamed member has been recognized in test hole FW41 where it consists of about 2 m. (6 ft.) of sandy silt with possibly a gravel layer at the upper surface.

The knowledge about the Sandiland Sand is rather limited because (1) it is too thick to drill through in many places and (2) it was the source of much of the overlying lacustrine sand and is therefore difficult to separate from younger sediment. The Sand is placed in this stratigraphic position because it lies below the Roseau till and is believed to post-date the Senkiw till. The Sandilands Sand is generally composed of fine to medium grained, well sorted sand, though in a few test holes some silt and coarse sand layers are present. Boulders are rare, and of those few seen on the surface more than 90 percent are composed of crystalline rock. The very coarse sand also contains a large proportion of crystalline grains (78% crystalline, 9% limestone, 12% dolostone). South of township 8 the sand forms one body (Figure 13, cross sec. AA', BB', and Figure 14, CC', DD') and further north there are two bodies (Figure 14, cross sec. EE'). About seven kilometers (4 mi.) north of the study area some parts of the subunit are much coarser. In one large gravel pit (sec. 34, tp. 12, rge. 9) it is a sandy gravel which shows well developed southwestward dipping cross beds. The sediment in the pit is composed mainly of crystalline material (pebbles, 8-4 mm: 81% crystalline, 14% limestone, 4% dolostone).

The Sandilands Sand occupies much of the area east of range 9 where it is mapped as glaciofluvial sand or underlies a major portion of the lacustrine sand north of township 8 and the till in township 11, ranges 9 and 10, and township 9 range 11 (Figures 8 and 14). The thickness of the sand increases southward. North of township 8 the drilling indicates it ranges from 16 m. (48 ft.) to 27 m. (80 ft.). South of township 8 the sand is generally more than 33 m. (100 ft.) thick and, adjacent to the Bedford Hills the unit is more than 60 m. (200 ft.) thick. Hole FW95 (tp. 6, rge. 10, Figure 16(a)) located about 15 m. (50 ft.) below the highest point on the Sandilands Sands, was drilled 53 m. (160 ft.) without apparently reaching the bottom of the unit.

Similar thicknesses are also suggested by the logs from a few rotary groundwater test holes which have been drilled in the Bedford Hills (Figure 13, cross sec. BB' and Figure 14, CC'). The log of one rotary hole drilled on the southern margin of the Hills records 70 ft. (23 m.) of "very sandy till" (Figure 13, cross sec. AA', hole W20) which may be a continuation of the Senkiw till ridge, which is present west of the Bedford Hills. The Sandilands Sand extends north and in some places a few kilometers east of the area.

The upper surface of the member is commonly exposed but where it is overlain by the Roseau or Steinbach Formations the contact is sharp. Information on the lower contact is limited. In the north the lower part of the subunit generally includes some silt and clay and overlies till (Figure 14, EE'). Farther south in FW77 (Figure 14, DD') interbedded silt and some sand are present near the base of the member and the underlying till. In the Bedford Hills rotary test holes suggest fine stratified sediment below the sand (Figure 13, BB'; Figure 14, CC').

The Sandilands Sand is distinguished by (1) its stratigraphic position below the Roseau Till and (2) its geographic position on the east side of the area - east of the Senkiw till which has been recognized in different places in range 9.

Roseau Formation

The source of the name is the settlement of Roseau River (sec. 2, tp. 3, rge. 5) near which the till is exposed. The type section is test hole FW3 (C L.S.D. 8, sec. 21, tp. 4, rge. 7). Reference sections are FWS36 and FWS42 (Figure 16(b)) and FW84 (Figure 16(a), tp. 6, rge. 8, Appendix H).

The Roseau Formation is a pebbly sandy silt till (Figure 35), or a loam to silty loam (USDA, 1951) with a mean matrix texture of 32 percent sand, 50 percent silt, and 18 percent clay (Table 2). The very coarse sand fraction has a mean composition of 34 percent crystalline, 26 percent limestone and 40 percent dolostone grains. The carbonate content of the fine matrix consists of 17 percent calcite, 37 percent dolomite, and 54 percent total carbonate. The till fabric is northwest-southeast (Figure 36). In outcrop the till is massive with closely spaced reddish brown stained vertical and horizontal joints.

The texture is generally uniform throughout the area (Figure 17) with some exceptions (1) in places south and west of the Bedford Hill the unit becomes sandier (mean 45% sand, 42% silt, 13% clay), and (2) the till becomes finer on top of, and east of, the Bedford Hills (mean 24% sand, 55% silt, 21% clay). Local variations in composition include (1) the samples from cross section EE' which contain an above average proportion of limestone grains and a below average proportion of crystalline grains in the very coarse sand

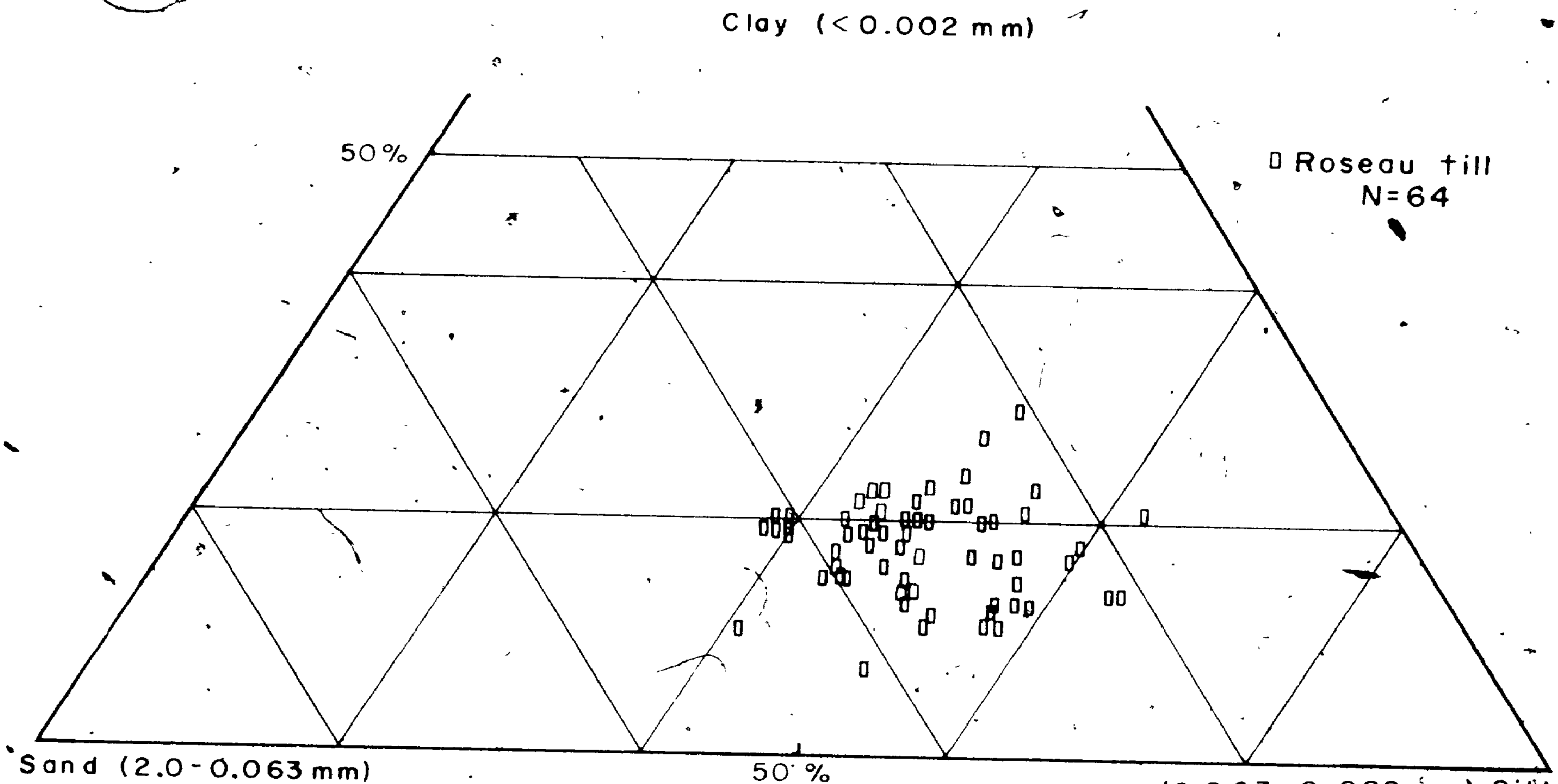


Figure 35. Ternary plot of the texture of the Roseau till matrix samples.

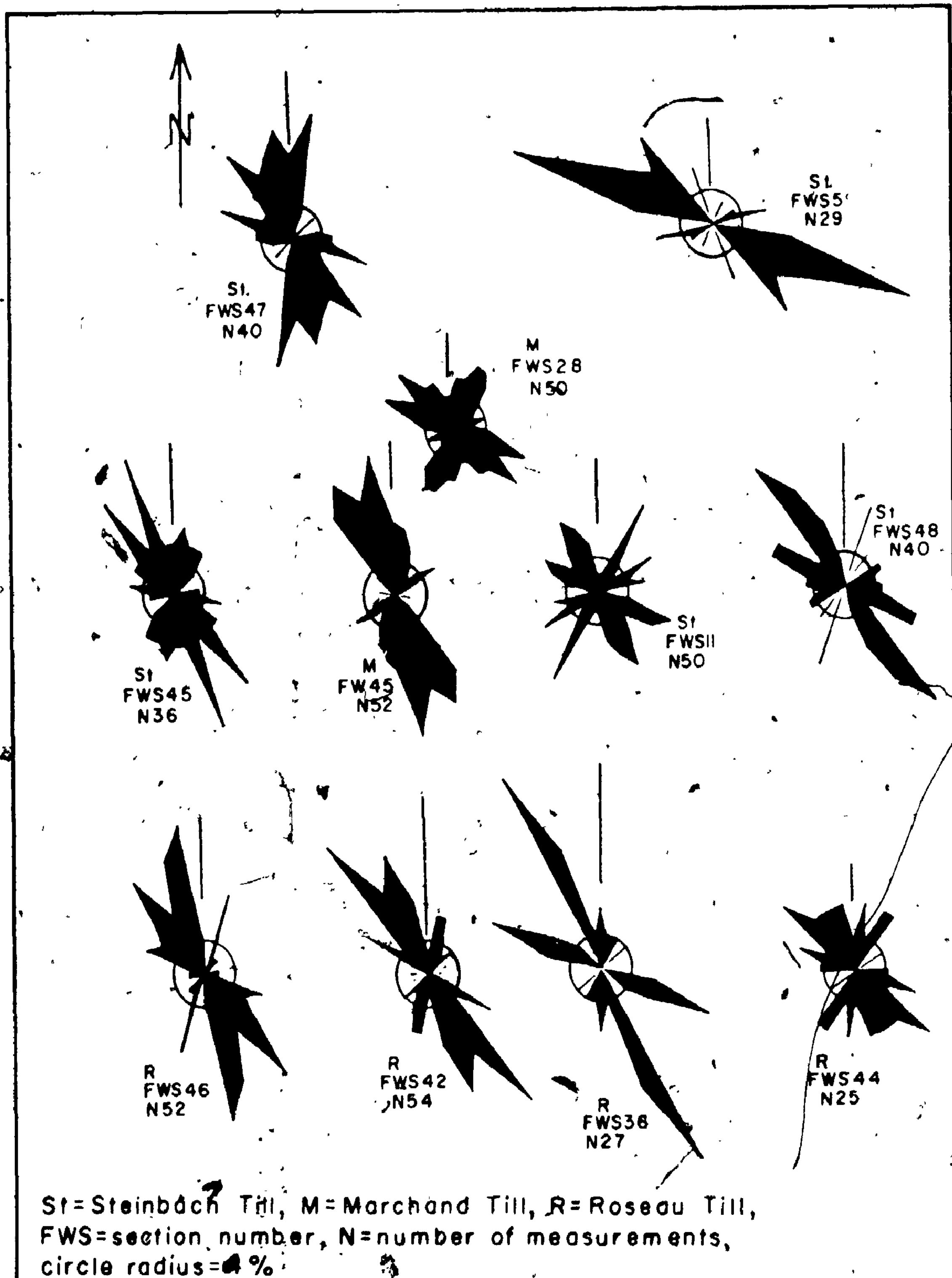


Figure 36. Clast fabrics of the Roseau, Marchand, and Steinbach Tills.

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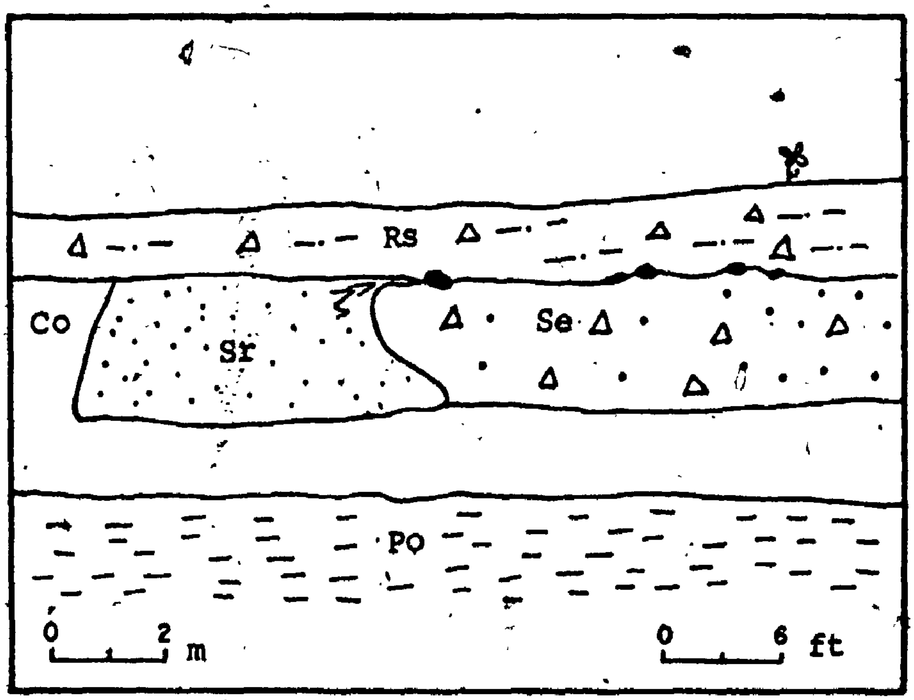
fraction (Figure 18), (2) the southeastern samples which show an increase in crystalline grains with a crystalline to carbonate ratio of about 0.7 (mean 0.5, Table 2), and (3) a large proportion of calcite in the fine matrix of samples from cross sections EE' and DD'.

The Roseau Formation underlies either the Marchand till or stratified drift. The contact with the Marchand till appears sharp. The contact with the stratified sediment west of the Bedford Hills is interbedded in one hole (Figure 14, cross sec. CC', hole FW41). On the Hills the till is in sharp contact with the overlying sand and gravel (FWS25, tp. 11 rge. 3 and FWS44, tp. 4, rge. 10, Figure 16 (a)). The Roseau till rests on either the Senkiw till or stratified sediment. In some sections the unit forms a sharp contact with the underlying sand (FWS25 and FWS42 for example). In section FWS36 (Figure 16(b)) different parts of the Roseau Formation are in sharp contact with either the underlying stratified sand and gravel or the Senkiw till. In some places along the contact the lower portion of the Roseau till has descended into fossil ice wedges in the underlying sand and in a few other places southeastward dipping till wedges of the Roseau extend into the underlying sand (Plate 2). In section FWS46, (Figure 16(a), tp. 2, rge. 5) deformation caused by the Roseau ice has resulted in the Roseau till resting in part on Senkiw till and in part on pre-Senkiw stratified material (Figure 37). The Roseau till has been

Plate 2. Southeastward dipping till wedge at the base of the Roseau till, section FWS36 (sec. 4, tp. 3, rge. 5). The wedge extends into a layer of stratified sediment within the Senkiw till.



Co	Covered	Sr	Stratified sediment
Rs	Roseau till	Po	Pond
Se	Senkiw till	●	Boulder

Figure 37. Sketch of deformation caused by overriding of drift by Roseau ice, section FWS46 (sec.32, tp. 2, rge. 5). Sketch from a photograph.

recognized throughout much of the area east of the boundary of the Red River plain (Figure 38). It extends north, east, and south of the study area but has been found in only a few places on top of the Bedford Hills and is likely discontinuous there. The till was found east of the Hills in hole FW58 (sec. 16, tp. 3, rge. 13). The till has not been found on top of the glaciofluvial deposits in townships 7 and 8, ranges 9 and 11. The thickness of the till ranges from 0 to 10 m. (30 ft.) and is generally about 5 m. (15 ft.).

The Roseau till is differentiated from the overlying Marchand till by (1) its lower sand content (Figure 17; mean Rs 32%, M 42%), (2) the larger proportion of limestone and smaller proportion of crystalline grains in the very coarse sand (Figure 18; mean Rs 26% Ls, 34% Cr. M 16% Ls, 41% Cr.), (3) the larger calcite content in the fine matrix (Figure 19), (4) the greater limestone to dolostone ratio in the pebble fraction (Figure 20; mean Rs 1.2, M 0.63). The properties distinguishing this till from the Senkiw till were described previously in the section on the Senkiw Formation. Differentation from the Steinbach Member (till) is not as easy because the textures are similar. The criteria used are however (1) the stratigraphic position (Figures 13 and 14) and (2) a slightly higher limestone and crystalline grain content in the very coarse sand fraction of the Roseau (Figure 18, Appendix J).

A northwestern source for the ice which deposited the Roseau Formation is suggested by (1) the low proportion of

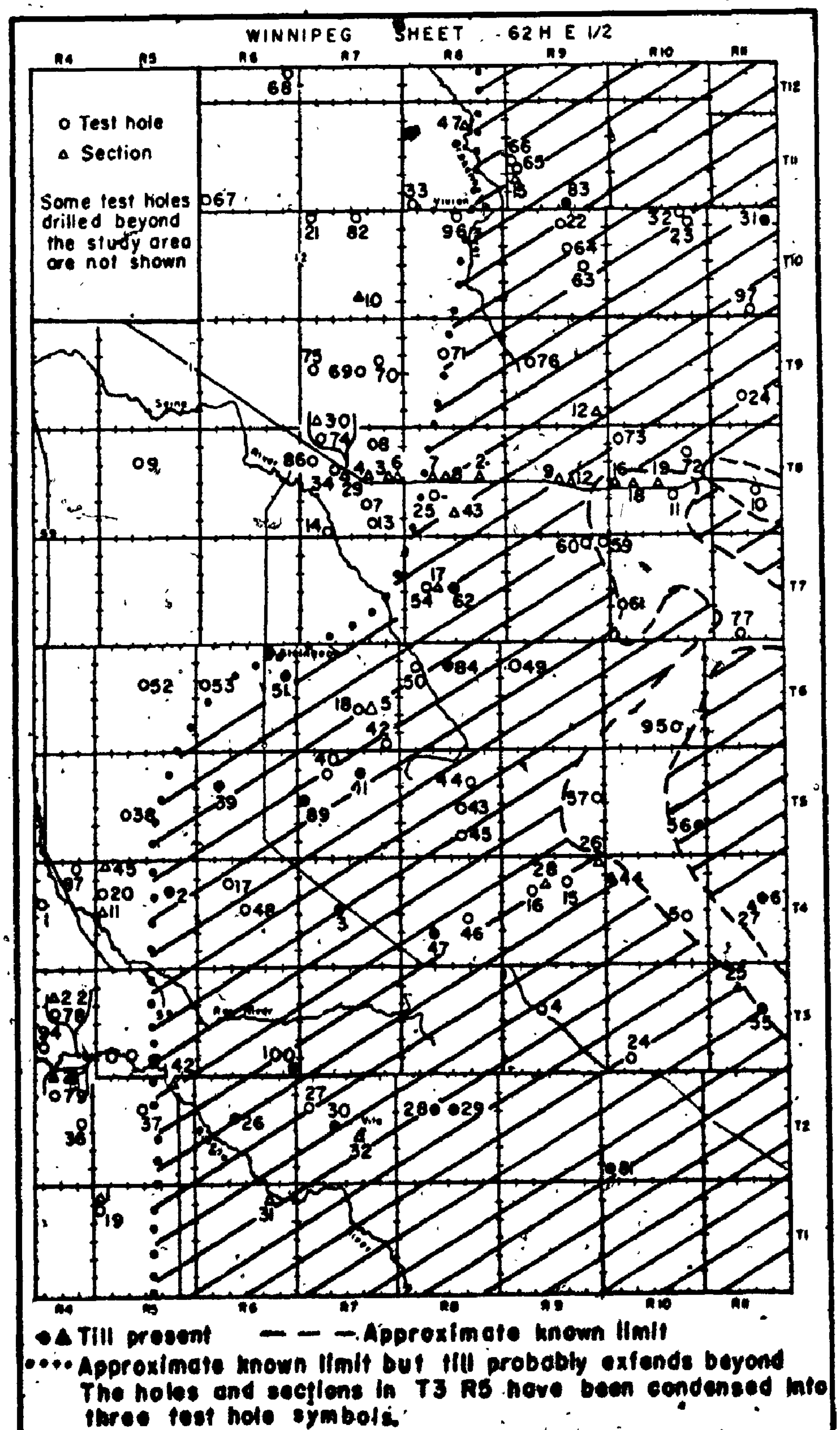


Figure 38. Map showing the distribution of the Roseau till.

sand (Figure 17, Table 2), (2) the high proportion of carbonate grains in the very coarse sand fraction (Figure 18, Table 2), and (3) the northwest-southeast clast fabric.

Grunthal Formation

The name is derived from the town of Grunthal (sec. 21, tp. 5, rge. 5). No type section is designated at this time. Reference sections include test holes FW39, (Figure 16 (a): tp. 5, rge. 6) and FW51 (tp. 6, rge. 6). This unit consists of the stratified sediment above the Roseau Formation and below the Marchand Formation.

In test holes FW39 and FW41 (Figure 14, CC', Figure 16 (a)) and FW51 (Figure 14, DD') the unit consists of interbedded sand, silt, and clay. Laboratory analyses show the texture varies from 63-1% sand, 31-33% silt, and 6-66% clay. The wet sediment is generally dark gray (5Y 4/1). In FW41 the upper and lower contacts appear to be interbedded with the adjacent tills. In the other two holes they are sharp.

It has been definitely recognized in only a few test holes (FW39, FW41, and FW51) because generally either the Marchand Formation rests directly on the Roseau Formation or one of the two tills is absent (Figures 13 and 14). The thickness varies from about 5 m. to 7 m. (15 to 21 ft.). The unit is differentiated from the other stratified units by its stratigraphic position between the Roseau and Marchand Formations.

Marchand Formation

The source of the name is the town of Marchand (sec. 1, tp. 6, rge. 8). The type section is test hole FW84 (NE¼ L.S.D. 16, sec. 28, tp. 6, rge. 8). Reference sections are FW3 (tp. 4, rge. 7, Figure 16(a) and Appendix H) and FW83, (tp. 11, rge. 9).

The Marchand Formation is a pebbly silty sand to sandy silt till (Figure 39), or a loam (USDA, 1951), with a mean matrix texture of 42 percent sand, 43 percent silt, and 15 percent clay (Table 2). The mean composition of the very coarse sand is 41 percent crystalline, 16 percent limestone, and 43 percent dolostone grains. The fine matrix yields mean values of 15 percent calcite, 38 percent dolomite, and 53 percent total carbonate. The two till fabrics measured are northwest-southeast (Figure 36). The exposure of the till on the west side of the Lake Terrace Plain (FW45, tp. 4, rge. 5, Figure 16(a)) indicates the unit to be massive with closely spaced horizontal and vertical joints. In section FWS28 (tp. 4, rge 9) on the west flank of the Bedford Hills the Marchand till is interbedded with fine grained lacustrine sediment and some layers of the till contain an above average proportion of fine material (21% sand, 54% silt, 25% clay). The colour is grayish brown (2.5Y 5/2) in wet oxidized till and olive gray (5Y 4/2) in wet unoxidized till.

Local concentrations of boulders are present in this till which can make power augering impossible (tp. 4, rge.

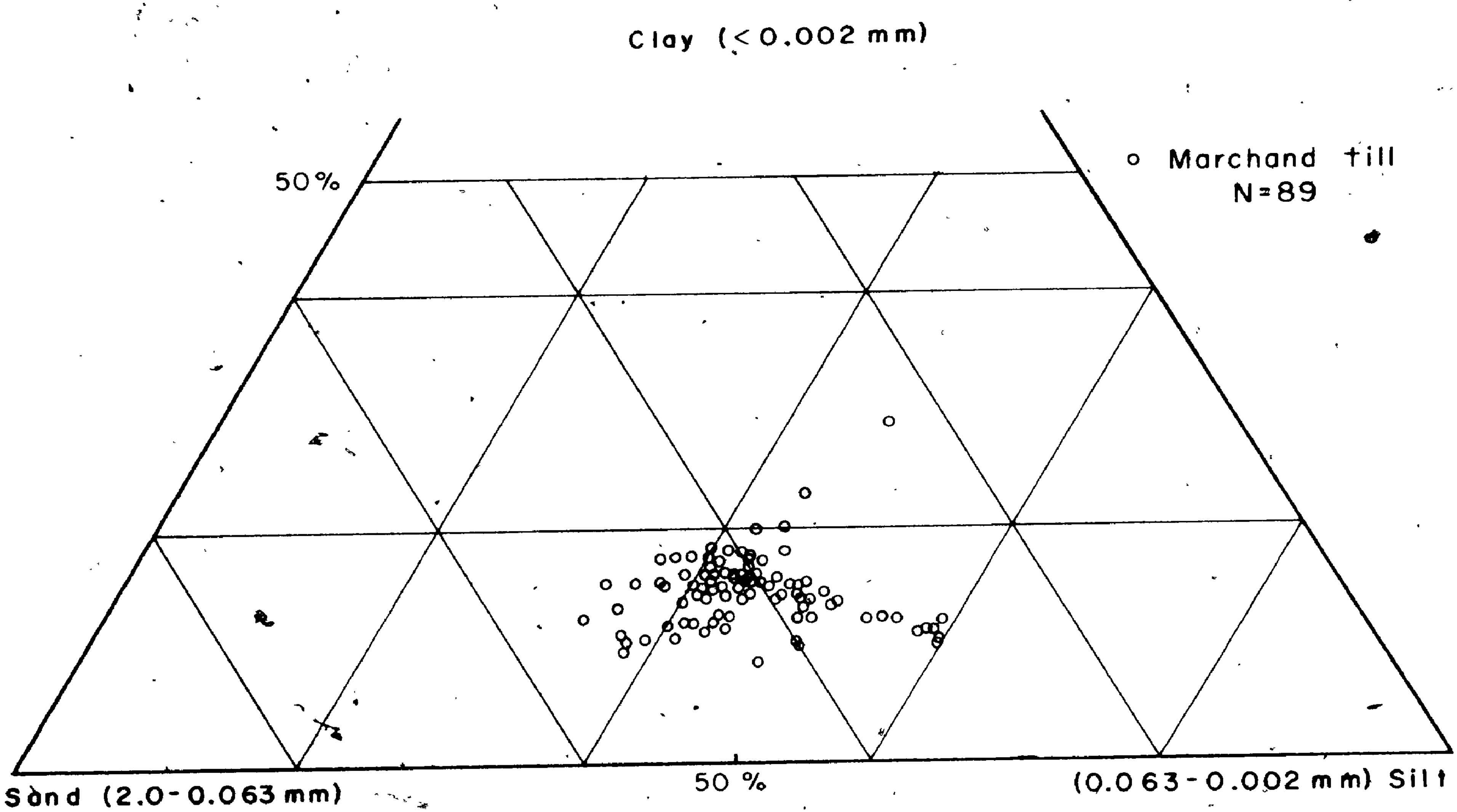


Figure 39. Ternary plot of the texture of the Marchand till matrix samples.

6, tp.4 and 5, rge. 8). There are also local variations in composition. The very coarse sand fraction of samples from section EE' (Figure 14) has an above average limestone to dolostone ratio and a below average crystalline to carbonate ratio (Figure 18) and the fine matrix fraction has an above average calcite to dolomite ratio (Figure 19). Southward from section DD' there is a gradual decrease in the proportion of both crystalline grains (Figure 18) and calcite (Figure 19).

Information concerning the nature of the upper contact is mainly from subsurface data. North of township 6 the contact is generally with the Steinbach Member of the Hazel Formation (Figure 14). In section FWS45 the contact was observed to be sharp. In hole FW33 (tp. 11, rge. 8, Figure 16(a)) the till is in sharp contact with overlying kame-delta deposits. South of township 6 the till is generally either exposed or overlain by fine lacustrine sediment. In hole FW4 (tp. 3, rge. 4) split spoon samples show at least 2 m. (6 ft.) of interbedded till and fine lacustrine sediment and in section FWS28 the till is also interbedded with fine material. The lower contact is in most cases with the Roseau Formation and analyses indicate some incorporation of this till into the base of the Marchand. In hole FW39 (tp. 5, rge. 6) the lower part of this unit is interlayered with the underlying fine stratified drift (Figure 14, Cross sec. CC').

Within the Red River Plain the Marchand Formation may be present only in the south (FW1, S. 21, TP. 4, Rge. 4). The unit is widespread east of the Plain (Figure 40). In

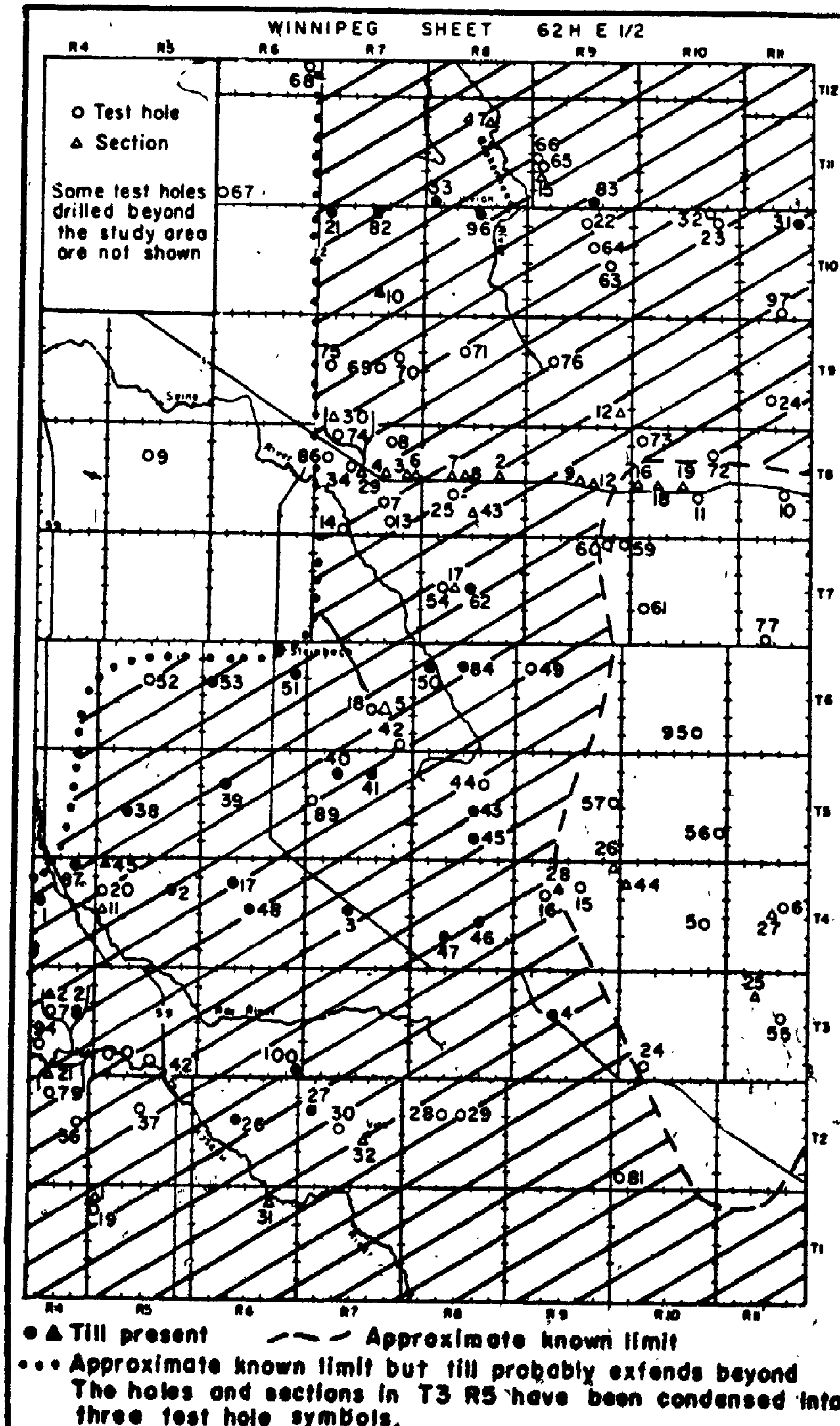


Figure 40. Map showing the distribution of the Marchand till.

the northern half of the area it forms a subsurface unit and extends beyond the eastern and northern boundaries (Figure 14). In the south the unit forms the uppermost till in most places and extends to the western flank of the Bedford Hills and south of the map area into Minnesota. The till has not been found on top of the glaciofluvial deposits (tp. 7 and 8, rge. 9 to 11). The thickness of the Marchand till ranges from 0 to 17 m. (50 ft.) and is usually about 3 m. (9 ft.).

The Marchand Formation is distinguished from the Steinbach Member and the Roseau Formation by the following: (1) a sandier texture (Figure 17; mean M 42%, St 31%), (2) a smaller proportion of limestone grains (Figure 18: M 16%, Rs 26%, St 27%) and a larger proportion of crystalline grains (M 41%, Rs 34%, St 30%) in the very coarse sand fraction, and (3) a smaller calcite to dolomite ratio in the fine matrix (Figure 19). The attributes differentiating this formation from the Senkiw Formation have been described previously in the section dealing with that formation.

The Marchand Formation was deposited by ice advancing from the north or possibly the northwest. The northern source is favored by the till (1) being rather sandy and containing a relatively large percentage of crystalline grains and also (2) having a high proportion of carbonate (-0.063 mm.) and a high percentage of dolostone pebbles (Table 2).

Hazel Formation

The source of the name is the Hazel Creek (tp. 11, rge. 10). No type section is designated at this time. Reference sections include FW21 (tp. 10, rge. 7, Figure 16(a)), FW39, (tp. 8, rge. 4), FW47, (tp. 4, rge. 8), FW83, (tp. 11, rge: 9), FW84, (tp. 6, rge. 8), and FW96, (tp. 10, rge. 8; Appendix H).

This formation includes all the drift above the Marchand Formation. In the northern part of the area the unit can be divided into, in ascending order, the lower member, the Steinbach Member, and the upper member. The Formation is undivided in the southern part because the Steinbach Member is absent and the data are insufficient to allow separation of the lower and the upper member without the presence of the Steinbach member.

Undivided Hazel Formation

The undivided Hazel Formation covers the southern half of the Lake Terrace Plain. The lower part is clay and the upper part sand. The lower part is present in test holes FW3 (tp. 8, rge. 4, Figure 16(a)), FW4 (tp. 3, rge. 9), FW39, (tp. 8, rge. 4), FW47 (tp. 4, rge. 8), and FW81 (tp. 2, rge. 10) (Figures 13 and 14). It is a slightly silty clay (average 1% sand, 14% silt, 85% clay), very dark gray to black (5Y 2.5/1) when wet and unoxidized, and dark gray (5Y 4/1) when dry. It contains many thin, lighter coloured silty laminations and silty specks, of which the former increase in number, thickness and average grain size with depth as the till contact is approached. The sand is generally well sorted and medium to fine grained and where it overlies the clay is often silty near the base. Plant, mollusc, and insect remains are present in the lower meter (3 ft.) in test holes FW4 and FW81 and the plant material from FW81 has yielded an uncorrected radiocarbon date of 10,200$\pm$80 years B.P. (GSC 1909, unpublished). The average texture is 86 percent sand, 11 percent silt, 3 percent clay.

The upper surface of this subunit is often exposed but where overlain by peat the contact is gradational. The lower contact of the clay with the till is interbedded and that of the sand with the till is always sharp and marked by a gravel concentration.

The undivided Hazel Formation is present in much of the area south of township 6 and east of the Red River Plain though it has been recognized on only one part of the Bedford Hills (sec. 36, tp. 4, rge. 9). The thickness ranges from 1 to about 20 m. (3 to 60 ft.), and is greatest west of the Bedford Hills (tps. 4 and 5, rges. 6,7, and 8) thinning westward toward the margin of the Red River Plain.

Lower Member

The lower member of the Hazel Formation is an informal subdivision which comprises all of the stratified drift above the Marchand Formation and below the Steinbach Member.

The lower member in the Lake Terrace Plain consists of coarse kame-delta deposits and finer sands and silts. The Steinbach Member overlies the top of these kame deposits in section FWS10 (tp. 10, rge. 7, Figure 16(a)) and test hole FW13 (tp. 9, rge. 7). Sand and silt are present below the Steinbach Member in section FWS7 (tp. 8, rge. 9), FW34, (tp. 8, rge. 7), and FW96, (tp. 10, rge. 8). In FW21 (tp. 10, rge. 7) silt overlies the Marchand Formation and in FW33 (tp. 11, rge. 8) kame-delta deposits overlie the Marchand (Figure 14, cross sec. EE'). Within the Red River Plain area in hole FW1 (tp. 4, rge. 4) 15 m. (45 ft.) of dark gray (2.5Y N4/wet), thinly laminated silty clay are present below what is believed to be the Steinbach Member. This sediment differs from that overlying the Marchand till to the east in that this sediment lacks the white specks and dries to a light gray (5Y 6/1) colour. In the few places where exposed the contact between the lower member and the Steinbach Member is sharp where the till overlies sand and silt but shows signs of deformation where the till overlies the kame-delta deposits (Plate 3).

These deposits have been recognized north of township 6 and east of range 6 and tentatively in township 5 range 4. The thickness can be determined in only two places, FW21 where it is about 2 m. (6 ft.) and FW1 where it is

Plate 3. Steinbach till overlying kame-delta deposits which were deformed during the advance of the Steinbach glacier, section FWS10 (sec. 3, tp. 10, rge. 7), view looking eastward.

about 15 m. (45 ft.). One kame-delta with the upper surface now exposed gives a minimum thickness of 25 m. (75 ft.) of sediment over the Marchand Formation (FW33).

Steinbach Member

The Steinbach Member is a formal subdivision of the Hazel Formation comprising the sediment lying above the lower member and below the upper member. The source of the name is the town of Steinbach (sec. 35, tp. 6, rge. 6). The type section is test hole FW84 (NW¼ L.S.D. 16, sec. 28, tp. 6, rge. 8). Reference sections are test holes FW31 (tp. 10, rge. 11, Figure 16(a)) and FW83 (tp. 11, rge. 9).

The Steinbach till is a pebbly sandy silt till (Figure 41), or a loam to silty loam (USDA, 1951), with a mean texture of 31 percent sand, 52 percent silt, and 17 percent clay (Table 2). The mean composition of the very coarse sand fraction is 31 percent crystalline, 27 percent limestone, and 42 percent dolostone grains. The fine matrix has a mean composition of 23 percent calcite, 35 percent dolomite, and 58 percent total carbonate. The data suggest the pebble fraction to have a mean composition of 18 percent crystalline, 55 percent limestone, and 27 percent dolostone clasts. The fabric is generally northwest-southeast (Figure 36). Where exposed the till is massive and cut by closely spaced, reddish brown stained, horizontal and vertical joints. On the western margin of the Lake Terrace

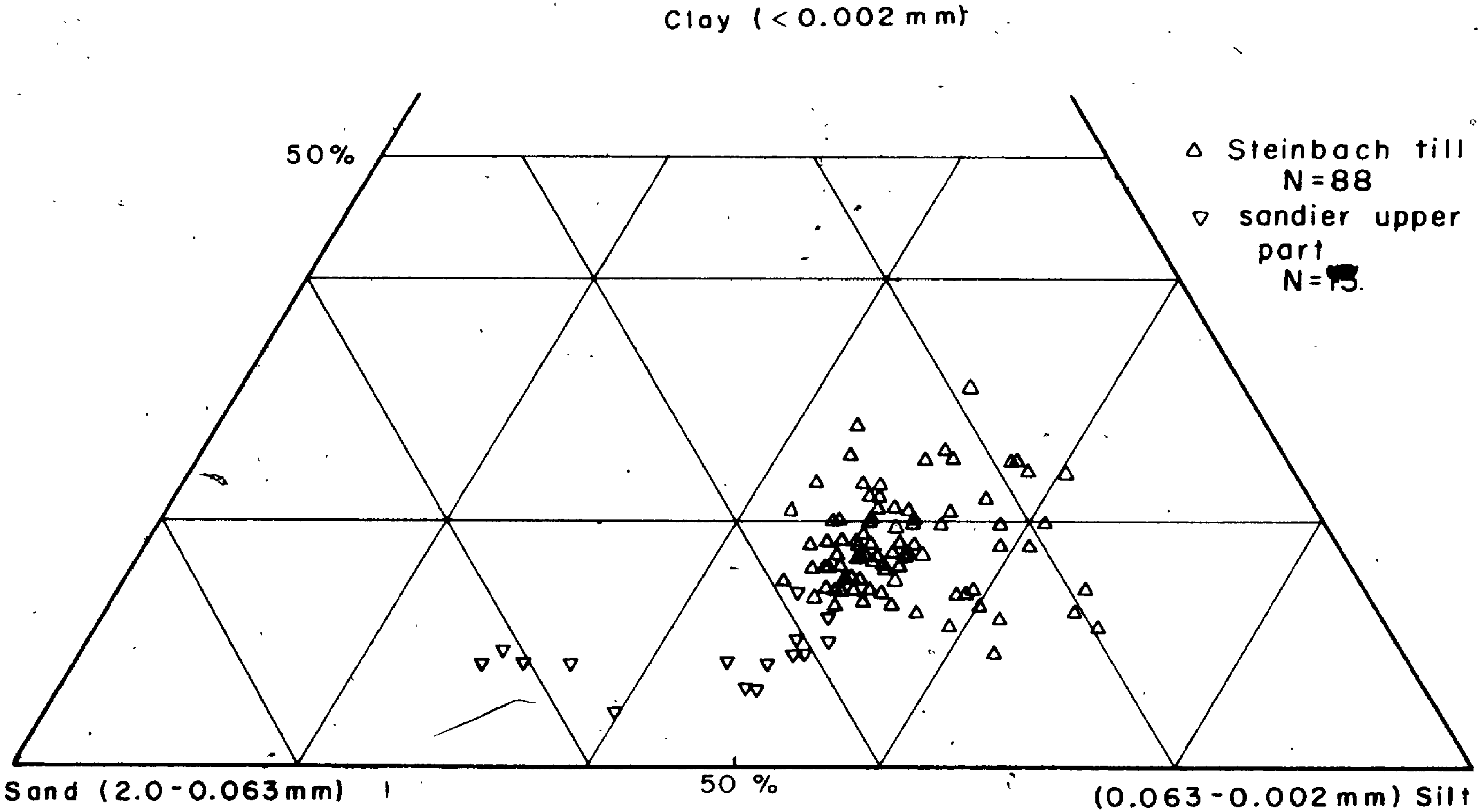


Figure 41. Ternary plot of the texture of the Steinbach till matrix samples.

Plain the upper portion of the till often contains a layer of, or is interbedded with, fine lacustrine sediment (sections FWS10, tp. 10, rge. 7; FWS11, tp. 4, rge. 5; FWS45, tp. 4, rge. 5). The colour is generally grayish brown (2.5Y 5/2) when wet and oxidized, and olive gray (5Y 4/2) when wet and unoxidized.

Local variations in the composition include (1) along section EE' an above average proportion of limestone grains in the very coarse sand fraction (Figure 18) and an above average proportion of calcite in the fine matrix (Figure 19), (2) a decrease in the amount of crystalline grains (very coarse sand fraction) in the Red River Plain area (mean R.R.P. 19% Cr., Appendix J; member mean 30% Cr), (3) an increase in the content of crystalline grains in some places along the western margin of the Lake Terrace Plain (mean 47% Cr, Appendix J) and (4) an above average proportion of fine material near, and west of, the western margin of the Lake Terrace Plain (mean 23% sand, 56% silt, 21% clay; member mean 31%, 52%, 17% respectively).

The contact with the upper member is generally interbedded on the western margin of the Lake Terrace Plain and sharp east of this. The contact between the Steinbach till and the Marchand till is marked by a sharp change in the till properties though the analyses indicate some incorporation of the Marchand till into the lower part of the Steinbach till in a few places.

The Steinbach Member is the uppermost till in the northern half of the area (Figure 42). The Member is present along the western margin of the Lake Terrace area (tp. 1 to 5, rge. 4 and 5) and extends below the lacustrine sediments of the Red River Plain (test holes FW1, sec. 21, tp. 4, rge. 4; FW67, sec. 6, tp. 11, rge. 6; and FW94, sec. 9, tp. 11, rge. 4). The thickness varies from 0 to about 10 m. (30 ft.) and is generally about 7 m. (21 ft.).

The Steinbach Member is distinguished from the other till units by its stratigraphic position and the contrasting properties of the tills. These properties have been discussed previously in the sections describing the Senkiw, Roseau, and Marchand Formations (tills) but briefly the Steinbach till has a lower sand and a lower crystalline grain (very coarse sand) content than the Marchand or Senkiw tills (Figures 17 and 18 ; Table 2) and a slightly lower limestone and crystalline grain content that the Roseau till (Figure 18, Appendix J).

A northwest to north source for the ice which deposited the Steinbach Member is suggested by (1) the fine texture (Table 2), (2) the large proportion of carbonate and small proportion of crystalline grains in the very coarse sand fraction (Table 2), (3) the northwest-southeast till fabric (Figure 36), and (4) the large amount of carbonate in the fine matrix (Table 2).

Upper Member

The upper member of the Hazel Formation is an infor-

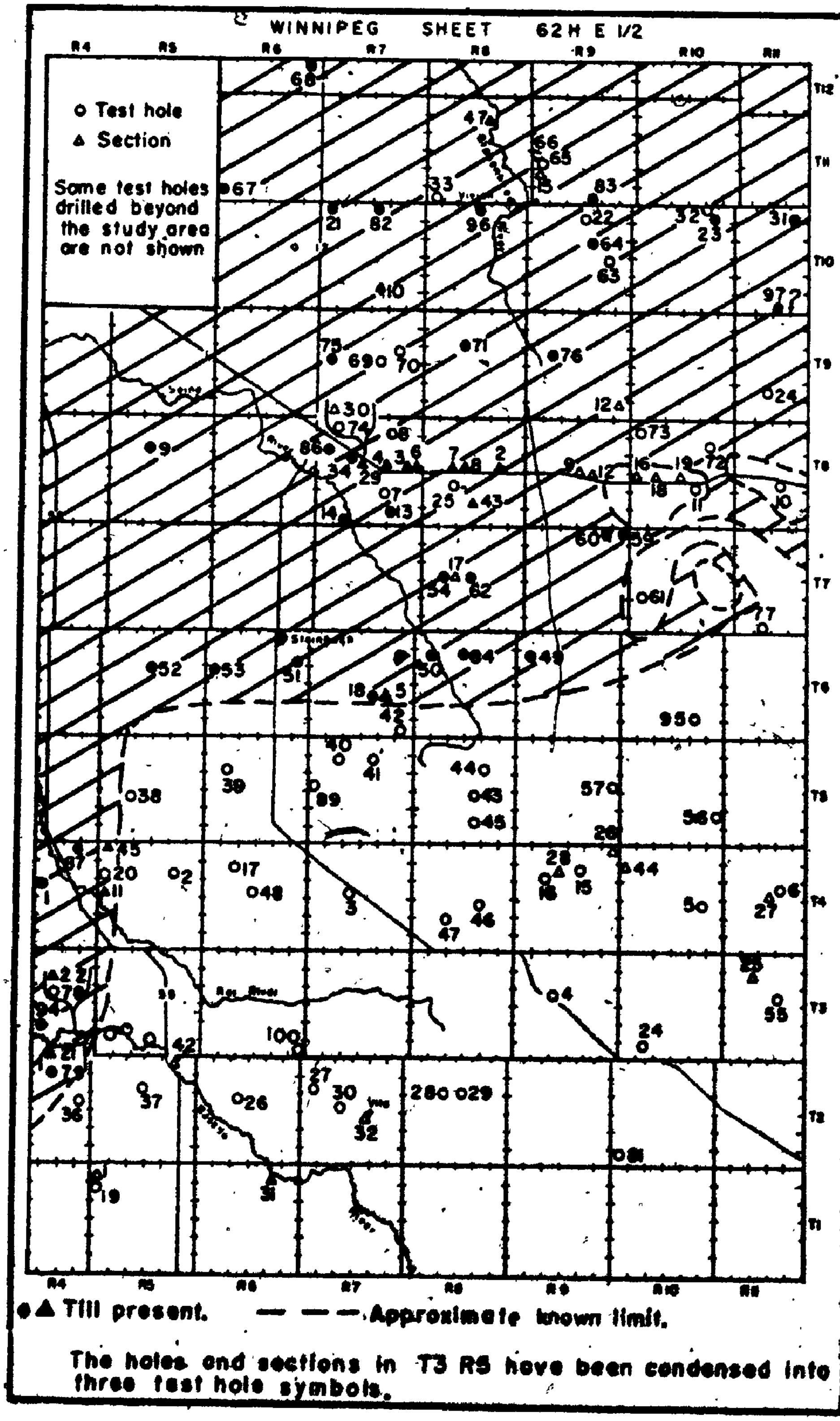


Figure 42. Map showing the distribution of the Steinbach till.

mal subdivision which comprises all the stratified sediment above the Steinbach Member.

Within the Red River Plain the upper member is an olive gray (5Y 5/3 wet) when oxidized and very dark olive gray (5Y 3/2 wet) when unoxidized, slightly silty clay (mean 1% sand, 14% silt, 85% clay) (FW1, sec. 21, tp. 4, rge. 4; FW9, sec. 28, tp. 8, rge. 5; and FW67, sec. 6, tp. 11, rge. 5). The clay is generally massive but light coloured silty to sandy inclusions are scattered throughout it and some silty laminae are present in the upper part. The number and size of the light coloured inclusions increases with depth as the contact with the underlying till is approached and in the lower part of the clay they become abundant enough to form layers which truncate the clay below them (Plate 4). This subunit becomes siltier at the margin of the Red River Plain (FW21, 7% sand, 79% silt, 14% clay). Within the Lake Terrace Plain the upper member partly fills in many of the depressions and consists of fine to medium grained sand overlying, where present, clay. The upper surface of this subunit is exposed over much of the area but where it is overlain by peat the contact is gradational. The contact with the underlying Steinbach Member is interbedded in most cases. East of the Red River Plain this unit has been recognized north of township 7, and within the Red River Plain in townships 3 to 11 range 4, and townships 6 to 11 ranges 5 and 6. The thickness varies from 0 to about 20 m. (60 ft.) with the greatest thickness being in the Red River Plain.

Plate 4. Split spoon samples from the upper member of the Hazel Formation test hole FW9 (sec. 28, tp. 8, rge. 5).

CHAPTER 3

DISCUSSION OF SOME FEATURES OF THE QUATERNARY GEOLOGY

This chapter discusses a number of features not included in the description of the stratigraphy because they (1) are either locally applicable to individual units or generally applicable to a number of units and/or (2) involve interpretation of, rather than just description of, the geology.

Incorporation and Local Variations in the Till Units

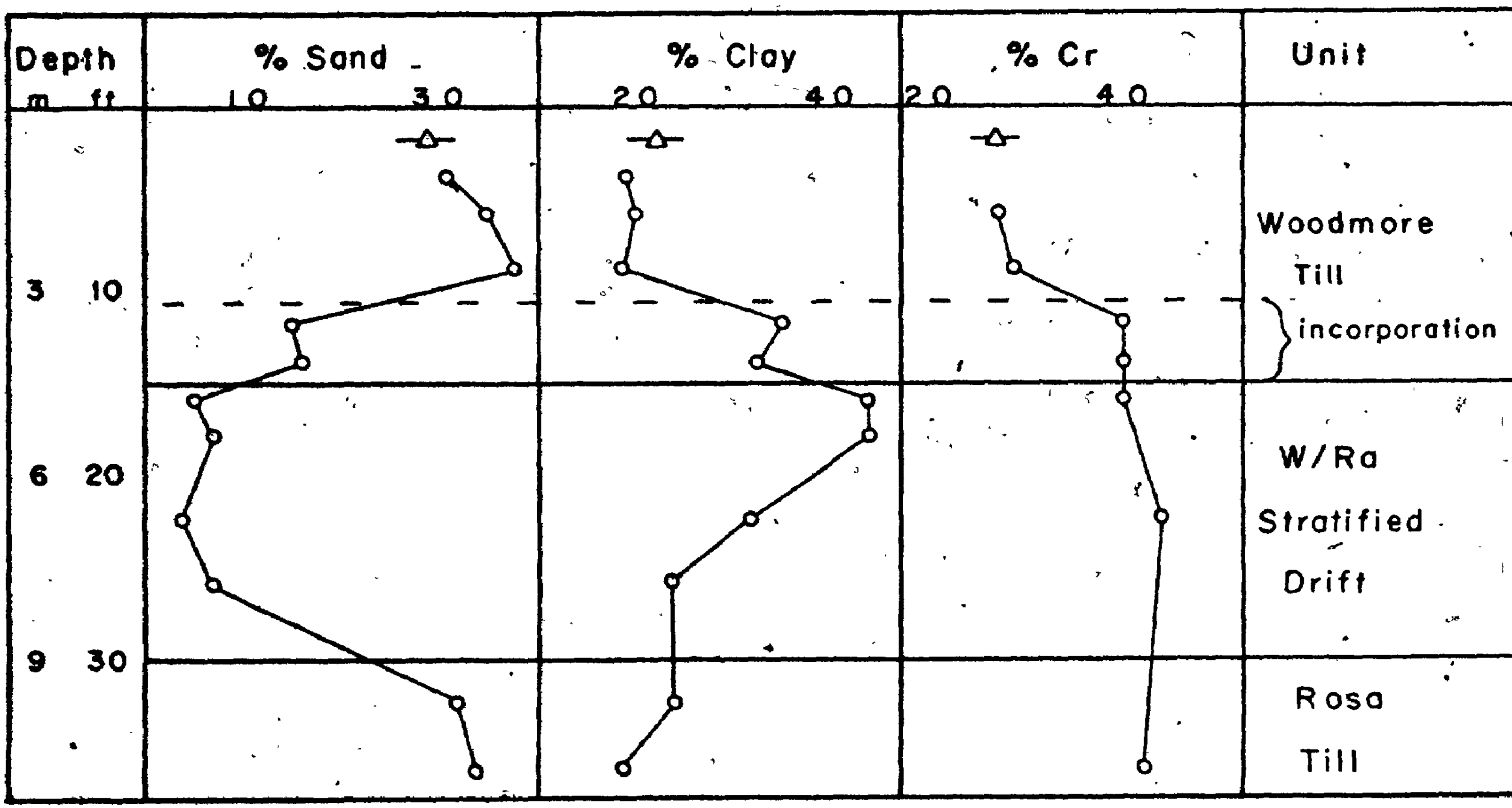
Incorporation of the underlying sediment is a major factor controlling the texture and composition of the tills and therefore it has an important bearing on the stratigraphic interpretations. Local alteration, by incorporation, of the properties characterizing a particular till is a problem in certain parts of the area, particularly where the till is thin. Fortunately, generally the properties do not change simultaneously so that the till is still recognizable.

Although incorporation has been recognized in many places, only a few examples have been selected to illustrate this. The most obvious and widespread example is the effect of the predominantly carbonate bedrock located north of the western part of the study area and only partially covered by a thin layer of drift. The larger ratio of limestone to dolostone and calcite to dolomite of the Steinbach, Marchand, and Roseau tills in the north (Figures

18 and 19) is most probably the result of direct contact between the ice and the bedrock north of the study area. South of the northern boundary of the area, the ice moved over pre-existing drift that both separated the ice from the bedrock surface and provided a source with a comparatively small proportion of limestone for incorporation. As a result the carbonate ratios decreased to about the area average south of cross section DD' in the Roseau till and south of cross section EE' in the overlying Marchand and Steinbach tills (Figure 18 and 19).

An example of alteration of both the texture and composition of a till is shown by the analyses of the Woodmore till recovered from test hole FW80 (Figure 43) where incorporation of the underlying stratified sediment has resulted in the lower part of the till being finer grained and having a larger proportion of crystalline grains (very coarse sand) than the unit mean.

Generally incorporation will alter all the properties used to characterize the till to some extent but in most places the degree of change varies from one property to another. An example of incorporation altering the composition of the very coarse sand fraction with little effect on the texture is shown in Table 4. In section FWS45 the Steinbach till has a texture similar to the mean of samples from near the edge of the Red River Plain but the very coarse sand contains a larger proportion of crystalline grains than the mean value for the Red River Plain samples. This is



Test hole FW80

Cr = crystalline grains in the very coarse sand fraction. Sand = 2.-0.063mm, Clay = -0.002mm
o = data point. -△- = mean and standard deviation for the till

Figure 43. Incorporation of stratified sediment into the Woodmore Till.

	Texture (%) Sand	Silt	Clay	VCS (%) Cr	LS	DS
Steinbach Till Mean, Red River Plain samples	23	56	20	19	34	46
Steinbach Till Mean, section FWS45	21	60	19	45	13	42
Marchand Till Mean, section FWS45	41	42	16	46	12	41
VCS=very coarse sand, Cr=crystalline, Ls=Limestone, Ds=dolostone, sand=2-0.063mm, silt=0.063-0.002mm, clay=-0.002mm.						

Table 4. Change in the composition of the Steinbach Till because of incorporation of preexisting drift.

	Texture (%) Sand	Silt	Clay	VCS (%) Cr	Ls	Ds
Marchand Till Mean, test hole FW51	32	56	12	47	13	39
Marchand Till Mean, cross sec. DD'	40	46	15	46	14	40

Table 5. Change in the texture of the Marchand till because of incorporation of preexisting drift.

the result of the incorporation of the underlying Marchand till. The reason for the different responses of the texture and the very coarse sand composition is that the latter (VCS) amounts to only about 1 percent of the total weight of the sediment in the matrix and so could, in this case, be altered without the texture changing noticeably. Also the Marchand till was submerged by a proglacial lake and this probably resulted in a concentration of the coarser sand fractions on the surface of the unit prior to the overriding by the glacier which deposited the Steinbach till. An example of the reverse comes from FW51 (Table 5) where the silt fraction of the Marchand till has been enriched without altering the very coarse sand composition. The reason for this is that the incorporated sediment was mainly silt and did not contain enough very coarse sand to change the proportions already in the till. The source of this silt may have been the same stratified unit that was observed below the Marchand till in test hole FW1 (tp. 4, rge. 4, Figure 16(a)).

Considering areal changes, incorporation of the underlying drift is likely responsible for the westward decrease in the crystalline to carbonate ratio in the very coarse sand fraction of the Senkiw till (Table 2). Incorporation of the Senkiw till or the sandy stratified drift is likely the cause of the large crystalline to carbonate ratio of the Roseau till in the southeast. Incorporation often occurs where the ice, which deposited a particular till, moved up a slope such as where the Red River Plain meets the Lake Terrace Plain and along the flanks of the glaciofluvial deposits in the eastern half of the area (Figures 13 and 14).

Reorientation of Till Fabric

The till clast fabric measurements made at successively lower depths in the Senkiw Formation (Figure 32) at sections FWS17 (tp. 7, rge. 8, Figure 16(a)) and FWS22 (Figure 16(b)) show (1) the "strongest" or closest to unimodal fabric is always measured at the lowest depth, (2) this fabric parallels the fabric measured in this till at other locations, and (3) the proporation of clasts oriented in a north to northwest direction increases toward the top of the section.

The upward change in the till fabric is considered to be the result of reorientation of the clasts by one or more glacial advances from the northwest which deposited the Roseau, Marchand, and Steinbach tills. This conclusion is supported by the following: (1) the general stratigraphy of the study area that shows the Senkiw till to be older than the Roseau, Marchand, and Steinbach tills, (2) the presence of a remnant of one of the above tills overlying the Senkiw till in both sections, (3) the present geographic position of the sections which is such that they would have been subjected to strong shear stresses by the overriding ice. Section FWS22 (adjacent to test hole FW78, Figure 15) would have formed a slope inclined toward the advancing glaciers if the present surface of the Senkiw till west of FW78 is similar to that during advances from the northwest. Section FWS17 is situated in a knob of Senkiw till about 5.2 km.^{2} (2 mi.^{2}) in area. The local relief is at least 9 m. (30 ft.) because a large part of the surrounding drift is now covered by peat of unknown thickness.

The mechanisms for the reorientation of till clasts by overriding ice have been discussed by MacClintock and Dreimanis (1964) and Ramsden and Westgate (1971); the mechanism of "remoulding" suggested by MacClintock and Dreimanis is likely most applicable here. This process requires the till to be "made into a viscous mass" (MacClintock and Dreimanis, 1964). Two factors that would have contributed to this process in the study area are (1) the area was probably submerged by a proglacial lake during each of the glacial advances which deposited the three post-Senkiw tills, and (2) fragments of the Senkiw till have been observed to disintigrate easily when placed in water. Portions of the Senkiw till having a high water content as a result of submergence by the lake and prominently exposed to the shear stresses of the overriding glacier could be expected to undergo remoulding with the associated reorientation of the clast fabric.

Shearing Associated with the Senkiw Formation

East of section FWS38 (Figure 15) shearing by the ice which deposited the Senkiw Formation has resulted in

(1) the deformation of the underlying stratified drift, (2) the incorporation of large fragments of it into the Senkiw till, and (3) repetition of the stratigraphic section. In section FWS35 part of the underlying sand has been sheared up into the Senkiw till, folded, and the upper limb of the overturned fold removed (Plate 5). Shearing and inclusion in section FWS36 have resulted in the repetition or "stacking" of three layers of stratified drift and till (Figure 15). Careful examination of the first meter (3 ft.) of thin bedded sand and silt immediately below the base of the middle till layer (the only one adequately exposed) revealed numerous drag folds indicating a generally westerly thrusting of the overlying till layer. In section FWS34 the 2 m. (6 ft.) of Vita stratified sediment just above the base may be an incorporated block because the Senkiw till is abnormally thick in the nearby test hole FW101.

The absence of the Senkiw till from test hole FW88 (Figure 15) which was drilled about 300 m. (1000 ft.) north of section FWS36 may be the result of either drilling beyond the edge of the sheared till blocks or drilling through a "gap" in the till similar to, though larger than, the one shown in Plate 5.

Deformation and incorporation, both small and large scale has been described by many authors including Bluemle (1966, North Dakota), Christiansen, (1971, southern Saskatchewan), Harris, (1972, northwestern Minnesota), Hopkins,

Plate 5. Shearing of stratified sediment into the Senkiw till, section FWS35 (sec. 4, tp. 3, rge. 5). The glacier moved from right to left (E to W).

(1923, central Alberta), and Moran, (1971, Minnesota, North Dakota, Saskatchewan, and other areas).

Buried Valleys

Buried valleys of Tertiary or Pleistocene age have been described in western Canada and adjacent areas of the United States by numerous workers including Christiansen (1967, 1972), Lemke et al. (1965), Klassen and Wyder (1970), Stalker (1961), and Prest (1970). New valleys may be excavated by meltwater following each retreat of the ice but frequently segments of old valleys are reoccupied (Christiansen, 1972, p. 28; Klassen, 1972, and Stalker, 1961 and 1974).

The western reach of the Roseau River has partially reoccupied one or more of these channels. Evidence for this includes (1) the flood plain origin of the middle part of the Vita Formation, (2) the deltaic environment indicated by the Vita Formation in section FWS21 (Figure 16(b)), and (3) the presence of a possible pre-Senkiw channel indicated by the stratigraphy in test hole FW101 (Figure 15).

Inspection of Figure 15 suggests as many as three periods of channel development: (1) erosion of an early channel, (intersected in test hole FW101) and now filled by the Rosa Formation, (2) the development of the channel in which the Vita Formation flood plain sediment was deposited, and (3) the fluvial excavation of the post-Rosa channel intersected in test hole 101, which was subsequently filled with the Senkiw till. An alternative interpretation to the above is that the topographic low on the Rosa till in hole FW101 was produced by erosion of that till and the overlying sediment by the Senkiw ice. If this happened periods (1) and (3) probably did not occur.

The exact position of the channel(s) is unknown because of the lack of test holes within a few kilometers of the Roseau River. The presence of only flood plain deposits at all but one of the sites (FWS21) where the Vita Formation was sampled indicates the thalweg was probably north or south of the River.

Depositional Environments of the Stratified Units

The purpose of this part is to comment briefly on the depositional environments of the different stratified units and to present the evidence supporting these comments.

Hazel Formation

The stratified sediment in this unit can be split into (1) gravelly sand deposits of glaciofluvial origin and (2) finer sands, silts, and clays of lacustrine origin. The first are kame-delta deposits. The term kame is used because of (1) their geomorphology - isolated hills or in a few places short ridges (Figure 8), (2) sudden and marked changes in texture between beds such as coarse gravel adjacent to medium or fine sand, (3) the presence of current generated features, for example cross bedding, climbing-ripples, and cut and fill structures, (4) a few water-worn clasts of till in the gravelly layers, and (5) the presence of faults in a few of the deposits suggesting post depositional deformation caused by the melting of the adjacent glacial ice. The term delta is used because these kames were probably deposited from water flowing into a proglacial lake as suggested by (1) fine lacustrine sediment and/or interbedded till and lacustrine sediment immediately overlying some of the deposits (sec. 17, tp. 5, rge. 5, and sec. 3, tp. 10, rge. 7), (2) the presence of fine lacustrine material on the distal margins of the kame delta deposits (FWS6, sec. 24, and FW34, sec. 21, tp. 8, rge. 7, Figure 8), and (3) the history of the study area, discussed in later chapters, and of the region immediately south of the area (Moran and Clayton, manuscript, 1972; Harris et al., 1974) which suggests a proglacial lake formed during the retreat of both the Marchand and Steinbach glaciers.

The lacustrine origin for the finer deposits is supported by (1) their fine texture, mainly silts and clays with only minor fine to medium grained sand laminae, (2) their wide distribution, described previously, and (3) the horizontal and laminated bedding observed in the clays and silts.

The kame-deltas were deposited during a retreat of the ice that deposited the Marchand Formation or perhaps a halt in the advance of the ice which deposited the Steinbach Member as indicated by (1) the stratigraphy, with the Marchand till recognized below one of the deltas (Figure 13, cross sec. EE') and the Steinbach till overlying, and involved in the deformation of, some of the deposits (Plate 2), (2) a generally eastward current in those kame-deltas deposited east of the Red River Plain, (3) the generally eastward decrease in grain size of the Hazel stratified drift east of these deposits. Studies of the glaciofluvial deposits in the northwestern corner of the area have also revealed a generally eastward current direction and decrease in grain size (Upham, 1910; Organ, 1952; and McPherson, 1970).

Grunthal Formation

As stated previously this unit has been sampled in only a few test holes. It is believed to be of lacustrine origin because of the predominance of silt and clay and the thin bedding.

Bedford Formation

In section FWS36, in the western part of the area, where three layers of Senkiw till are interbedded with stratified sediment (Figure 15) frost wedges are present beginning at the top of the stratified drift immediately overlying the middle till and extending a maximum of about 2.5 m. (8 ft.) into the till (Plate 6). At this place in the section the upper layer of Senkiw till is absent and

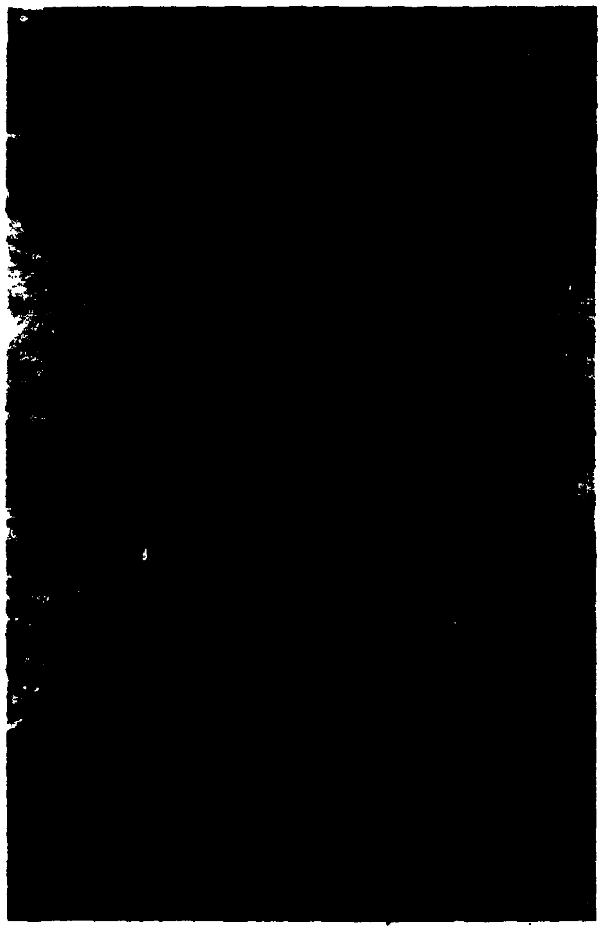


Plate 6. Upper two thirds of a fossil ice wedge in stratified sediment (str) and the Senkiw till, section FWS36 (sec. 4, tp. 9, rge. 5). The Roseau till (Rs) is present in the upper part of the plate and as fragments in the wedge. The scale is divided into 30 cm. (1 ft.) intervals.

the Roseau till directly overlies the frost wedges and has in part descended into some of the wedges (Plate 5). This suggests an interval of erosion and permafrost activity between the deposition of the Senkiw Formation and the Roseau Formation.

The Sandilands Sand, present only in the eastern half of the area, was likely deposited in a generally north-south trending ice-walled channel carrying meltwater and sediment from the northeastern ice. Evidence for this northeastern sediment source includes the high proportion of crystalline grains in the very coarse sand fraction (79% cr, 9% Ls, 12% Ds; FW5, Figure 13, cross sec. BB') and in the gravel pit north of the area (1) an abundance of crystalline clasts, and (2) southwest dipping cross beds (see thesis section 2.2).

The glaciofluvial origin of the Sandilands Sand is supported by (1) the composition, which is almost entirely sand and a few gravel bodies (Figure 13, cross sec. CC', FW57), (2) the presence of the abundant gravel and cross beds in the previously mentioned gravel pit, (3) the generally north-south slightly sinuous trend of the sand (rather than the tabular form of the lacustrine deposits), (4) the presence of an ice-walled channel (discussed below). McPherson (1970) also identified correlative deposits immediately north of the area as glaciofluvial sediment.

The existence of ice walls on the channel is indicated by the following: (1) the trend of the Sandilands Sands is generally north-south (Figures 8, 13, and 14) suggesting confinement on the east and west (2) the geomorphic form of the deposit is a ridge with the crest generally 60 m. (200 ft.) above the surrounding land surface in the southern part of the area and up to 60 m. (200 ft.) above, for the correlative sediment, north of the area (McPherson, 1970), (3) the presence of the Roseau, Marchand, and Steinbach tills immediately adjacent to the Sandilands Sand in the north (Figure 14, cross sec. EE') suggests the filling of a depression left by melting ice. The possibility that this depression was excavated by the ice which deposited the Roseau Formation is slight because the texture of the till in the lows is typical of the Roseau but the till on the sand crests is abnormally sandy indicating erosion and incorporation on the pre-existing highs, (4) the ridge of Senkiw till west and likely south (thesis section 2.2) of the Sandilands Sand may represent where the Senkiw ice formed the west wall of the channel. The eastern margin of this channel was likely the northeastern ice and the western margin an isolated mass of the same ice.

One anomaly of the Sandilands Sand is that the surface is generally above 330 m. (1100 ft.) in elevation in the south and below 300 m. (1000 ft.) in the north reflecting the fact that the downstream part of the sand is thicker than the upstream part (Figures 13 and 14, and thesis section 2.2). Greater erosion of the northern part by Lake Agassiz may explain some of this difference in elevation, particularly in townships 7 and 8 ranges 10 and 11 where a well developed boulder lag, derived from the underlying almost boulder free sand, requires the removal of a great volume of sand. Erosion does not explain the major part of the difference however. Another explanation is that initially the open channel existed only south of about township 8. Later continued retreat of the northeastern ice opened channel farther to the north and allowed the meltwater to discharge east of what are now the Bedford Hills. McPherson (1970) also postulates a minor eastward retreat of the ice to form the eastern of the two sand ridges, correlative with the Sandilands Sand, north of the study area. The limited amount of exploratory drilling done by the author east of the southern part of the area has not revealed any thick sand deposits. This may be because (1) the volume of sand transported this far south was much smaller, which is supported by the smaller volume of the Sandilands Sand north of township 9, (2) the sand deposited was eroded by later ice advance(s) from the northwest which deposited at least one till in the area east of the Bedford Hills, or (3) the test holes were not drilled in the proper locations to intersect the sand.

Vita Formation

This unit has been divided into three parts (thesis section 2.2). The contorted sand and gravel, the lowest, is believed to be a zone of involutions produced by exposure following the deposition of the Tolstoi Formation. A permafrost origin for the involutions is suggested by (1) their wide distribution, a distance of at least 3.2 km. (2 mi.) along the Roseau River, (2) their stratigraphic position overlying a glacial till and underlying floodplain deposits containing a mollusc and ostracode fauna that indicates a climate cooler than the present and perhaps a tundra environment, and (3) the presence of a possible fossil ice wedge at the base of the gravel in section FWS40 (Figure 16(b)).

The middle part of the unit is believed to consist of flood plain and associated pond deposits. This conclusion is based on the massive, and in some cases, leached nature of the deposits, and the habitats of the molluscs and ostracodes found in the deposits (thesis section 2.2 and Appendix K).

The depositional environment of the overlying sand and silt division of the unit depends on the section they are exposed in and the elevation of the deposits. The sediment in section FWS21 lies below about 258 m. (860 ft.) and is likely a deltaic deposit because of (1) the evidence of current action and erosion (sec 2.2), (2) the abundance of transported wood fragments, (3) the location of the section on the eastern rim of a low area (about 38 m., 125 ft., below the deposits in FWS21) in which the Vita Formation consists of a thick sequence of fine lacustrine sediment (Figure 15, FW-94), (4) the absence of coarse river channel deposits, and (5) the absence of evidence suggesting subaerial exposure such as mud cracks and vegetation mats. The sand and silt in all the other sections except FWS38, lies between about 258 m. (860 ft.) and 270 m. (900 ft.) (Figure 15) and is probably of lacustrine origin. This is indicated by (1) the fine grained texture of the deposit (all medium sand or finer (2) the predominance of thin and generally horizontal bedding, and (3) the relatively great thickness and uniformity of the sediment, up to about 6.5 m. (22 ft.) in section FWS41 (Figure 15). In section FWS38 the sediment overlying the floodplain deposits, about 270 to 272 m. (900 to 906 ft.) in elevation, may be loess as suggested by the high proportion of silt (81%), the generally massive appearance, and the presence of some gastropods.

West of the Roseau River sections the Vita sediment in hole FW94 (Figure 15) is believed to be of lacustrine origin because of the fine texture and thin laminations. The small clasts of silt and till-like material, present in the lower part, are probably the result of ice rafting.

East of the River the Vita sediment and the sediment that likely belongs in the unit (thesis section 2.2) is also mainly of lacustrine origin. This is suggested by the fine texture of the sediment and the thin bedding, where it was recognizable in the auger samples. In test hole FW100 (Figure 13, cross sec. AA') the sediment containing abundant organic material, recovered at an elevation of about 258 m. (860 ft.) indicates a period of subaerial exposure.

St. Malo Formation

This unit is so thin that it contains very little information on its origin. The organic layer is probably a flood plain deposit and the overlying sand to clay may have a similar origin or be a lacustrine deposit.

W/Ra Stratified Drift

This unit is considered to be of lacustrine origin because of the fine texture and thin laminations.

CHAPTER 4

DISCUSSION OF THE QUATERNARY STRATIGRAPHY

The purposes of this chapter are to (1) discuss the age and depositional climate of the different stratigraphic units and (2) to suggest correlations between these units and those in other areas. The correlations are divided into regional and distant. The regional correlations are with areas adjoining the study area or situated such that the availability of stratigraphic sections and test holes allow a stepwise correlation to those areas.. The distant correlations are with areas located farther away and to which stepwise correlations can not be made either because the intervening stratigraphic units are absent or their stratigraphy is unknown or poorly understood. The regional correlations will be dealt with first because they are important to the discussion of age and climate and the distant correlation last because they are based on the climatologic and chronologic interpretations.

Regional Correlations

Lithostratigraphic correlations can be made with a number of areas in the surrounding region (Figure 44). The units correlated are generally tills because the criteria used to recognize particular tills remain constant or change in a predictable manner from one area to the next. The criteria used to make the correlations include: (1) stratigraphic position, (2) the texture of the till matrix (-2.0

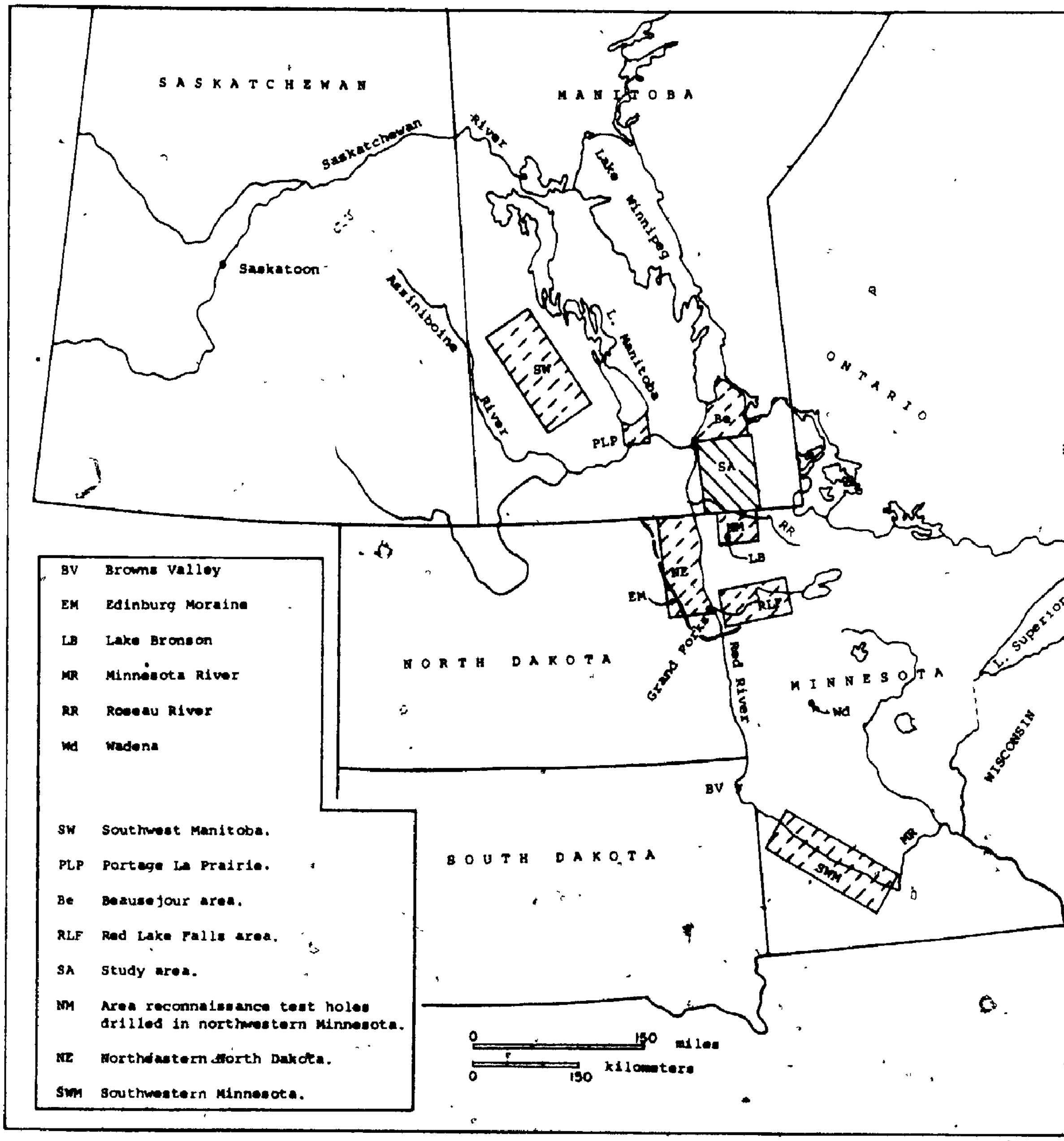


Figure 44. Location map showing the areas referred to in the regional correlation.

mm.), (3) the lithologic composition of the very coarse sand (VCS) fraction (2.0-1.0 mm.), (4) the presence of boulder pavements, (5) the clast composition, (6) colour, and (7) the source area of the till, with the first three being most frequently used.

The proposed correlation of the Quaternary stratigraphic units with those in the surrounding region is shown in Table 6. The correlations with northeastern North Dakota and the Red Lake Falls area (Figure 44; Table 6, columns V and V111) will be discussed first because (1) the most detailed stratigraphy of the surrounding region has been developed in these areas (Harris, 1973; Harris et al., 1972, 1974; Salomon, in press; and Salomon et al., 1973), (2) this stratigraphy closely resembles that in the study area (Table 6, col. V1), and (3) a few reconnaissance test holes (FW90 to FW93) were drilled in the northwestern part of Minnesota (Figure 44, col. V11, Table 6) to aid in these correlations.

First some comments have to be made on a comparison of the analytical methods used by the author and the researchers in North Dakota who furnished all the textural and very coarse sand composition data from the Red Lake Falls area, SW Minnesota, and NE North Dakota. A number of very coarse sand samples were counted by both parties and the difference between the results was generally only about 1 percent and never more than 3 percent. A comparison of textural analyses of different samples collected from similar depths on the same test

Column I	II	III	IV	V (west part)	V (east part)	VI	VII	VIII	IX
S Saskatchewan Christiansen (1968).	SW Manitoba Klassen (1969, 1972)	Portage La Prairie area Fenton (1970).	Beausejour Area McPherson (1970).	NE North Dakota west part Salomon (in press)	NE North Dakota east part Salomon (in press)	Study Area SE Manitoba.	Test holes Northern NW Minnesota	Red Lake Falls Area Harris <u>et al.</u> (1972, 1974)	SW Minnesota Matsch (1972) Salomon and Moran (1972).
		Sand Silt Clay Cr Cb Sh 4)	Sand Silt Clay Cr Cb Sh	Sand Silt Clay Cr Cb Sh	Sand Silt Clay Cr Cb Sh	Sand Silt Clay Cr Cb Sh	Sand Silt Clay Cr Cb Sh (▲)	Sand Silt Clay Cr Cb Sh	Sand Silt Clay Cr Cb Sh
				Sherack Formation		↓		Sherack Formation	
		Upper Till 24 47 29 32 68 0				Hazel Fm. upper member ↓			
		Middle Till 35 47 18 21 79 0				Steinbach Mem. 31 1 17 31 69 0		Brenna Formation ↓	
			Libau Drift ↓	Falconer Fm. 31 49 20 40 36 24		Hazel Fm lower member Marchand For 42 43 15 41 58 0	Marchand Fm. 41 42 17 45 54 4	Huot Fm 6 23 71	
						Grunthal Fm		Wylie Fm.	
Battleford Fm.	Lennard Till Till			Dahlen Fm. 35 45 20 31 21 48		Roseau Fm. 32 50 18 34 66 0	Roseau Fm. 37 41 23 32 62 5	Up Red Lake Falls Fm 35 41 24 51 34 13	New Ulm Till 31 43 26 27 23 45
	Selene silts		Belair Drift Glaciofluvial sand ↓			Bedford Fm			
Floral Fm.	Minnedosa Till		Lower Till 50 32 19 mainly Cr	Gardar Fm. 35 43 22 13 9 78	Lo. Red Lake Falls Fm. 42 39 19 43 54 3	Senkiw Fm. 60 29 11 W50 50 0 E70 30 0	Senkiw Fm. 48 38 13 69 31 0	Lo Red Lake Falls Fm 40 42 18 57 37 5	Granite Falls Till 38 43 20 49 43 3
	Roaring River Clay					Vita Fm			
					Unit 1 32 48 20 32 67 1	Tolstoi Fm. 25 53 22 28 72 0			
	Shell Till			Unit A 34 37 29 21 17 62		Stuartburn F 41 45 14 41 59 0	Stuartburn F (▲) 30 46 24 41 59 0	St. Hilaire F 38 42 20 40 31 29	
				Unit B ? 35 37 28 ? 25 21 54				Marcoux Fm. ? 54 33 13 78 19 5	Hawk Creek ? 51 38 11 79 12 <1
				Unit C 30 32 38 29 30 41		Woodmore Fm 29 49 22 27 73 0			
						W/R Stratified Drift			
				Unit D 28 34 38 35 44 21		Roza Fm 29 50 21 42 58 0	Roza Fm. 21 51 28 39 61		

Explanation of data presentation

Unit D			
28	34	38	mean texture
35	44	21	mean composition very coarse sand

Percent sand (2.0-0.063mm), silt (0.063-0.002mm), and clay (-0.002mm). (2) Percent sand (2.0-0.063mm) silt (0.063-0.004mm), and clay (-0.004mm)
Percent crystalline (Cr), carbonate (Cb), and shale (Sh) grains in the very coarse sand fraction (2.0-1.0mm)
(▲) Limited number of samples, results may not be representative. All numerical data are mean values.

Table 6. Regional correlations.

holes, in NW Minnesota, showed that while the proportion of clay was generally similar (mean difference 2%) the author's sand analyses always yielded a larger proportion of sand (mean difference 8%) and therefore a lower proportion of silt. Because of the above variations and the uncertainty of whether these variations could be applied to the textural data from the other areas in the surrounding region more emphasis has been placed on the textural contrasts between the till within each area than a direct comparison of individual tills in the study area and those in the areas being considered. The term "modified texture" is used to refer to textural data which has been modified to take into account (1) the generally greater proportion of sand in the author's analyses and (2) the fact that the North Dakota researchers use 0.004 mm. as the upper boundary of clay while the author uses 0.002 mm. (Appendix C).

The proposed correlations will be discussed beginning with the lowest unit. The Rosa Formation is correlated with Unit D (the letters assigned to these units do not imply any correlation with the lower tills in the northeastern part of the study area) and the Woodmore Formation with Unit C in NE North Dakota (Table 6, cols. V and Vl) for the following reasons: (1) the stratigraphic position of a till containing a small proportion of crystalline grains (very coarse sand fraction) over a till containing a large proportion and (2) a relatively small amount of sand in each of the tills in both sections. The large proportion of shale grains (VCS fraction) and clay in the North Dakota tills is the result of incorporation of the gray shale bedrock (Figure 45). A till unit tentatively correlated with the Rosa till was intersected in hole FW91 in Minnesota (Table 6, col. V11).

No correlative of Unit B has been recognized in the study area. This statement is based on the following considerations: (1) Unit B is sandier than either the Woodmore and Rosa tills which would be very unlikely if it were a correlative because the abundance of shale (VCS) should make it finer or at least similar to the shale-free tills in the study area and (2) the properties of Units C and D closely resemble the Woodmore and Rosa till. The Marcoux Formation (Table 6, col. V111) has no correlative in the area and the possible reasons for this will be given when the correlations with southwest Minnesota are discussed.

The Stuartburn Formation is correlated with the St. Hilaire Formation in Minnesota and Unit A in North Dakota (Table 6, col. V, V1, and V111). The most obvious property common to the three tills is their colour which is always darker than all the other tills, with the exception of the Rosa Formation in the study area. In North Dakota the till is gray (Salomon, in press), in Manitoba dark olive gray (Table 2) and in Minnesota very dark gray (Harris et al., 1974). The texture of the Stuartburn and St. Hilaire tills is similar (Table 6, cols. V1, V111), though the latter is

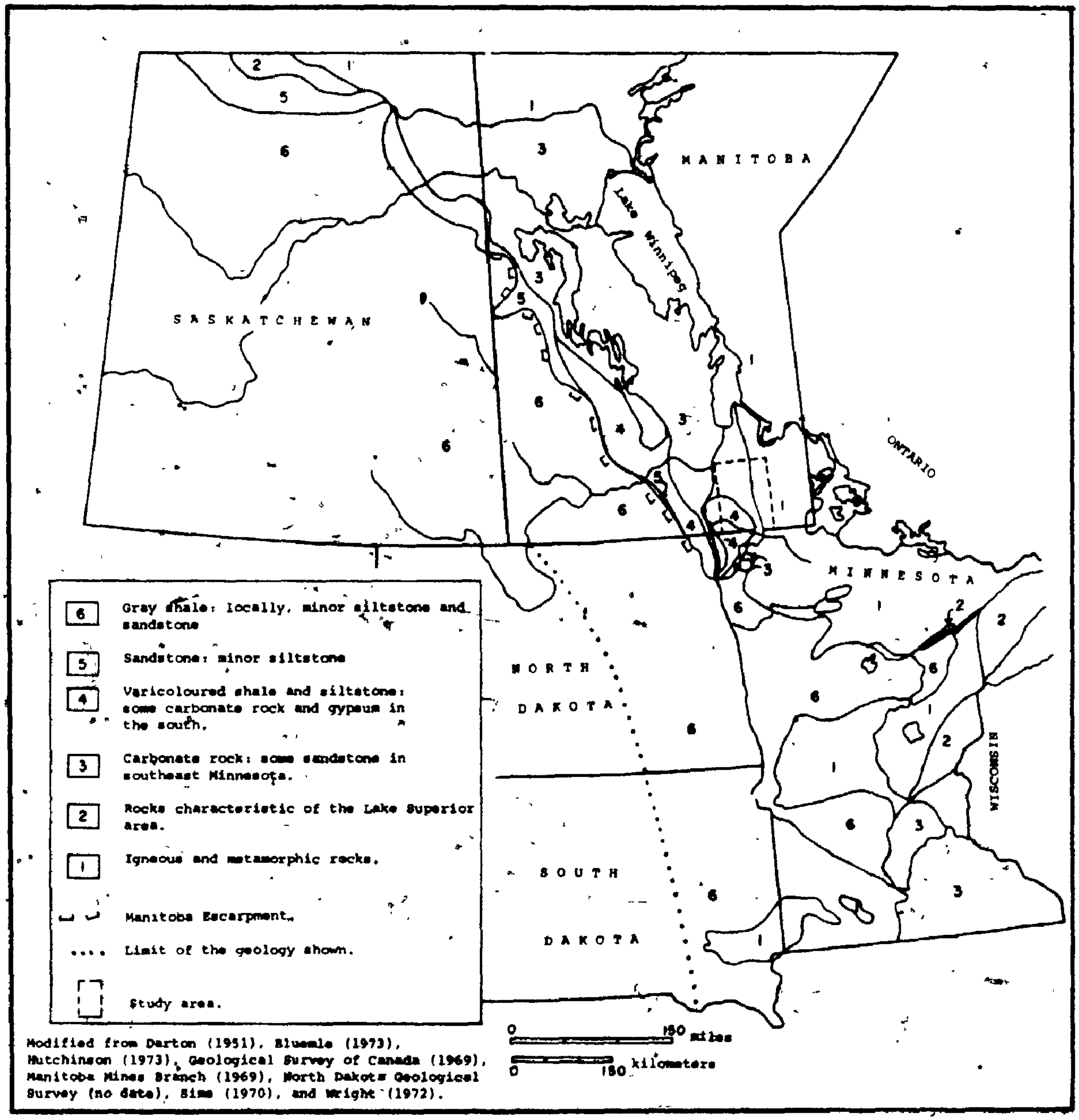


Figure 45. Map showing the generalized bedrock geology of the surrounding area.

slightly finer because of incorporation of shale, and both have a northwest source (thesis section 2.2 and Harris et al., 1974). The finer texture of Unit A (col. V) is a reflection of its much larger shale content (62%, very coarse sand fraction). In NW Minnesota the same unit has been identified as the Stuartburn till by the author and as the St. Hilaire till by the North Dakota researchers (S. R. Moran, written com., 1974).

The Tolstoi Formation is correlated with Unit 1 (Table 6, col. V) on the basis of the large proportion of carbonate grains in the very coarse sand fraction and carbonate clasts in the pebbles (Table 2 and Salomon, in press). The finer texture of the Tolstoi Formation is probably the result of incorporation of the fine stratified sediment with which it is interlayered. However, because this till has been recognized in only these two areas the areal variation in the properties are insufficiently understood to be certain there may not be other reasons for the observed textural differences. The till is much thicker in North Dakota (10 to 30 ft., 3 to 9 m., Salomon, in press) than in the study area.

The Senkiw Formation is correlated with the Gardar Formation and the lower part of the Red Lake Falls Formation (Table 6, cols. V, Vl, Vlll). The main reasons are (1) stratigraphic position, (2) texture, and (3) very coarse sand composition. The variation in texture and composition between the three areas is a product of the different material the glacier traversed before depositing the till. The Gardar Formation contains a larger proportion of shale (very coarse sand fraction) and is finer textured because of the incorporation of shale in the western part of North Dakota (Figure 45 and Salomon, in press). The textural similarity between the lower Red Lake Falls and the Senkiw in NW Minnesota is even greater if the proportion of sand in the mean texture (Table 6, cols. V, Vlll) is increased slightly (a textural modification suggested by the previously discussed comparison of analytical methods). The finer texture of this till in Minnesota, compared to the study area, is probably the result of incorporation of underlying drift. The very coarse sand composition of the lower Red Lake Falls is similar to the Senkiw in the study area.

The Roseau till is correlated with the upper part of the Red Lake Falls Formation and the Dahlen Formation (Table 6, cols. V, Vlll) because of (1) texture, (2) VCS composition, (3) stratigraphic position, and (4) a boulder pavement. The proportion of crystalline grains in the very coarse sand is similar in both the Roseau and the Dahlen, and the Dahlen contains some gray shale from the underlying bedrock (Figure 45). The larger proportion of crystalline grains in the upper Red Lake Falls is caused by a combination of (1) incorporation of the underlying Senkiw (rich in crystalline grains) and lower Red Lake Falls till (Table 6, cols., Vl, Vlll). (2) incorporation of crystalline-rich sand that accumulated during the non-glacial period preceding this ice advance (3) comminution of the shale grains without replenishment, caused by ice moving over the tills, that in this part of Minnesota, contain a small proportion of shale, and (4) the proximity of the Red Lake Falls area to the crystalline rocks in the northeast (Figure 45). The incorporation of sandy sediment is also supported by the observation that the proportion of sand in the samples analysed by the North Dakota researchers should be increased slightly for comparison to the author's (MMF) results (see the preceding paragraph discussing the comparison of analytical methods), which would make the upper Red Lake Falls sandier than the Roseau till. This correlation is also upheld by the shale, in the very coarse sand fraction, that appears in this till in NW Minnesota and increases toward the Red Lake Falls area because shale is absent from the overlying till and nearly absent from the underlying till. A well developed boulder pavement is commonly present at the base of the Dahlen Formation (Salomon, in press) and a poorly developed one is present at the base of the Roseau till.

The Marchand Formation is correlated with the Falconer and the Huot Formations (Table 6, cols. V, V111) because of (1) stratigraphic position, (2) very coarse sand composition, and (3) texture. The Marchand Formation is the uppermost till over the southern half of the Lake Terrace Plain, and the Falconer the uppermost till in adjacent areas of Minnesota and in North Dakota (Harris et al., 1974). The reconnaissance drilling in NW Minnesota (Figure 44) allowed the author to trace the Marchand till into that area and the north Dakota researchers have identified samples from the same depth in these test holes as the Falconer Formation (S. R. Moran, written com., 1974). The very coarse sand composition in the two units is similar except that in NE North Dakota the Falconer contains about 24 percent shale and proportionally less carbonate. This is because the generally southward flowing glacier that deposited the Falconer incorporated gray shale from the underlying bedrock and till as it moved into NE North Dakota. The textural differences between the Marchand, the Falconer, and Huot is to be expected when the history of the last two units is known. The glacier that deposited these formations advanced into a proglacial lake and incorporated great quantities of fine sediment and as a result the texture becomes finer southward. The Huot (Table 6, col. V111) is farthest south and therefore finest and Falconer becomes coarser northward (160 km., 100 mi., south of the Manitoba-North Dakota border: 10% ~~sand and~~ 55% clay, 64 km. south: 27% S and 30% C, and 32 km. south: 31% S and 20% C, Harris et al., 1974, and Salomon, in press).

The correlative of the Steinbach Formation has not been recognized in NE North Dakota. The Steinbach till does not extend south of township 7 over much of the Lake Terrace Plain but along the margin of the Red River Plain it has been traced south of the Roseau River. The distribution of this till within the Manitoba portion of the Red River Plain is unknown but if the till does extend into North Dakota it is only for a short distance because Salomon (in press) did not find it in test holes drilled in NE North Dakota about 32 km. (20 m.) south of the border.

The fine grained lower part of the Hazel Formation in the southern half of the area is correlated with the Brenna Formation, a fine grained lacustrine unit, on the basis of the stratigraphic position above the Marchand till and the very dark gray to black colour. Harris et al. (1974) mention that the Brenna Formation is a dark gray to black colour.

The Sherack Formation is correlated with the upper part of the Hazel Formation on the basis of stratigraphic position.

Within the other areas being considered (Figure 44) only the upper few tills can be correlated with those in the study area. In southwestern Minnesota Matsch (1971 and 1972) recognized two calcareous tills separated by a boulder pavement (Table 6, col. lX); the New Ulm Till, which was deposited by a southeastward flowing glacier and contains many shale fragments, and the underlying Granite Falls Till, which contains few shale fragments. The Granite Falls Till is correlated with the Senkiw Formation and the New Ulm Till with the Roseau Formation (Table 6, cols. Vl, IX). The very coarse sand composition of the

Granite Falls is similar to that of the western part of the Senkiw, and the texture becomes similar to that of the Senkiw in NW Minnesota when the proportion of sand is increased slightly, a textural modification indicated by the comparison of analytical methods (discussed in a previous paragraph). Matsch (1971, 1972) and Wright (1972, 1973) suggest a generally southward flow for the glacier which deposited the Granite Falls Till to account for the small proportion of shale and large proportion of crystalline and carbonate fragments in the till. The author proposes a generally southwestward flow similar to that for the Senkiw ice. The Senkiw till in the study area and till samples collected from the igneous and metamorphic terrain to the east (Figure 45) show that ice advancing from the northeast can, over a relatively short distance (about 64 km., 40 mi.), incorporate enough pre-existing drift to change from a non-calcareous till to the till in the study area, which contains a large amount of carbonate and crystalline grains but no shale grains. The small amount of shale grains in the Granite Falls Till is probably the result of incorporation of the pre-Senkiw tills which contain shale grains. This direction of glacial advance is also supported by the southwestward ice flow direction found in the Wadena drumlin field (Figure 44; Wright 1962 and 1972), which is composed of till correlated with the Granite Falls (Matsch, 1972, and Wright, 1972). Also in northeastern Minnesota, Winter (1971) measured a number of northeast-southwest till fabrics in a till which Wright (1972, p. 526) states resembles that in the Wadena area. The correlation of the Senkiw and Granite Falls tills is also supported by Salomon et al. (1973) who correlated the lower part of the Red Lake Falls Formation with the Granite Falls Till (Table 6). This till likely also extends into the northeastern part of South Dakota (Matsch, 1972, and Rutford, 1972).

The New Ulm Till is correlated with the Roseau Formation because of (1) stratigraphic position, (2) texture, (3) large proportion of shale, and (4) the boulder pavement at the base. The shale content differentiates the New Ulm from the Granite Falls as it does the Roseau from the Senkiw, in NW Minnesota (Table 6, cols. Vll, IX). The abundant shale fragments in the New Ulm Till are the result of incorporation as the general southeastward flowing ice passed over the gray shale bedrock in eastern North Dakota and adjacent parts of Minnesota (Figure 45). When the proportion of sand in the mean texture of the New Ulm (Table 6, col. IX) is increased slightly (a textural modification suggested by previously discussed comparison of analytical methods) the texture more closely resembles those of the proposed correlatives in northern Minnesota and that for the New Ulm Till shown by Matsch (1972, p. 554). This correlation is also supported by Salomon et al. (1973) who correlate the New Ulm Till with the upper part of the Red Lake Falls Formation (Table 6, cols. V11l, IX).

The Hawk Creek Till (Table 6, col. IX) was deposited by ice flowing westward out of the Lake Superior basin (Matsch, 1971 and 1972, and Wright, 1972) and is correlated with the Marcoux Formation (Salomon et al., 1973). The absence of the correlative of the Marcoux in the study area may be because (1) the Superior lobe did not reach the study area or (2) a thin till was deposited and later removed by glacial and/or nonglacial erosion.

Matsch (1971 and 1972, p. 552) reports a calcareous, shale-free till lying below the Hawk Creek Till. At the present time there is not enough information to correlate this with any of the pre-Senkiw tills in the study area.

North of the study area (Figure 44) McPherson (1970) recognized the Belair Drift and the overlying Libau Drift. The Belair Drift consists of the "lower till" and overlying thick glaciofluvial deposits, both of which were deposited by ice from the northeast. The lower till is correlated with the Senkiw Formation and the glaciofluvial deposits with the Sandilands Sand Member of the Bedford Formation (Table 6, cols. IV, VI) on the basis of texture, source area, and stratigraphic position. The Libau Drift includes "all the drift deposited by a significant glacial advance from a northwest direction" (McPherson, 1970, p. 111). This drift includes his "upper till" which based on test holes drilled by the author in approximately the same locations as some drilled by McPherson includes the Roseau, Marchand and Steinbach Tills.

Fenton (1970) recognized an Upper Till and Middle Till in the Portage La Prairie area (Figure 44; Table 6, col. 111). Samples from the test hole in which the tills were originally recognized were reanalysed during the present study. The Upper Till was deposited in an end moraine situated a few miles south of Lake Manitoba (Figure 44) and post dates the Steinbach Member. The Middle Till extends at least as far south as the Assiniboine River and is correlated with the Steinbach Member of the Hazel Formation (Table 6, cols. 111, V1). The textures are similar though the very coarse sand fraction of the Middle Till is much higher in dolostone (Middle T. 20% Cr., 16% Ls., 64% Ds., Steinbach 30% Cr., 27% Ls., 42% Ds.) because of the dolostone bedrock to the north, up-glacier of the drill site.

In southwestern Manitoba (Figure 44) Klassen (1969) defined, in ascending order, the Shell Till, the Minnedosa Till, and the Lennard Till, the latter having a boulder pavement at its base (Table 6, col. 11). Over much of southern Saskatchewan Christiansen (1968) has recognized the Floral Formation (till) and the overlying Battleford Formation (till) which has a boulder pavement at its base (Table 6, col. 1). The Shell Till is correlated with the Stuartburn Formation (Table 6, cols. 11, V1) because of their stratigraphic position and because both tills underlie stratified sediment which contains a variety of plant and animal remains suggesting a significant nonglacial interval. The Minnedosa Till is correlated with the Senkiw Formation on the basis of (1) stratigraphic position, (2) the presence of a boulder pavement overlying each of them, and (3) a northeastern source for both. The Lennard Till is correlated with the Roseau Formation because both record the last major glaciation of the region and both have a boulder pavement at their base. Klassen (1969) correlated the Minnedosa Till with the Floral Formation and the Lennard Till with the Battleford Formation, an interpretation with which the author agrees (Table 6, cols. I, II). The above correlations are supported by Salomon et al. (1973) who correlated the lower part of the Red Lake Falls Formation with the Minnedosa and the Floral, and the upper part of the Red Lake Falls Formation with the Lennard and the Battleford (Table 6, cols. I, II, VIII).

Age and Climate

This section completes the interpretation of the stratigraphy of the study area and serves as an introduction to the discussion of the long distance correlations. The age of, and the climate indicated by, the different units will be discussed on the basis of (1) information available from within the study area and (2) information from the surrounding region interpreted using the lithostratigraphic correlation proposed in the preceding section.

Age

Within the study area information on the age of the units is limited by the scarcity of material suitable for dating. Three dates on wood and fine organic material found in stratified sediments lying stratigraphically below the Senkiw Formation are more than 38,000 radiocarbon years old (Table 7). This agrees with the dates of wood found below the Granite Falls Till (Matsch, 1972 and Table 7) and from organic material recovered from the Lake Bronson area (Figure 44, Table 7). One of the reconnaissance test holes drilled near Lake Bronson indicated that the dated material, recovered from an earlier test hole, lies below the Senkiw till.

The only other information from within the study area is a date of 10,200±80 years B.P. (GSC 1900, Table 7) obtained from organic material deposited on top of clay during the low water interval of Lake Agassiz.

Considering the correlative units in the surrounding region an approximate minimum age for the Senkiw Formation of >40,000 can be obtained from the following: (1) the minimum age for the Granite Falls Till is >40,000 B.P. based on a radiocarbon date from organic silts on top of the till in the Wadena area (Figure 44, Table 7); (2) the minimum age for the Floral Formation is provided by a date of 38,000±560 years B.P. from wood lying between the Battleford and Floral Formations (GSC 1041, in Christiansen, 1971) and for the Minnedosa Till by a date of 37,000±1500 years B.P. (GSC 653, in Klassen, 1969) from the Zelena silts

Date Years B.P.		Location	Relationship to Stratigraphy	Source of Information
Beginning of Lake Agassiz				
14,300 ±1970	(GSC 1369)	Near Thornhill, SW Man. W of Red River Basin.	Provides minimum date for withdrawl of ice from Caledonia Advance (Moran and Clayton manuscript, 1972)	Klassen (1972, Table 1),
13,500 ±220	(I 2289)	"Sheyenne Delta" E North Dakota	Incision of head of the delta below highest lake level.	Moran et al. (1973)
12,000±250	(12537)		Fluvial Terrace inset into delta.	
Dates directly related to Lake Agassiz				
10 310 ±260	(GX498)		Peat from base of raised bog	Elson, 1967 p.71.
10,200 ±80	(GSC 1900)	Test hole FWB1 86,T7, R10	Organic detritus deposited when lake level fell below 314 m (1040 m).	This study, UPD.
9,990 ±160	(GSC 391)	Buffalo Point SW corner Lake Of The Woods, Man.	Driftwood fragments found just below Lower Campbell beach.	Elson 1967 p.71
10,960 ±300	(W 723)	Eastern North Dakota	Lake level at or below the Ojata level.	Moran et al. (1973).
10 820 ±190	(TAM 1)			
10 340 170	(I 5213)			
10 080 ±280	(W 900)			
10,050 ±300	(W 1005)			
9,900 400	(W 993)		Lake below Campbell level	
9 820 ±300	(W 1361)		Rise of Lake to Campbell level.	
9,810 ±300	(W 1360)			
9 730 ±160	(W 1523C)			
9,650 ±150	(W 1523)			
9,130 ±150	(I 1982)		Lake Falls from Campbell level.	
Earlier Dates				
15 250 ±220	(I 5051)	Central Minnesota	Pond bottom dates which provide minimum age for lake formed by ice which deposited New Ulm (Roseau) Till.	
16,150 ±550	(W 1973)			
>40,000	(W 123)	Central Minnesota	Organic silts on top of Granite Falls (Senkiw) Till	Wright (1973 p.524)
>41 000	(GSC 1663)	Section FWS21 study	Log from Se/T sediment.	This study, UPD.
>43,000	(GSC 1801)	Section FWS35	Log from Se/T sediment.	This study, UPD.
34,000	(Gx 1309)	SW Minnesota	Logs from same site below Granite Falls (Senkiw) Till.	Matsch (1972, p 555)
>39,900	(I 4932)			
>38,000	(GSC 1465)	Section FWS14	Layers of fine organic in St Malo.	This study.
>36,000	(W 102)	Lake Bronson area NW Minnesota	Wood, likely below the correlative of the Senkiw till.	Harris et al (1974).
>36,000	(W 498)			
>38 000	(W 1028)			
>39,000	(GSC 1666)	Red Lake Falls area.	Log from stratified drift below Marcoux Formation (till).	This study, UPD.
>39,900	(I 5317)			Harris et al (1974).

(UPD=unpublished date)

Table 7. Pertinent radiocarbon dates from the study area and the surrounding region.

(Table 6). The actual time of advance and retreat of the "Senkiw ice" is unknown.

A minimum age for the glacial advance which deposited the New Ulm Till is about 16,000 years B.P. (Wright, 1973, p. 181 and Table 7). This is the date of the advance of the Grantsburgh sublobe which is an off-shoot of the Des Moines Lobe - the ice lobe which deposited the New Ulm Till (Matsch, 1972, p. 560). Possibly, a finite age for the New Ulm is obtained from the tentative correlation of this till with a lithologically similar till in the extreme southwestern part of Minnesota (Matsch, 1972, p. 556) which is equivalent to the Tazewell in Iowa. Radiocarbon dating has shown the Tazewell to be about 20,000 years old (Ruhe, 1969). This date would provide a minimum age for the advance and a maximum age for the retreat of the glacier which deposited the Roseau till (Table 6) because time must be allowed for the ice margin to move from southern Manitoba to northern Iowa (800 km., 500 mi.). Using an estimate of 0.067 km/radiocarbon year, given by Kempton and Gross (1970) for the advance of the Woodfordian glacial margin in Illinois, about 12,000 years would be required for the advance. However, because the rates of glacial advance vary from one lobe to another and even between different sublobes (Dreimanis and Goldthwait, 1973, p. 89) it is quite possible that this figure is inapplicable.

A minimum age for the deposition of the Marchand Formation is similar to that for the Falconer Formation because of the close geographic proximity of these correlatives. The minimum age for the Falconer Formation is obtained from (1) the lowering of Lake Agassiz from beaches cut into the Falconer which have been dated at 13,500±220 years B.P. (Moran and Clayton, manuscript, 1972, and Table 7) and (2) a date of 14,300±1970 years (Table 7 and Klassen 1972, Table 1) from organic detritus in lacustrine sediment which was deposited, in southwestern Manitoba, after the retreat of the glacier that formed the Falconer Formation (Moran and Clayton, manuscript, 1972).

The only information on the age of the Steinbach Member is that it is younger than the Marchand Formation and likely older than the low water level of Lake Agassiz which began about 11,000 years B.P. (Table 7). The reasons for the Steinbach till being formed prior to the low level are the following: (1) the Caledonia Advance (Moran *et al.*, 1973), during which the Falconer Formation was deposited, shows that the glacier did fluctuate during its initial retreat and it is reasonable that other minor fluctuations during this retreat deposited the Steinbach till and ~~later~~ the Upper Till in the Portage La Prairie area (Figure 44, Table 6); (2) an ice advance following the low level of Lake Agassiz would require the ice to readvance from a northwest line about 160 km. (100 mi.) north of Lake Winnipeg (Elson, 1967) and this is a much greater distance than that required for minor readvances during the ice retreat; (3) the Sherack Formation deposited in Lake Agassiz after the low water phase, shows no evidence such as ice rafted sediment or rhythmites (Harris et al., 1974) to suggest an ice advance further to the north in the study area.

The lower part of the Hazel Formation was deposited during the early high water Lockhart Phase, 13,000 to 11,000 years B.P. (Ashworth et al., 1972, p. 187; and Table 7) of Lake Agassiz. The low water Moorehead Phase lasted from about 11,000 to 10,000 years B.P. and the high water Emerson Phase, during which the upper part of the Hazel Formation was deposited, until about 9,000 years B.P. when the lake gradually drained (Table 7; Ashworth et al., 1972, p. 187, and Moran et al., 1973).

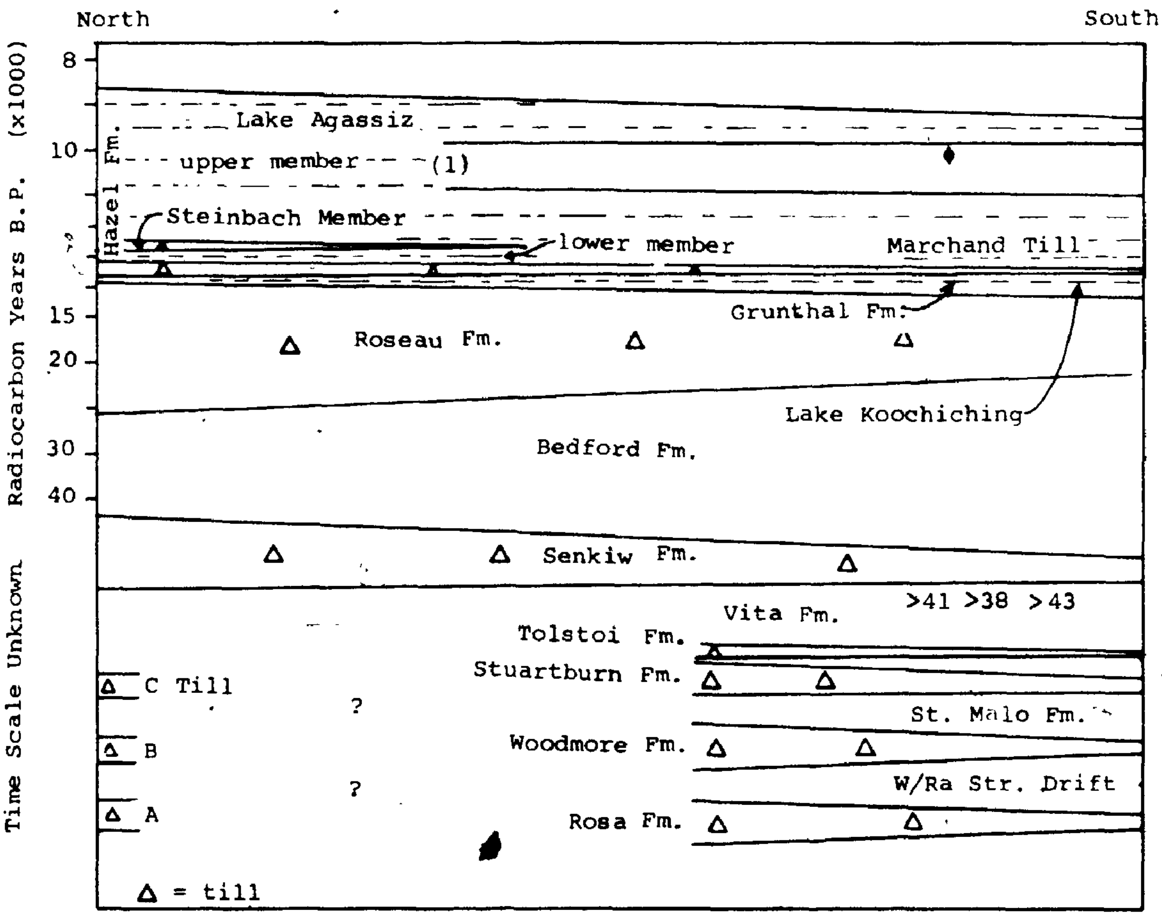
The three tills A, B, and C, which are present in the northeastern part of the study area, are probably older than the Senkiw Formation and therefore more than 40,000 years old.

The age relationships of the different units are summarized in Figure 46.

Climate

The climate during the deposition of the W/Ra Stratified Drift was mild enough to cause the glacier to retreat a sufficient distance beyond the southwestern part of the study area to prevent the deposition of dropstones in the drift.

The St. Malo Formation is likely only a remnant of the original unit with the younger portion of the deposit having



Based on data from the study area and Ashworth et al. (1973), Moran and Clayton (1972), Matsch (1972), and Wright (1972).

♦ Finite radiocarbon date with one standard deviation (bar).

>41 Minimum radiocarbon date (x1000).

(1) See the figure showing the history of Lake Agassiz for more detail.

Figure 46. Schematic time-distance diagram showing the deposition of the tills and the stratified units.

been removed during the advance of the Stuartburn ice. The presence of peat shows that during at least part of the nonglacial interval the climate was moderate enough to cause the ice to retreat from the area and to allow vegetation to establish itself. If the drainage was similar to that during the Late Wisconsin ice retreat, which formed glacial Lake Agassiz, the ice margin must have retreated at least to a position along a northwest trending line about 160 km. (100 mi.) north of Lake Winnipeg to prevent the area being submerged by a proglacial lake. The pollen from one sample of the organic layer shows a resemblance to the late-glacial or early Holocene assemblages in southern Manitoba or adjacent Minnesota (R. J. Mott, written com., 1972). The sediment was deposited during an interstade or possibly an interglaciation (Table 8).

The Vita Formation contains a more complete climate record. Climate amelioration caused the Tolstoi ice to retreat. Later the lake in which the till was deposited drained, from at least the southwestern part of the area, and erosion produced the sandy gravel. The moderation of the climate continued during the development of the floodplain deposits because only the underlying sandy gravel and the lowest part of the floodplain deposits appear to have been subjected to permafrost conditions. Results of the examination of biota samples from the middle and upper part of the floodplain deposits indicate a tundra or grassland environment, and the data together with the numerous twigs and

UNIT	CLIMATE	EFFECT	UNIT RANK	CORRELATIVE
Hazel and Grunthal Formations	Warming to about 6,000 years B.P., cooling to the present.	Major retreat of the glaciers, establishment of vegetation and gradual change to the present condotions.	Interglaciation	
Bedford Formation	Warm, though cooler than the present.	Ice retreated from SW Minnesota to a position far enough north of area to allow subaerial exposure.	Interstade	Interstade Zelena silts (Klassen, 1969).
Vita Formation	Warming at least to conditions slightly cooler and drier than the present. Record incomplete because of erosion.	Ice retreated far enough to allow subaerial exposure. Initial permafrost followed by warmer conditions, biota established in a grassland or tundra environment with nearby spruce dominated forest.	Interstade or interglaciation.	Interstade or interglaciation Roaring River Clays (Klassen, 1969).
St. Malo Formation	Warm, conditions at least as moderate as late-glacial early Holocene. Record incomplete because of erosion.	Ice retreated far enough to allow subaerial exposure and establishment of vegetation.	Interstade or interglaciation.	
W/Ra Drift.	Nonglacial.	Ice retreated north of southern part of area and lake formed.	Interstade.	

Table 8. Summary of the climatic conditions indicated by the nonglacial units.

spruce logs in the sediment suggest the presence of a nearby boreal forest or woodland. Ostracodes from these deposits in section FWS34 indicate a mean annual temperature of 1.2°C and a total annual precipitation of 45 cm. (17.7 in.; L. D. Delorme, written com., 1974) which is only slightly cooler and drier than the present (1.9°C and 52 cm., 20.5 in.; Smith et al., 1964). A lake was present in the Red River Basin at this time and the river which formed the floodplain deposits discharged into it forming the deltaic deposits in section FWS21 (Figure 16(b) and thesis section 2.2). Subsequently a minor readvance, possibly in response to a climatic deterioration, caused (1) the lake level to rise, (2) the deposition of lacustrine sediment over the floodplain deposits below 270 m. (900 ft.) and (3) the deposition of loess above 270 m. The water level then rose above 285 m. (950 ft.) if the stratified sediment above the organic layer in test hole FW100 is part of the Vita Formation. The sequence was later truncated by the glacial advance which deposited the Senkiw Formation. The Vita sequence is believed to be incomplete with an unknown portion having been eroded by the Senkiw ice because the lacustrine sediment in the upper part of the Vita Formation contains no evidence of either the advance of the Senkiw ice into the lake or of subaerial exposure. Also the Vita lacustrine sediments were not found on top of the loess deposit though the loess is below the lake level suggested by the stratigraphy in test hole FW100. In summary, the sequence in the Vita

Formation indicates a gradual amelioration of the climate to at least conditions only slightly cooler and drier than the present, possibly followed by a slight deterioration of the climate, and then the erosion of the subsequent climatic record by the advance of the Senkiw ice. This sequence may represent the lower part of the cool-warm-cool cycle recorded by the interglacial or interstadial Roaring River Clays in southwestern Manitoba (Klassen, 1969, and Klassen et al., 1967).

The Bedford Formation was deposited during an interval of probably interstadial rank (Table 8). The lithostratigraphic correlation of the Senkiw Formation with the Granite Falls Till (Table 6) requires an ice retreat from southwestern Minnesota to north of the Beausejour area (Figure 44) because all of the above region was subsequently covered by the ice which deposited the Roseau Formation and its correlatives. Permafrost existed in the southwestern part of the area during at least the later stages of this interval, to produce the frost wedges in section FWS36 (Figure 15) which extend into the Senkiw till and are partially filled with Roseau till. Permafrost features of this age have been observed throughout southwestern North Dakota (L. Clayton, written com., 1974) but have not been found in Minnesota (Matsch, 1971, p. 54). In southwestern Minnesota this interval records a period of erosion which produced a well developed boulder pavement (Matsch, 1971). In southwestern

Manitoba (Figure 44) the interstadial fossiliferous Zelena silts were deposited in a lake similar to, but cooler than, the present day lakes in that area (L. D. Delorme, per. com., in Rutter and Christiansen, 1972, p. 20). No evidence of the establishment of vegetation within the study area has been found so far, possibly because most of the information on this unit is from subsurface data.

The Grunthal Formation and the Hazel Formation were deposited during the recession of the Late Wisconsin glacier. The only climatic information from within the study area is the results from one pollen sample, collected from hole FW81, which were typical of the late-glacial or early Holocene of southern Manitoba (R. J. Mott, written com., 1972). Palynological studies, including Ritchie (1967, 1969), Shay (1967) and Wright (1970, 1971), in the surrounding region suggested a gradual change in climate following the start of the ice recession, from one conducive to at least local tundra conditions, to warmer wetter conditions, to warmer drier conditions about 8,000 to 4,000 years ago, to the cooler wetter conditions of the present.

The climatic interpretations are summarized in Table 8.

Long Distance Correlations

Long distance correlations are generally made on the basis of time and climate. The correlation is often hampered by (1) a lack of adequate chronologic and/or climatic information for either or both of the units being compared, and (2) a geographic change from one ice lobe to another because the movements of different lobes and even sublobes are not always synchronous nor of the same magnitude (Dreimanis and Goldthwait, 1973, p. 89; Flint, 1971; Willman and Frye, 1970; Wright, 1972).

The stratigraphy in the study area will be compared to that in southern Ontario because the Wisconsin Stratigraphy in that area is one of the most detailed and well documented in North America. This stratigraphy has recently been discussed by Dreimanis and Karrow (1972), Dreimanis and Goldthwait (1973), and Dreimanis and Raukas (1973).

A brief description of the stratigraphy in southern Ontario (taken mainly from Dreimanis and Goldthwait, 1973) will be given before comparing it with the study area. The first Early Wisconsin event was the Nicolet Stade (Table 9) during which a deterioration of the climate caused (1) glacial advance in the St. Lawrence Lowlands, (2) a lowering of the mean annual temperature about 6°C in the Toronto area (Terasmae, 1960), and cooler summer conditions farther to the southwest (Dreimanis and Goldthwait, 1973). During the following St. Pierre Interstade, the ice retreated an unknown distance, but the climate remained cool (Terasmae, 1960). The succeeding Guildwood Stade records a major climatic cooling and an ice advance as far south as Indiana and Ohio. The start of the Middle Wisconsin is marked by the beginning of the Port Talbot Interstade during which the ice retreated an uncertain distance into northern Ontario and

1000's YRS. B.P.		SOUTHERN ONTARIO from Dreimanis and Raukas (1973).	SOUTHEASTERN MANITOBA INTERPRETATION I	SOUTHEASTERN MANITOBA INTERPRETATION II
10	LATE WIS			
20	LATE WIS	Nissouri Stade	Roseau	Roseau
	MIDDLE WISCONSIN	Plum Point Interstade	↑	Bedford
30	MIDDLE WISCONSIN	Cherry tree Stade		Senkiw
40	MIDDLE WISCONSIN	Port Talbot II Interstade	Bedford	↑
(50)	MIDDLE WISCONSIN			Vita
(60)	MIDDLE WISCONSIN	Port Talbot I Interstade	↓	↓
(70)	EARLY WISCONSIN	Guildwood Stade	Senkiw	Stuartburn
	EARLY WISCONSIN	St. Pierre Interstade	Vita	St. Malo
(80)	EARLY WISCONSIN	Nicolet Stade	Stuartburn	Woodmore

Note, the lithostratigraphic names from within the study area are used to informally refer to the corresponding climatic units.

Table 9. Two possible correlations of the Quaternary stratigraphy in the study area with that in southern Ontario.

Quebec. This retreat may have been as far as the West shore of Hudson and James Bays and the Ontario-Quebec border (McDonald, 1969, 1971), a position supported by an ocean level only a short distance, about 20 to 30 m. (66 to 99 ft.) below the present one (Bloom et al., 1973; Machida, 1973; Chappel, 1974). One or more ice advances, weaker than the preceding Early Wisconsin advance, occurred during Cherrytree Stade and later the ice retreated northward during the Plum Point Interstade. The Late Wisconsin began with the strong ice advance of the Nissouri Stade during which the ice reached its maximum Wisconsin Limit in Ohio and Indiana. This was followed by an oscillating retreat from about 17,000 to 7,000 years B.P.

In long distance correlation the major events are of greatest interest because they are more likely to have effected both areas under consideration. The major events in southern Ontario are the Guildwood, Cherrytree, and the Nissouri Stades and the port Talbot and Plum Point Interstades. The Roseau till and the Senkiw till, if the regional lithostratigraphic correlations are correct, both record major climatic deteriorations, and ice advances from positions in northern Manitoba and Ontario to at least the southwest Minnesota, South Dakota and Iowa border. The Roseau Formation was probably deposited during the equivalent of the Nissouri Stade.

The available chronologic data on the Senkiw Formation furnish only enough information to propose two alternative interpretations (Table 9), which are (I) that the Senkiw

Formation was deposited during the equivalent of the Guildwood Stade and (II) that the Senkiw was deposited during the equivalent of the Cherrytree Stade. The evidence supporting I is that the age data indicate the Senkiw is more than 40,000 years old.

The evidence supporting interpretation II is the following: (1) the Cherrytree Stade may have begun earlier than shown in Table 9 (Dreimanis, personal com., 1974); (2) the suggested age (greater than 40,000 years B.P.) for the Senkiw Formation may not be correct because it is based on a limited amount of data that have been extrapolated into the area on the basis of the proposed lithostratigraphic correlations. Future research may indicate the age to be about 40,000 years, rather than greater than 40,000 years; (3) interpretation II allows a reasonable correlation of the "Bedford interstade" (this informal term refers to the climatic unit equivalent to the Bedford Formation) with the Plum Point Interstade and the "Vita interstade" with the Port Talbot Interstade (Table 9), a "reasonable correlation" because the Bedford Formation records an interval that was probably cooler and shorter than that recorded by the Vita Formation. The evidence supporting the above statement is the following: (a) the Vita Formation includes a thick and varied sequence of nonglacial deposits while the Bedford Formation does not; (b) the Vita Formation contains abundant and varied organic remains while no organic material has yet been found in the Bedford Formation; (c) the presence of frost wedges (section FWS36) extending into the Senkiw Formation, which stratigraphically underlies the Bedford, and involving the lower part of the Roseau Formation (Plate 6, Chapt. 3), which stratigraphically overlies the Bedford indicates permafrost conditions with no intervening period of sediment deposition. In the Vita, however, the only evidence of permafrost conditions is in the contorted sand and gravel near the base of the unit and this gravel is overlain by a thick sequence of nonglacial deposits that contain biota indicating a climate only slightly cooler and drier than the present; (d) interpretation II would also avoid having to (1) correlate both the Plum Point and Port Talbot Interstades, two major interstades with the relatively minor "Bedford interstade" and (2) correlate the comparatively minor St. Pierre Interstade with the relatively major "Vita interstade".

Interpretation I suggests the Senkiw Formation was deposited during the equivalent of the Guildwood Stade and interpretation II than the Stuartburn Formation was deposited during the equivalent of the Guildwood.

Whether the Nicolet Stade is recorded in the study area, as suggested in Table 9, is uncertain. The Nicolet Stade is believed to have caused only a limited advance from a single ice center in Labrador (McDonald, 1971; Dreimanis and Goldthwait, 1973) but its recognition in the study area would require a stronger advance to move the glacier as far as southern Manitoba.

Considering more recent events, the Grunthal Formation may have been deposited during the equivalent of the Erie Interstade because this interstade correlates with a world-wide amelioration of climate (Mörner and Dreimanis, 1973) and it is reasonable that such an event may have been recorded in southern Manitoba. Glacial fluctuations following the deposition of the Grunthal Formation involved a re-advance into Lake Agassiz and may reflect responses to local hydrologic conditions rather than widespread climate variation. Therefore because of the above and lack of good chronostratigraphic control, in the study area, it is premature to speculate on the relationship between the younger stades and interstades in southern Ontario and the units in the study area.

CHAPTER 5

QUATERNARY HISTORY OF THE AREA

The history of the area can be divided into two parts for the purpose of this discussion: (1) events up to and including the deposition of the Roseau Formation, and (2) post-Roseau events. The reason for this division is because the knowledge of the post-Roseau events is much more detailed. The events discussed below are numbered for the purpose of description but are not of equal duration however.

Events Pre-dating the Bedford Formation

(1) Prior to deposition of the Rosa Formation glaciers advanced and retreated through the area an unknown number of times to deposit the drift which lies below the Rosa till.

(2) A glacier advanced, probably from the north, and deposited the Rosa formation.

(3) This glacier retreated from at least the southern portion of the area and the meltwater formed a proglacial lake in which the W/Ra Stratified Drift was deposited.

(4) A glacier advanced through the area, most probably from the northwest, and formed the Woodmore Formation.

(5) Glacial retreat, likely as far as northern Manitoba and Ontario, allowed subaerial exposure of the area and subsequently vegetation established itself. The St.-Malo Formation was deposited during this interval.

(6) An ESE glacial advance deposited the Stuartburn Formation and extended at least as far as the northern portion

of Minnesota and North Dakota.

(7) A minor ice retreat caused the formation of a proglacial lake and the upper part of the Stuartburn was deposited in the southwest. Subsequently, a few minor ice advances into this lake resulted in the deposition of the Tolstoi Formation.

(8) Continued ice retreat, most probably into northern Ontario and Manitoba, allowed the lake to drain from the Lake Terrace Plain and permafrost conditions developed on the newly exposed land. Progressive climatic amelioration resulted in the development of a grassland or tundra in the southwest and a spruce dominated forest or woodland in at least part of the surrounding area, probably the west.

(9) A glacial advance from the northeast caused a proglacial lake to form in the area, and lacustrine sediment was deposited over the subaerial sediment. The Vita Formation includes both 8 and 9.

(10) The northeastern glacial advance continued through the area depositing the Senkiw Formation and extending as far as southwestern Minnesota and adjacent areas of South Dakota.

(11) Climatic amelioration caused the retreat of this glacier and the Sandilands Sand Member of the Bedford Formation was deposited in an ice walled channel during this retreat. Permafrost conditions developed sometime during the nonglacial interval and were still present at the start of the succeeding glacial advance.

(12) A glacial advance from the northwest overran the

study area, deposited the Roseau Formation, and moved southward into southwestern Minnesota and adjacent areas of Iowa and South Dakota.

Events Post-dating the Roseau Formation

(13) The glacier, which had deposited the Roseau Formation, retreated from the Lake Terrace Plain and at least as far northwestward as shown in Figure 47, and proglacial Lake Koochiching (Nikiforoff, 1947; Moran and Clayton, manuscript, 1972) which had formed in northwestern Minnesota extended into the area. The Grunthal Formation was deposited.

(14) The ice readvanced during the Caledonia Advance (Moran and Clayton, manuscript, 1972; Moran et al., 1973) as far south as the Edinburgh Moraine (Figure 44) in Minnesota and North Dakota. The Marchand Formation was deposited in the study area though the upper part of the Bedford Hills probably formed a nunatak (Figure 48(a)). The small area of fine stratified drift near the west side of the Bedford Hills (sec. 36, tp. 9, rge. 4) was likely deposited as the ice retreated.

(15) The ice again retreated from the Lake Terrace Plain and-formed the kame-deltas situated east of the Red River Basin (Figure 8, and 48(b). The extent of the retreat in the basin itself is unknown but the ice remained at the margin of the Lake Terrace Plain long enough to form the kame-deltas in townships 3 and 4, ranges 4 and 5. Lake Koochiching reoccupied the area and later, after the disintigration of a

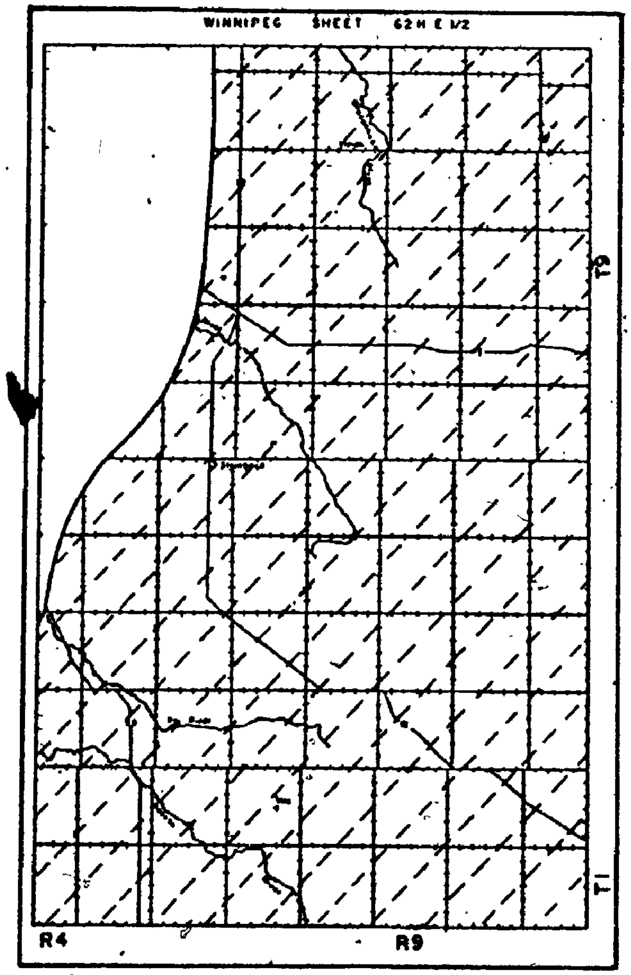


Figure 47. Known or minimum extent of glacial retreat during the deposition of the Grunthal Formation (ice = white, Lake Koochiching = dashed lines).

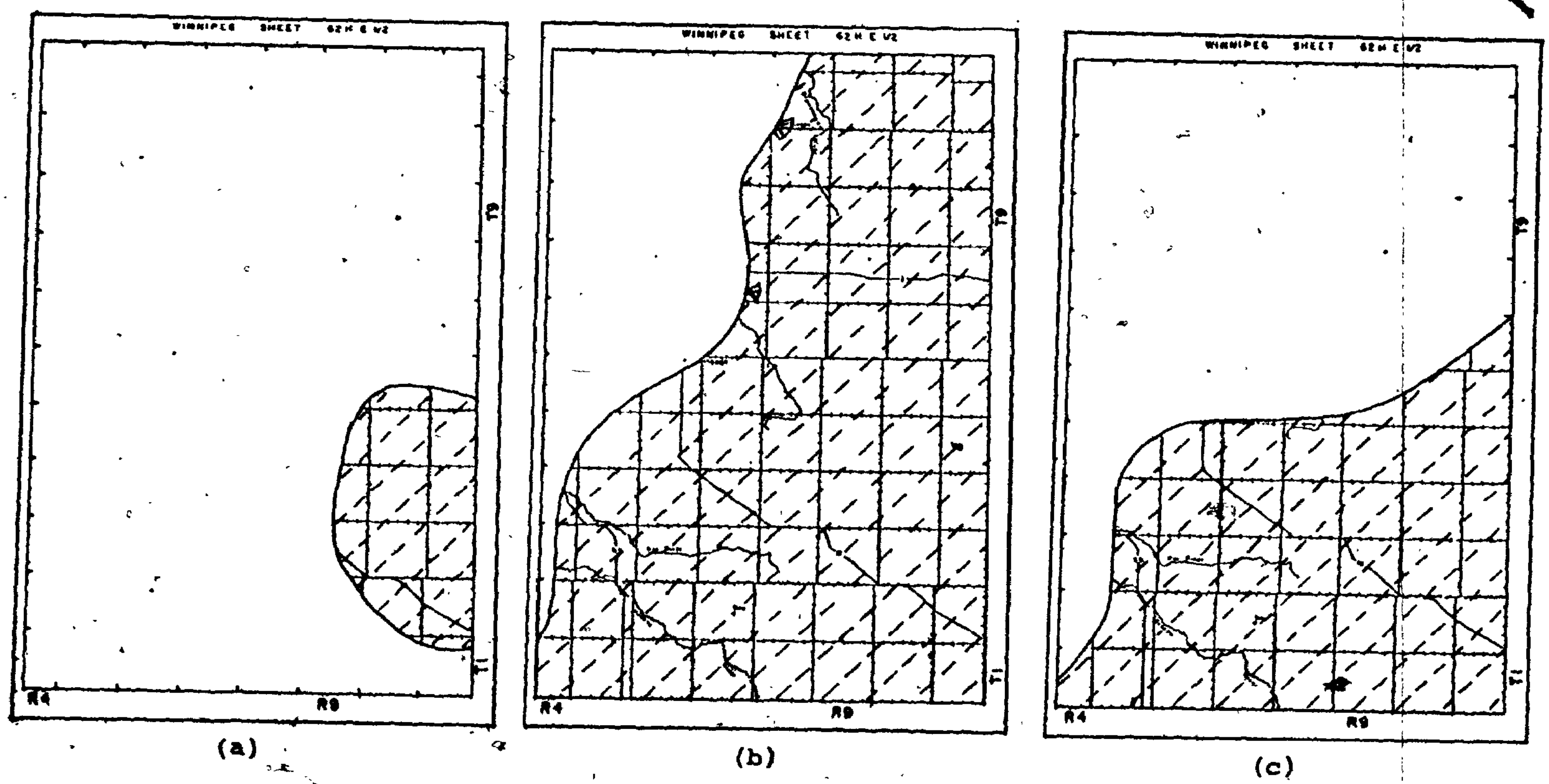


Figure 48. (a) Study area during the Caledonia Advance, (b) glacier margin during the retreat following the Caledonia advance and during the deposition of the kame deltas, (c) glacier margin during the Richer Advance. (ice = white, water = dashed lines, kame deltas = ◁)

mass of stagnant ice south of the Canada-United States border, Lake Agassiz formed (Moran and Clayton, manuscript, 1972), The lower part of the Hazel Formation was deposited.

(16) Following the formation of the kame-deltas the glacier either (1) readvanced or (2) retreated farther to form the kame-deltas in the northwestern part of the area and then readvanced. This readvance from the northwest, herein called the Richer Advance, deposited the Steinbach Member of the Hazel Formation in the northern half of the Lake Terrace Plain and along the eastern margin of the Red River Basin (Figure 48(c)). It is probable that the ice in the basin did not extend more than a few kilometers south of the Manitoba-North Dakota border.

(17) The glacier retreated from the area and likely paused or readvanced a number of times in the region to the north. The kame-deltas in the northwest, if they had not already been deposited during (4), and the Upper Till end moraine in the Portage La Prairie area (Figure 44) were formed during this retreat. Lake Agassiz, at its highest waterplane - the Herman, entirely submerged the area and drained southward through Brown Valley into the Minnesota River (Figure 44; Upham, 1895).

(18) Aperiodic erosion of the southern outlet allowed the lake level to fall in stages (Figure 49(a)) and the Tintah and Norcross scarps were eroded into the Bedford Hills (Figure 12). About 13,000 years ago erosion lowered Lake Agassiz to the Campbell level and it remained there during the Lockhart

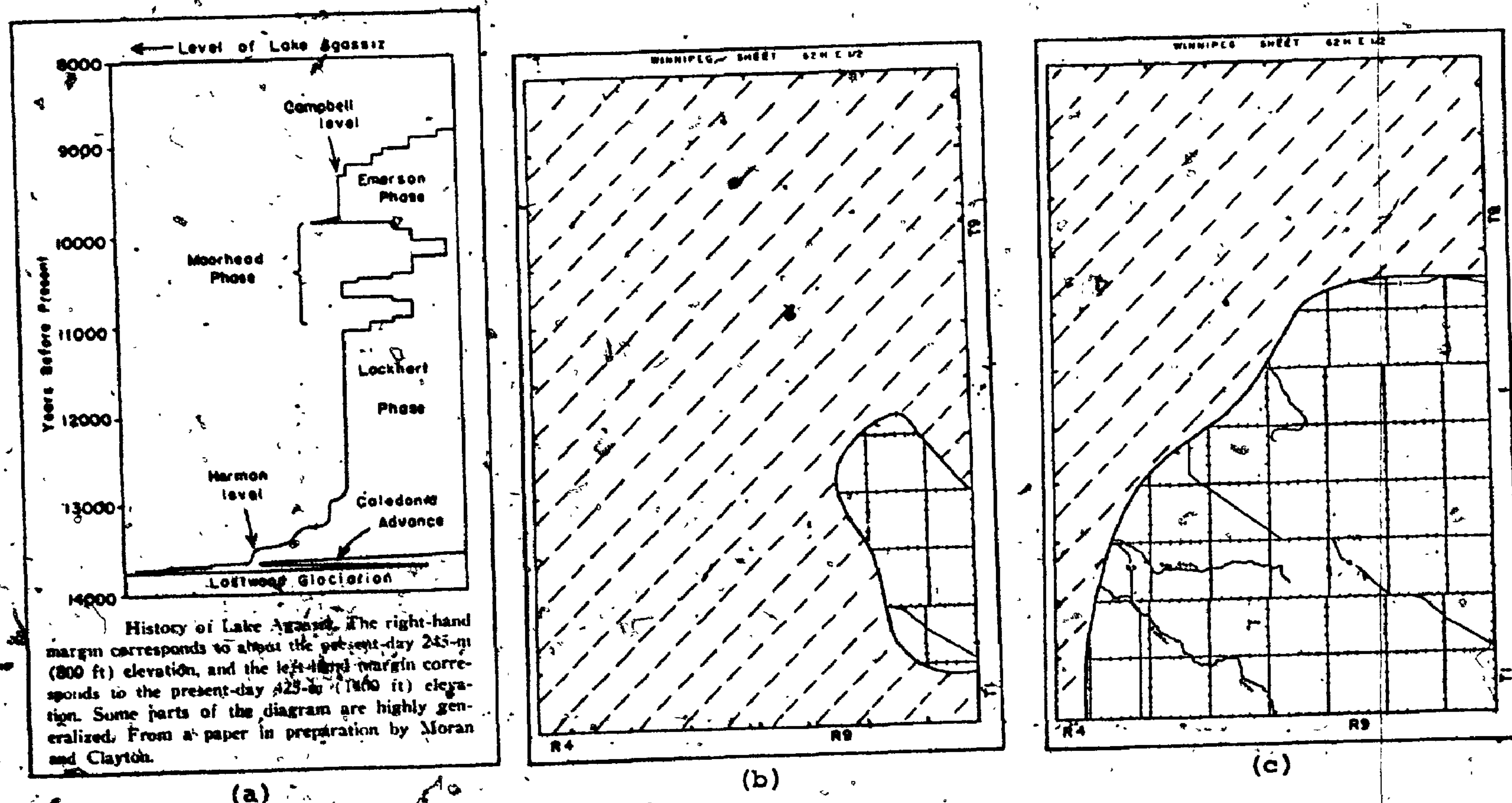


Figure 49. (a) History of Lake Agassiz showing lake phases (figure modified slightly from Ashworth et al., 1972), (b) Lake Agassiz at the Upper Campbell level during the Lockhart Phase, (c) Lake Agassiz at the Ojata level during the Moorehead Phase. (water = white with dashed lines, land = exposed portion of map)

Phase (Figure 49(a); Ashworth et al., 1972; Moran et al., 1973). The well developed Upper Campbell strandline features were eroded into the Bedford Hills at this time (Figures 12, 49 (b)).

(19) About 11,000 years ago the continued northward retreat of the ice sheet uncovered lower outlets allowing drainage through northwestern Ontario into Lake Superior and the lake level fell starting the low water Moorehead Phase (Figure 49(a); Ashworth et al., 1972). The lowest level reached is uncertain but the lake did fall below the Ojata waterplane (Figure 12; Moran et al., 1973). During this phase the falling water formed a thin layer of sand in some areas and an extensive gravel layer, and vegetation established itself on the newly exposed surface. Minor fluctuations of the lake level (Figure 49(a)) are recorded by gravel/sand/gravel sequences in sections FWS1 (tp. 2, rge. 7) (Figure 16(a)).

(20) About 9,900 years ago a glacial readvance in northwestern Ontario closed the Superior outlet and Lake Agassis rose above the Campbell level (Ashworth et al., 1972; Moran et al., 1971) beginning the Emerson Phase (Figure 49(a)). Stabilization of the water level resulted in additional erosion of the Bedford Hills producing the Lower Campbell scarps and strandline features, and the resumption of deposition of the Hazel Formation.

(21) Continued glacial retreat in northern Ontario and Manitoba opened successively lower outlets and the lake level

fell aperiodically. During this falling water period and the preceding still-stand at the Lower Campbell waterplane sand eroded from the Bedford Hills was transported westward, buried the vegetation later recovered from test holes FW4 and FW81 (Figure 16(a), and produced the extensive cover of lacustrine sand, the upper part of the Hazel Formation, that now mantles a major part of the study area (Figure 8). Lake Agassiz drained from the study area between 9,000 and 8,600 years B.P. (Prest, 1970, p. 722).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

(1) In general the bedrock surface dips gently westward and southwestward from more than 240 m. (800 ft.) above sea level in the southeast to less than 210 m. (700 ft.) in the west and 195 m. (650 ft.) in the southwest. Locally a northwest trending bedrock low is present in the northern quarter of the area.

(2) Unconsolidated sediments, consisting mainly of glacial, fluvial and lacustrine material, completely cover the study area and range from less than 12 m. (40 ft.) thick in the northwest to over 120 m. (400 ft.) thick in the southeast.

(3) Eight lithostratigraphic units composed of till can be recognized in the study area. They are, in ascending order, the Rosa Formation, Woodmore Formation, Stuartburn Formation, Senkiw Formation, Roseau Formation, Marchand Formation, and the Steinbach Member of the Hazel Formation (Table 1).

(4) The most useful criteria in differentiating these tills are (1) the proportion of sand (2.0 to 0.063 mm.), silt (0.063 to 0.002 mm.), and clay (-0.002 mm.) in the till matrix, (2) the lithologic composition of the very coarse sand fraction (2.0 to 1.0 mm.), (3) stratigraphic position, and (4) till clast fabric. Other criteria that are sometimes

useful include (a) pebble composition and concentration (4 to 8 mm.), (b) percent calcite and dolomite in the fine matrix (-0.063 mm.), and (c) colour.

(5) The main characterizing properties of each till, in addition to stratigraphic position, are the following:

The Rosa Formation: texture (mean 29% Sand and 21% Clay) and the very coarse sand composition (mean 42% Crystalline grains).

The Woodmore Formation: texture (29% S and 22% C) and the VCS (27% Cr).

The Stuartburn Formation: texture (41% S and 14% C), VCS (41% Cr), a WNW-ESE clast fabric, and a dark colour.

The Tolstoi Formation: texture (25% S and 22% C), VCS (28% Cr).

The Senkiw Formation: texture (60% S and 11% C), VCS (70% Cr in the east, 50% Cr in the west), a NE-SW clast fabric, and low fine matrix total carbonate (38%, all others 49-61%).

The Roseau Formation: texture (32% S and 18% C), VCS (34% Cr), a NW-SE clast fabric.

The Marchand Formation: texture (42% S and 15% C) and VCS (41% Cr).

The Steinbach Member: texture (31% S and 17% C), VCS (31% Cr), and a NW-SE clast fabric.

(6) Specific till properties vary both areally and locally. Areal variations include (1) an above average proportion of carbonate (very coarse sand and fine matrix) in the northern part of the area in each of the tills and (2)

in the Senkiw till, only, a westward increase in the carbonate content. Local variations in (1) the Roseau till include (a) an increase in the amount of sand south and west of the Bedford Hills, (b) an increase in the proportion of the fine sediment east of, and on top of the Bedford Hills, and (c) an increase in the crystalline grain content (VCS) in the southeast and (2) the Steinbach till include (a) an increase in the proportion of fine sediment to the west of and including the western margin of the Lake Terrace Plain, (b) a low crystalline grain content (very coarse sand) in the Red River Plain, and (c) a high crystalline grain content along the western margin of the Lake Terrace Plain,

The above variations are believed to be the result of the glacial incorporation of pre-existing sediment and/or the carbonate bedrock, which is exposed north of the area.

(7) Within the area the various tills have different known distributions. The Steinbach Member has been recognized in the northern half of the Red River Basin and the Marchand Formation is present over much of the Lake Terrace Plain and at least the eastern portion of the Red River Basin. The Roseau Formation is present in the Lake Terrace Plain, the Bedford Hills, and at least the eastern margin of the Red River Basin. The Senkiw and Stuartburn Formations have been recognized only in the southern two-thirds of the area and west of the Bedford Hills, and the Rosa, Woodmore, and Tolstoi Formations only in the southwest.

(8) The direction of glacial advance was from (1) the west-northwest for the Stuartburn and Tolstoi tills, (2) the northwest for the Woodmore, Roseau, and Steinbach tills, (3) the north to northwest for the Rosa and Marchand tills, and (4) the northeast for the Senkiw till.

(9) These till units can be correlated with other lithostratigraphic units in the surrounding region (Table 6). The Rosa Formation and the Woodmore Formation are correlated with Unit D and Unit C respectively in NE North Dakota and the Rosa may also be present in NW Minnesota. The Stuartburn Formation in equivalent to the St. Hilaire Formation in NW Minnesota and Unit A in NE North Dakota. The Tolstoi Formation is equivalent to Unit 1 in NE North Dakota. The Senkiw Formation is correlated with the Gardar Formation in NE North Dakota, the lower part of the Red Lake Falls Formation in NE North Dakota and NW Minnesota, the Lower Till in the Beausejour area, the Minnedosa Till in SW Manitoba, and the Floral Formation in S Saskatchewan. The Roseau Formation is correlated with the Dahlen Formation in NE North Dakota, the upper part of the Red Lake Falls Formation in NW Minnesota, the Libau Drift in the Beausejour area, the Lennard Till in SW Manitoba, and the Battleford Formation in S Saskatchewan. The Marchand Formation is equivalent to the Falconer and the Huot Formations in NE North Dakota and NW Minnesota and the Libau Drift in the Beausejour area. The Steinbach Formation is correlative with the Middle Till in the Portage La Prairie area and the Libau Drift in the Beausejour area.

(10) Three, or possibly only two, pre-Roseau and likely pre-Senkiw tills are present in the northeastern part of the area but the data does not permit their correlation with any other units.

(11) Stratified sediments are present, at least in a few places, between all the tills. These units are named, from the base upwards (Table 1), the W/Ra Stratified Drift (an informal unit lying between the Rosa and Woodmore Formations), the St. Malo Formation, the Vita Formation, the Bedford Formation, the Grunthal Formation, and the Hazel Formation (a unit which includes the Steinbach Member).

(12) The Hazel and Grunthal Formations were deposited near the start of the present interglaciation. The Bedford Formation and the W/Ra Stratified Drift were deposited during interstades and the Vita and St. Malo Formations were deposited during interstades or possibly interglaciations.

(13) Two of the stratified units can be correlated with similar units in southwestern Manitoba. The St. Malo Formation is correlated with the Zelena silts and the Vita Formation with the Roaring River clays.

Recommendations for Future Research

Future research should be concentrated in two general fields (1) obtaining a more detailed and complete understanding of the Quaternary stratigraphy within the study area and (2) correlation between the stratigraphic units in the study area and those in adjacent regions.

Within the study area research could include the following: (1) the drilling of a number of deep test holes to obtain information of the Quaternary stratigraphy below the depth sampled during this study; (2) detailed sampling of the Vita Formation for the study of the ostracod, mollusc, insect, and plant remains they contain; (3) additional till fabric measurements on the exposed units, particularly the Marchand till to determine their source area; (4) a continued search for suitable material to date the Vita and Bedford Formations.

Research extending beyond the study area could include the following: (1) sampling of the near surface, and therefore easily accessible, tills to obtain information on areal variation in properties such as texture, very coarse sand granule and pebble composition, and fabric; (2) the drilling of test holes to trace the tills beyond the study area.

Appendix A Field Methods

The mapping of the surficial deposits was accomplished by traverses along most of the roads, and a limited number of traverses into the less accessible areas and air photo interpretation. The boundaries of the different map units were plotted on air photographs and later transferred to the base map (scale 1:250,000). The scale of the air photographs covering the northwestern part (tps. 7 to 12, rges. 4 to 6) is 1 in. = 1/4 mile, and for the photographs covering the remainder of the area, 1 in. = 1 mile.

One hundred and one test holes were drilled using truck mounted power augers. A hollow stem auger was used to obtain split spoon samples from holes FW1 to FW9. It was discontinued however because of difficulties in sampling. The remainder of the test holes were drilled with a solid stem auger and auger flight samples collected. In total about 2,000 m. (6,700 ft.) of augering was done.

Appendix B Till Clast Fabric Measurements

The till clast fabric is the orientation of the clasts within the till matrix. The purpose of these fabric measurements was to obtain information of the regional flow direction for the glaciers which deposited the different till units in the study area.

The methods of measuring the clast fabric in a till have been discussed by Andrews (1971). The method used by the author was to dig 1 to 2 m. (3 to 6 ft.) into the till, form a horizontal bench about 0.3x1 m. (1x3 ft.) in area, and to carefully scrape away the surface of the bench and measure the orientation of the clasts thus exposed. Only pebbles with obvious long axes were considered and for each (1) the bearing, measured to the nearest 10° and in the direction of plunge, and (2) the amount of plunge, measured to the nearest 10°, were recorded.

Experience showed that the majority of clasts measured were carbonate pebbles with the long axes generally 3 to 6 cm. in length and the short axes 1 to 3 cm. in length. The number of clasts measured was generally between 25 and 50. The emphasis was placed on measuring the till fabric at as many sites as possible rather than measuring the orientations of a large number of clasts at only a few sites. In some of the large exposures two or more sites were sampled within the same unit.

The results from all the sample sites were plotted as mirror-image rose diagrams (Andrews, 1971, p. 21) and the results from those sites sampled after the first field season were plotted as plunge-sensitive rose diagrams (Andrews, 1971, p. 21). A recording error during the first field season made it impossible to determine the direction of clast plunge. The mirror-image diagrams proved more useful in determining the regional ice flow direction.

The major difficulty in making the fabric measurements was to be certain the sample sites were in undisturbed till. At about one quarter of the sites small scale slumping of the till had destroyed the original glaciogenic fabric and the results had to be discarded. The difference between the fabrics in slumped and unslumped till is often very noticable when the results are plotted (Figure B-1). The contact between the slumped and undisturbed till is sharp. For the samples shown in Figure B-1 the undisturbed till was reached by excavating only 30 to 60 cm. (1 to 2 ft.) farther into the section than where the slumped fabrics were measured. The author found that one to two hours of excavating were necessary to reach unslumped till in some of the sections, and that it is easily recognized by its much greater compactness than the slumped material. The best sampling sites are either fresh excavations or nearly vertical faces over 2 m. (6 ft.) in height.

The three sections where two or more sites were sampled in the same till (FWS17, FWS22, Senkiw Formation, Figure 32, and FWS41, Stuartburn Formation, Figure 27) show that the variability within the undistrubed portion of the units is

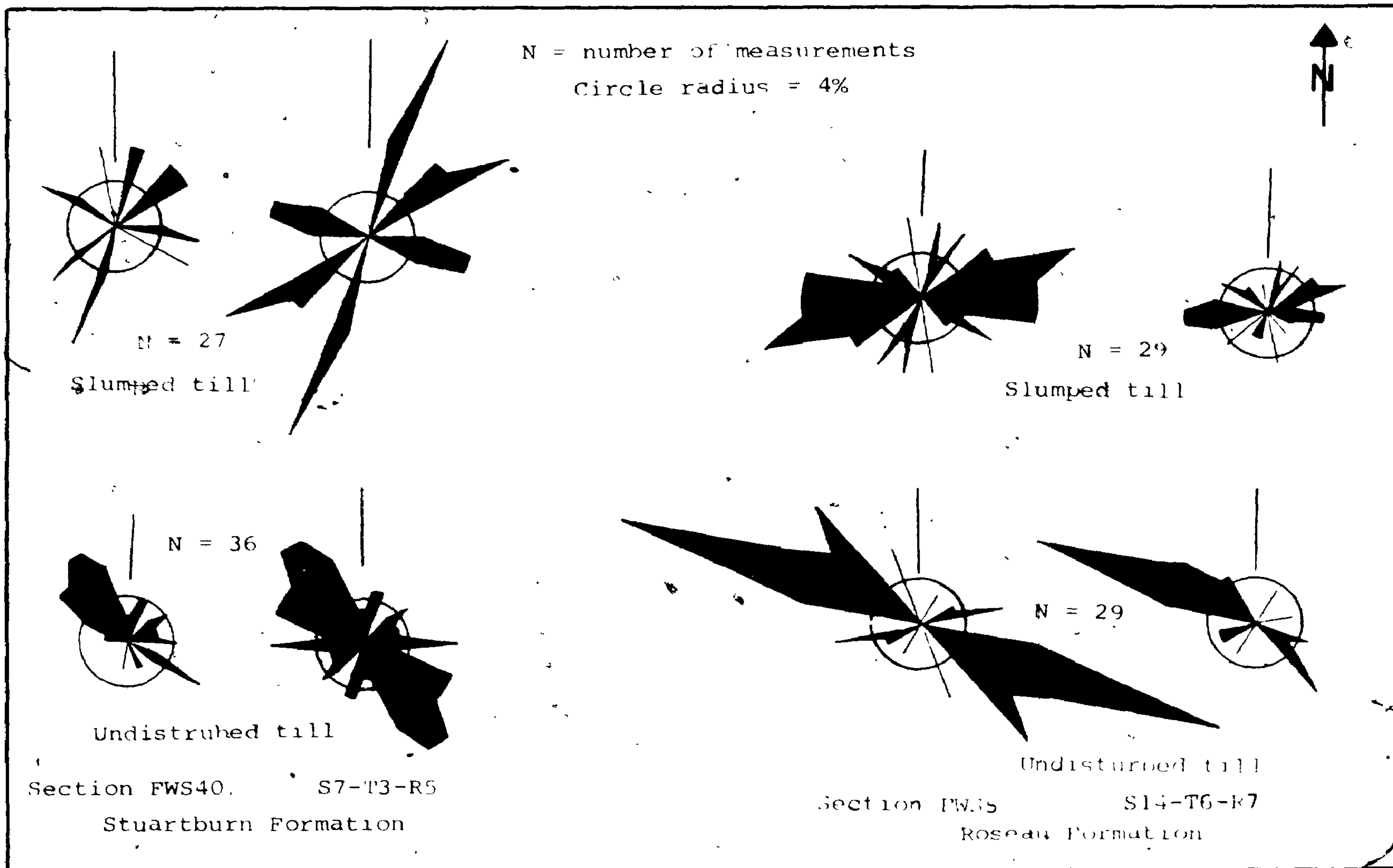


Figure B-1. Rose diagrams showing the effect of slumping on the clast fabric in till.

not great. Another set of three fabrics measured in the Stuartburn till, at the Circus Section, had to be discarded because of measurement in slumped material.

Appendix C - Textural Analyses

Each sample received the preliminary sample preparation shown in Figure C-1 and the portion of the sample split off for textural analyses was processed as shown in the flow chart (Figure C-2). The weight percents of sediment in the size classes greater than 0.037 mm. were determined using sieves and those below using the hydrometer method. The procedure was similar to the ASTM procedure D422-63 (American Society for Testing and Materials, 1964). Slight variations from the ASTM method included the elimination of the water bath for the hydrometer cylinders and the removal of the +0.037 mm. fraction of the sample prior to the hydrometer analyses. The removal of this fraction allowed the sieve analyses to be run during the two or three days the hydrometer readings were taken and thus shortened the analyses time. The effect of the removal of the +0.037 mm. fraction on the results of the hydrometer analyses was tested by the author, on some of his samples, and by A. Dreimanis and R. W. May (verbal com., 1972) and no noticeable change was detected.

Two types of textural analyses were run, the "long method" and the "short method". The "long method" yields sufficient information to draw a cumulative curve and requires sieve fractions of 2.0 to 1.0, 1.0 to 0.50, 0.50 to 0.147, 0.147 to 0.125, 0.125 to 0.063, 0.063 to 0.044, and 0.044 to 0.037 mm., and hydrometer readings at 0.6, 1, 2, 4, 10, 15, 30, and 60 minutes and 2, 6, 12, 24, 48, and 72 hours.

3 OF/DE 4

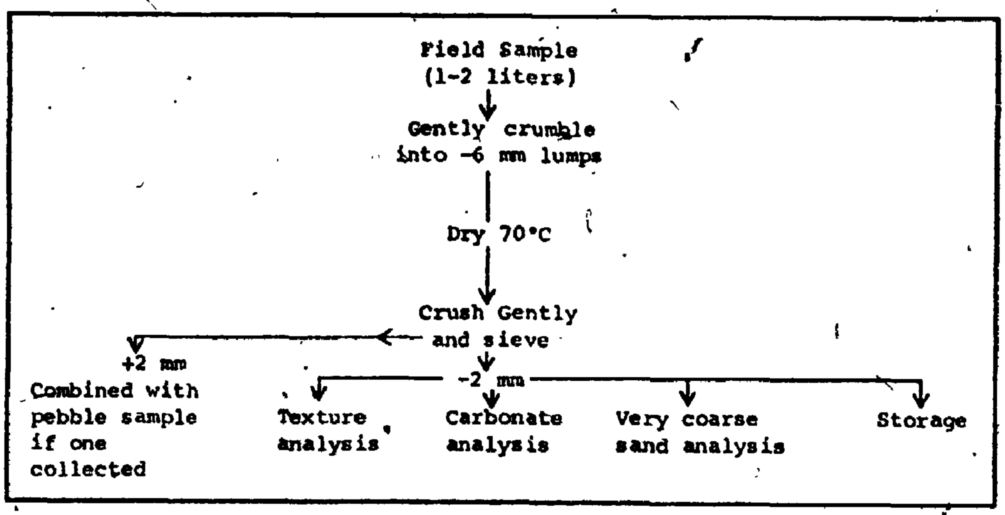


Figure C-1. Preliminary sample preparation flow chart.

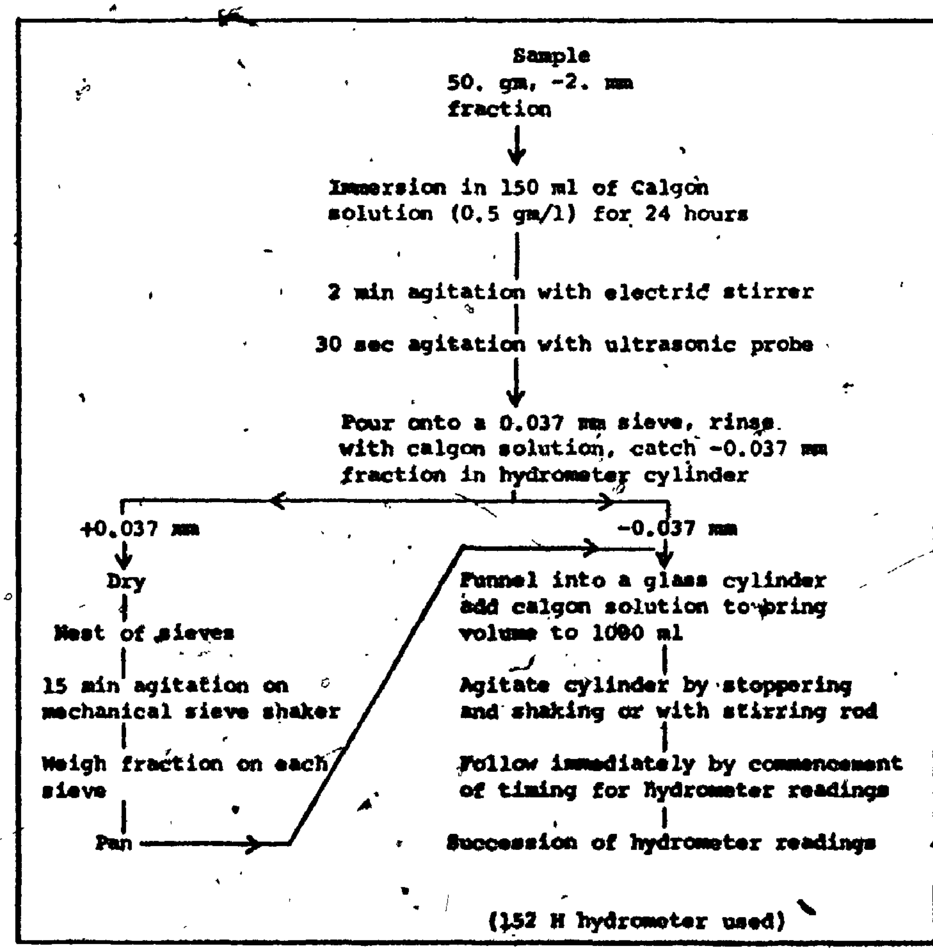


Figure C-2. Flow chart for the textural analysis.

The "short method" allows the determination of the percent sand, silt, and clay, and requires one sieve fraction, 2 to 0.063 mm., and three hydrometer readings at about 8, 9 and 12 hours. The short method was used after it was found that the percent of sand, silt, and clay was sufficient to distinguish samples of the different tills, to decrease the time required for each analyses.

The textural boundaries used by the author were sand (-2.0 to +0.063 mm.), silt (-0.063 to +0.002 mm.) and clay (-0.002 mm.). The percent finer than 0.004 mm. was also determined for some of the samples because a number of researchers have chosen this value as the upper limit of clay (Dreimanis, 1971).

Tests made to determine if there was any variation between the long and short methods, and the author and technician who were running the analyses showed that in both cases the variation was generally less than 1% (Table C-1, a and b).

Most of the textural data on the till units in Minnesota and North Dakota that have been correlated with units in the study area, come from research at the North Dakota Geological Survey or Department of Geology, University of North Dakota. Because of this the results of textural analyses run by the author and the North Dakota researchers on samples taken from similar depths in the same test holes (drilled in NW Minnesota) were compared, and the author's analyses generally had slightly more clay (mean difference 2%, 19 samples) and more sand (mean difference 8%, 19 sam-

SAMPLE & METHOD	TEXTURE Sand %	Silt %	Clay %
A			
Short	41	41	18
Long	41	40	19
B			
S	40	40	20
L	40	41	19
C			
S	39	40	21
L	39	42	19
D			
S	40	43	17
L	41	42	17
E			
S	40	42	18
L	39	42	19

(a)

SAMPLE & ANALYST	TEXTURE Sand %	Silt %	Clay %
W			
Fenton	45	44	11
Technician	47	42	11
X			
F	43	49	8
T	44	48	8
Y			
F	28	52	20
T	28	52	20
Z			
F	38	49	13
T	39	48	13

(b)

Table C-1. (a) Comparison of the results from the long and short methods of textural analysis, (b) comparison of the results from textural analyses of the same samples by the two analysts.

TILL	MEAN DIFF. %	NUMBER of MEASUREMENTS	ADJUSTED DIFFERENCE % (1)
Steinbach Till	6	38	4
Marchand Till	4	28	2
Roseau Till	5	23	3
Senkiw Till	3	38	1
Tolstoi Till	8	2	6
Stuartburn Till	7	14	5
Woodmore Till	6	3	4
Rosa Till	10	9	8

(1) Takes into account the 2% difference between the 0.004 clay boundary obtained by Fenton and the North Dakota researchers on similar samples.

Table C-2. Mean weight percent difference between the -0.002 mm and the -0.004 mm fractions for each till unit.

ples). The reason for the greater proportion of sand in the author's results is uncertain at this time but contributing factors include (1) the author using the hydrometer method (with 50 gram samples) and the North Dakota researchers using the pipette method (probably with smaller samples) and (2) the fact that the samples were not collected from identical depths in the test hole.

Another difference between the two sets of textural data is that the North Dakota researchers have chosen 0.004 mm. as the upper boundary of clay while the author regularly uses 0.002 mm. (0.004 was used in the textural comparison). Table C-2 shows the weight percent difference which takes into account the 2% mean difference in the proportion of clay indicated by the data comparison.

To determine the U.S.D.A. soil classification of the till units the 0-063mm sand-silt boundary was considered equivalent to the 0.050 mm boundary.

Appendix D Carbonate Analyses

The weight precent of calcite, dolomite, and total carbonate in the -0.063 mm. fraction of each sample was determined using the method described by Dreimanis (1962). Briefly, the method consists of adding 20% hydrochloric acid to a weighed sample and recording the volume of CO_2 evolved after 30 seconds and after about 30 minutes. The first reading is used to calculate the weight percent of calcite, and both readings to calculate the weight percent of dolomite. A slight modification to the method of Dreimanis (1962) involved the use of a stop watch rather than a time calibrated hydrochloric acid burette to time the first 30 seconds.

As recommended by Dreimanis (1962) analytical weights (the weight of sample used in each carbonate analyses, hereafter referred to as AW) of 0.85 grams and 0.425 grams were used for most samples because of their high total carbonate content.

The use of diffeřent AW influenced the rate of gas flow during the initial part of each analyses, In carbonate-rich samples (more than 40% total carbonate) it was generally observed that for each 0.85 gm. AW the gas flow was continuous throughout the first 35 or 40 seconds of the analyses but for 0.425 gm. AW the CO_2 flow slowed and sometimes stopped between 20 and 30 seconds and resumed between 31 to 35 seconds after the analyses started. Carbonate-poor samples (less than 40% total CO_3) showed this decrease in flow between 20 and 30 seconds for both 0.85 gm. and 0.425 gm. AW. In all samples the final volume was in proportion to the AW; that is, the 0.85 gm. AW yielded twice as much gas as the 0.425 gm. AW.

The above variation in the initial flow resulted in the following: (1) in carbonate-rich samples the 0.85 gm. AW yielded (apparently) larger calcite percentages than the 0.425 gm. samples; (2) in carbonate-poor samples the proportions of calcite were silimar for both AW; (3) in both carbonate-poor and carbonate-rich samples the total carbonate values obtained for a particular sample were similar for both AW. Because of the above only the results obtained from the 0.425 gm. analyses weights were recorded in the accompanying laboratory data summary (Appendix H).

The reasons for the observed variation in the apparent amount of calcite with AW are believed to be the result of (1) the large proportion of total carbonate in the samples and (2) the large proportion of dolomite in the carbonate fraction. According to the theory of this analytical method, the calcite reacts almost instantaneously with the HCl, and the dolomite later, so that the 30 second reading records the volume of CO_2 from the calcite (a small correction factor is also used to compensate for the dolomite which normally reacts during this time; Dreimanis, 1962). All of the 0.425 gm. AW and 0.85 gm. AW from low total carbonate samples behaved according to theory - the decrease in gas flow between about 20 and 30 seconds, for each sample, was the "lull" between the completion of the calcite reaction and the commencement of the dolomite reaction. The apparent high calcite value in each of the 0.85 gm. AW from high total carbonate samples was because of observed continuous and constant gas flow during the first 30 seconds of the reaction. This flow was probably caused by some of the dolomite reacting before it normally did. Factors which would contribute to this early dolomite reaction are (1) heat produced by the rapid reaction between calcite and the HCl which is greater in the larger and more concentrated sample and (2) the closer proximity of the calcite and dolomite grains in the more concentrated sample. Conversely, samples with a lower total carbonate content and/or smaller AW resulted in a greater dilution of the material when it entered the reaction flask and a lower amount of heat.

A number of tests were run to determine the variability to be expected in the analyses. The first involved repetitive analyses (3 to 6) made on a number of samples (about 150) to determine the analytical precision. Careful analysis would produce results, for a particular sample, with a range of generally less than 1% and never more than 3%. Another test was concerned with the effect of sample preparation on analytical results. Normally the -2 mm. fraction of a sample is crushed lightly and the -0.063 mm. fraction used in the carbonate analses. In this test the 2 to 0.063 mm. "residue" was crushed again and the residue from that crushed a third time. The results showed generally less than 1% variation and always less than 3%.

An operator variation was detected near the beginning of the laboratory analyses. This was between the author and the technician who initially also analysed some of the author's samples. The mean value for this difference (N=29) were that the author's analyses yielded 4% less calcite, 6% more dolomite and 2% more total carbonate. The reason for the variation in the proportion of calcite and dolomite was the technician agitated the reaction flask slightly during the first 30 seconds resulting in some of the dolomite reacting and being recorded as calcite. The author was able to produce similar results by agitating the flask. The slightly higher total carbonate values are believed to be the result of the author taking the final Chittick reading after a longer time interval (45 to 60 minutes) than the technician did (about 30 minutes). This variation was eliminated by the author making all the analyses. The analyses done by the technician are identified by the letter "T" in the carbonate section of the laboratory analyses summary.

Some of the till samples had iron staining along the joint planes. To see if this would effect the carbonate analyses the iron stained sediment was scraped off, analysed for carbonate content and compared to the results from the adjacent unstained till. In the three samples tested the variability was only 1 to 2 percent.

A number of samples were also reanalysed after periods ranging from about a month to one year. The variability was generally less than 1 percent, always less than 3 percent, and nonsystematic.

Appendix E Pebble Counts

At each sample site, bulk samples were taken from fresh material 1 to 2 m. (3 to 6 ft.) below the surface. All samples were large enough to contain about 500 pebbles in the 8-4 mm. range. These samples were about 4 to 6 liters for ths silty tills and 15 to 20 liters for the sandy Senkiw till. At some of the sample sites a second constant volume (4 liters) was collected to provide a measure of the concentration of pebbles in the till. Pebbles in the 8 to 4 mm. range were chosen to avoid having to transport bulk samples of an inconveniently large site. The lethology of any pebbles which crumbled during collection, manily the coarse grained crystalline pebbles, was recorded at the site and the pebble discarded; (later examination of all the pebbles showed the number of crumbled pebbles never exceeded one percent of the total).

In the laboratory the pebbles were separated from the matrix by drying the samples at about 75°C for 6 hours, placing them (hot) in water for a few hours, and then dumping them on a 4 mm. screen and washing the matrix away with a hose. For each bulk sample the pebbles were divided into crystalline (igneous and metamorphic), limestone and dolomitic limestone, dolostone, and others. In the first few samples collected the crystalline pebbles were divided into light and dark, and coarse and fine grained groups, but was discontinued because most of the pebbles were coarse grained light ones, and the total percent of the crystalline pebbles was sufficient to characterize a till.

The results of the pebble counts are shown in Table E-1.

SAMPLE		TILL	LOCATION -LSD-S-T-R	COMPOSITION Cr	Ls	Ds	Peb/Liter
FW34	3-10 ft	St	-13-21-8-7	12	49	38	
FW43	5-10 ft	M	NE-14-17-5-8	16	34	50	
	10-15			19	33	47	
	15-20			12	30	58	
FW98		St	NW-13-9-9-12	26	45	29	
FWS3		St	SW-4-24-8-7	19	44	37	
FWS7		St	NW-16-27-11-8	34	47	18	
FWS10	gravel		C-3-3-10-7	17	39	44	
	gravel			17	42	39	
FWS14		Se	NE-5-8-3-5	20	63	16	49
		Su		21	18	59	
		Su		17	27	56	
FWS17	gravel	St?	SW-2-20-7-8	22	40	37	
		Se		44	38	17	
FWS35		Se	C-11-4-3-5	22	57	20	44
FWS36		Rs	NE-9-4-3-5	16	43	40	181
		Se		40	38	22	59
		Se		48	38	13	37
FWS38		T	SW-8-8-3-5	21	21	58	159
		Su		19	39	41	255
FWS40		Su	SE-9-7-3-5	21	22	56	190
		Su		23	23	52	202
FWS47		St	NW-16-27-11-8	5	79	14	204
Pit	gravel		34-12-9	81	14	4	

Cr=crystalline, Ls=limestone+dolomitic limestone, Ds=dolostone pebbles, St=Steinbach Till, Rs=Roseau T. Se=Senkiw T., T=Tolstoi T., Su=Stuartburn T.

Table E-1. Summary of pebble count data (8-4mm fraction).

Appendix F Very Coarse Sand Lithologic Analyses

The lithologic composition of the very coarse sand fraction (2 to 1 mm.) was determined for many of the samples. This grain size was chosen because it required only 50 to 100 grams of till matrix and the composition of this fraction had been used to help characterize the till units in Minnesota and North Dakota.

The initial sample weight varied between 50 and 100 grams depending on the concentration of the very coarse sand in the sample. The Alizarin red staining, which causes the limestone grains to become red, (Figure F-1) was done using a slight modification of the procedure of Friedman (1959). The initial trials indicated that a 30 second etch in 10% HCl was sufficient to remove any fine sediment adhering to the washed grains. The water used to wash the stained sample had to be made slightly acidic (10 drops of 10% HCl/liter of H_2O) to prevent the staining solution turning red before it was completely washed away and leaving a slight pink tint on many of the unstained grains. Each sample was counted wet because of the more vivid colour of the stained grains and the few minutes required to prepare each sample for counting provided a rest from the 10x binocular microscope used to count the grains, minimizing eye strain. The counting was done with the sample spread out to form a layer one grain thick, in a Petri dish placed over a card on which were drawn consecutively different coloured lines 0.25 mm. (0.1 in.) in width. Five hundred grains were counted in each

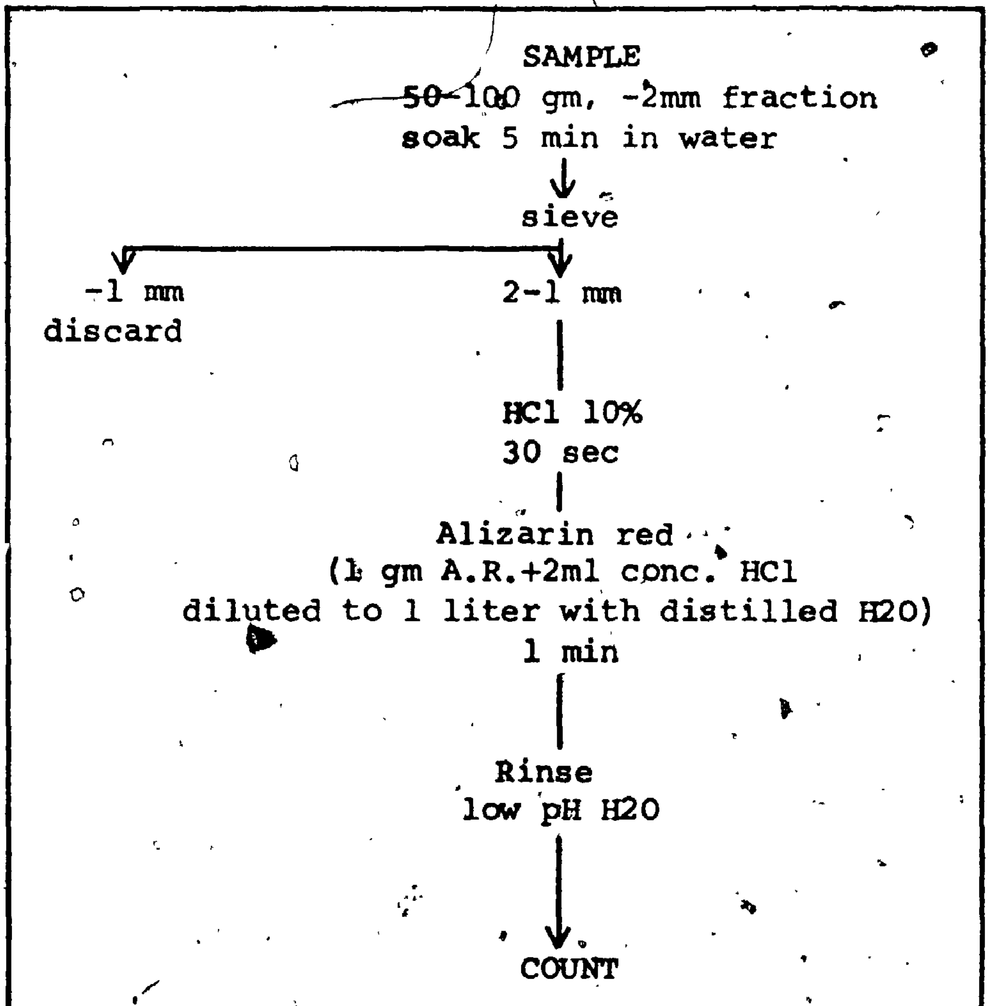


Figure F-1. Flow chart for very coarse sand (2-1 mm) lithologic analysis.

sample because preliminary analyses recording the component percentages versus the number of grains counted showed that the proportions of the major components had stabilized by that number (Table F-1).

During the counting of the first few dozen samples the crystalline grains were divided into coarse and fine grained types. It was found that the majority of the crystalline grains were generally coarse grained and thereafter both types were counted as a group. The few grains of chert, pyrite, lignite, wood and shale when present nearly always totalled less than one percent of the sample and were recorded under "others".

To check the analytical variability a number of the samples (about 25) were recounted and the results were always within 2 percent of the original ones. To aid in the comparison with the data obtained by researchers in North Dakota, the author counted a number of their samples. The variability between the analysts was normally less than 2 percent (Table F-2).

The results of all the analyses are shown in Appendix H.

Sample A													
Cr %	68.0	73.0	73.5	71.5	70.8	71.4	71.3	70.5	70.6	70.2	71.1	70.9	70.4
Ls %	14.0	13.8	11.2	11.5	10.4	10.8	11.0	11.2	11.5	11.8	11.8	11.4	11.8
DS %	18.0	13.8	15.2	17.0	18.4	17.0	17.0	17.7	17.7	17.1	16.2	16.7	17.3
No. grains	50	101	151	200	250	305	363	401	450	491	565	602	705
Sample B													
Cr %	85.0	79.2	76.9	77.1	76.8	77.3	76.9						
Ls %	6.2	7.2	7.9	7.4	7.6	6.9	7.2						
Ds %	8.7	13.4	14.9	15.8	15.3	15.3	15.3						
No. grains	80	193	300	403	509	601	702						
Sample C													
Cr %	38.1	36.2	35.0	36.6	35.6								
Ls %	26.8	31.0	30.5	30.0	30.5								
Ds %	33.7	31.8	33.7	32.7	33.9								
No. grains	160	248	317	412	519								
Sample D													
Cr %	24.5	24.2	25.2	25.9	24.9								
Ls %	34.2	29.6	32.1	31.9	32.8								
Ds %	41.2	45.6	42.2	42.1	41.9								
grains	114	206	305	401	520								

Table F-1. Variation in component percentages with the number of grains counted in the very coarse sand fraction (2-1 mm).

Counter	Cr	Cb	Sh
Fenton	49.3	49.3	0
North Dakota	50.9	49.0	
F	31.2	55.6	13.2
ND	30.4	58.6	10.4
F	81.5	16.0	1.2
ND	80.6	16.6	2.8
F	89.2	10.6	0
ND	90.1	9.9	0
F	86.4	13.6	0
ND	86.9	12.7	0
F	77.4	22.4	0
ND	78.4	21.6	0
F	78.4	21.4	0
ND	76.5	23.5	0
F	67.6	32.0	0
ND	68.9	31.6	0
F	68.1	30.9	0.8
ND	69.7	30.3	0
F	73.9	25.8	0
ND	76.5	23.5	0
F	73.3	22.1	3.3
ND	76.8	20.0	3.2
F	51.9	48.0	0
ND	53.6	46.4	0

North Dakota data from Moran (written com., 1974)

Table F-2. Results of analyses of the same very coarse sand samples by the author and the researchers in North Dakota.

Appendix G Light and Heavy Mineral Analyses

The light and heavy minerals were separated from I to 3 gram portions of the carbonate free residue of the 0.250 to 0.125 mm. fraction from selected samples of the different tills. The light minerals were mounted on plexiglass slides and the feldspar grains stained using the technique described by Vagners (1969, p. 22, Figure 11) which is a slight modification of the method of Laniz *et al*. (1964). The analyses were discontinued because (1) the initial samples did not allow positive differentiation between the different tills and (2) the time required per sample was too great. The results are shown in Table G-1.

The heavy minerals in the above samples were examined by R.N.W. DiLabio. The method of study was described by Gwyn (1971), and DiLabio (1973). The results of the study were (1) that the provenance of the heavy minerals in the till could not be established without more data, and (2) some information useful in the correlation of the tills in southeastern Manitoba may be available from additional work on the heavy mineral suites, particularly the hornblende, clinopyroxene, nonmagnetic opaque minerals and garnet contents. The results are summarized in Table G-2.

SAMPLE	LIGHT MINERAL COMPONENTS								
	Feldspar				Quartz				
	% K	% Na-Ca	% Perth.	% Total	% Angular	% Rounded	% Lignite	% Other	% Heavies of Total Sample
Steinbach Till									
FW83	6	20	2	28	63	8	0	0.1	0.97
FWS3 6 ft	9	26	4	39	56	4	0	0.6	1.34
FWS4 4 ft	7	21	2	30	66	3	0	1.1	1.46
12 ft	9	24	1	34	61	4	0	1.4	1.19
FWS7 #7	8	28	3	39	56	5	0	0.2	1.23
#8	8	20	2	30	65	4	0	0.6	1.10
FWS8 5 ft	7	22	1	30	65	5	0	0.4	1.32
12 ft	9	21	2	32	64	4	0	0.4	1.36
Marchand Till									
FW2 13-14 ft	8	18	3	29	67	2	0	1.5	1.20
FW83 30-33 ft	4	23	2	29	64	7	0	0.5	1.03
Roseau Till									
FW2 39-40 ft	9	22	3	34	61	2	1	3.1	1.03
FW83 40 ft	3	21	1	25	68	7	0	0.2	1.17
FWS42 4 ft	8	26	1	35	59	5	0	1.	1.33
6 ft	10	26	3	39	56	3	0	2.	1.26
8 ft	8	23	2	33	62	4	0	1.	1.26
Senkiw Till									
FW26 18-20 ft	7	23	2	32	62	4	0	2.	1.35
FW78 40-45 ft	4	24	1	29	67	2	0	2.	0.86
FWS17 17 ft	10	27	1	38	55	4	0	3.	0.73
22 ft	6	22	1	29	65	3	0	3.	0.72
FWS34 10 ft	6	30	1	36	59	4	0	1.	1.08
14	11	22	1	34	59	6	0	1.	0.90
FWS36 U5 4 ft	6	22	1	29	62	7	0	2.	1.10
8 ft	5	22	1	28	68	3	0	1.	1.15
12 ft	9	23	1	33	60	5	3	2.	1.15
Tolstoi Till									
FWS38 U11	10	20	2	41	52	2	0	3.	1.26
Stuartburn Till									
FWS38 U12 4 ft	7	20	2	29	61	8	0	2.	1.46
8 ft	12	33	1	46	49	2	0	3.	1.40
FWS41 U10 3 ft	9	24	1	34	57	6	1	2.	1.00
7 ft	11	22	2	35	55	4	0	5.	1.00
9 ft	10	26	1	37	57	2	1	3.	1.02
Woodmore Till									
FW26 55 ft	4	25	3	32	63	3	0	2.3	1.09
FW37 25-30 ft	3	17	0	20	77	2	0	1.	1.09
FW79 65-67 ft	9	19	2	30	62	6	0	2.	1.00
70-73 ft	6	18	1	25	71	4	0	0.3	1.05
75 ft	4	22	4	30	65	4	0	1.	1.00
FW80 35-37 ft	6	20	1	27	68	5	0	0.4	0.80
43-47 ft	10	19	0	29	66	3	0	2.	1.00
50-55 ft	7	17	2	26	69	4	0	1.	1.15

Sample locations can be found in Appendix H.

Table G-1. Data from light mineral analyses.

	FWS42	FW78	FWS22	FWS34	FWS36	FWS38	FWS38	FWS41	FW79	FW80
	Rs	Se	Se	Se	Se	T	Su	Su	W	W
HBLD %	62.1	53.9	55.5	57.8	57.6	58.2	54.8	51.9	57.4	59.8
EPDT %	15.2	13.1	12.2	15.8	12.1	11.7	11.3	13.3	11.2	11.7
OPRX %	2.7	2.9	3.2	3.3	4.2	3.1	4.2	4.8	3.5	3.1
CPRX %	6.2	12.4	13.1	7.7	8.3	2.9	12.9	14.1	4.8	2.9
PGRN %	5.6	8.7	5.2	7.6	7.3	4.9	6.1	5.8	6.5	4.9
RGRN %	1.6	0.9	1.7	1.1	3.3	1.6	2.2	1.2	1.8	1.6
OPAQ %	4.7	5.5	6.4	5.0	6.9	12.9	5.6	6.4	11.4	12.9
TRML %	—	0.2	0.2	—	0.1	0.9	0.3	0.3	0.1	0.9
SPHN %	1.8	2.0	1.7	2.2	2.2	1.2	1.6	1.7	1.9	1.2
ZRCN %	—	—	0.1	—	0.2	0.1	0.1	0.1	0.1	0.1
RUTL %	0.2	0.2	—	0.1	—	0.2	0.2	—	0.1	0.2
MICA %	0.1	—	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.2
TMLN %	0.5	0.2	0.8	0.3	0.5	0.8	0.4	0.3	0.9	0.8
OTHERS %	—	—	—	—	—	—	—	—	—	—
No. Samples	3	1	2	3	3	3	3	3	3	3

Sample locations can be found in Appendix L. All data are mean values. HBLD=hornblende, EPDT=epidote, OPRX=orthopyroxene, CPRX=clinopyroxene PGRN=pink + colourless garnet, RGRN=red garnet, OPAQ=opaque minerals, TRML=tremolite + actinolite, SPHN=sphene, ZRCN=zircon, RUTL=rutile MICA=mica, TMLN=tourmaline. Rs=Roseau Till, Se=Senkiw T., T=Tolstoi T., Su=Stuartburn T., W=Woodmore T.

Table G-2. Data from heavy mineral analyses.

Appendix H

Results of Textural, Fine Matrix Carbonate, And Very Coarse Sand Lithologic Analyses

SUMMARY OF LABORATORY DATA

NUMBER FW1

LOCATION NE-LSD16-S21-T4-R4
Elevation 800 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-43 Clay											
8-9		12	88	98							
12-15		10	90	98							
23-24		21	79	92							
43-50		Till, Steinbach									
50-93		Clay									
58-60		37	63	79							
88-90		17	83	92							

NUMBER FW2

LOCATION SW-LSD4-S26-T4-R5
Elevation 925 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-14	Till	Marchand									
7-8	38	48	14		16	36	52	46	10	44	
13-14	36	51	14		14	38	52				
18-50	Till	Roseau									
18-19	28	59	13								
23-24	29	58	13		7	25	31	38	20	42	
28-29	31	58	11		6	24	30	24	35	41	
33-34	35	53	12		7	25	32	37	17	46	
39-40	31	57	12		5	25	30				
43-44	32	57	11		6	23	29	39	19	42	
49-50	36	53	11		6	24	30	43	16	41	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

LSD=legal subdivision, S=section, T=township, R=range

SUMMARY OF LABORATORY DATA

NUMBER FW3

LOCATION C-LSD8-S21-T4-R7
Elevation 990 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-13	Sand fine grained										
13-14	Clay										
14-30	Till Marchand										
18-19	40-	50	10		13	45	58	33	14	53	
23-24	30	48	13		11	46	57	34	15	51	
33-59	Till Roseau										
33-34	28	59	15		13	42	55				
38-39	35	46	19		19	44	63				
43-44	28	55	17		17	46	63	30	30	40	
48-49	27	56	17		17	42	59	33	30	36	1
53-54	28	52	20		19	44	63				
58-59	27	53	20		19	43	62	28	31	40	1
63-79	Till Stuartburn										
63-64	34	52	14		15	43	58	33	22	43	
68-69	39	47	14		12	40	52	41	14	45	
73-74					11	42	53	45	7	47	1
78-79	41	44	15		14	39	53	42	14	44	

NUMBER FW4

LOCATION NW-LSD9-S20-T3-R9
Elevation 1080 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-53	Sand, medium to fine grained										
53-56	Sand with organic material										
56-60	Interbedded sand and clay										
60-72	Rythmically bedded clay and silt										
	1	14	85	90				40	13	47	
72-87	Interbedded massive poorly sorted sand, silt and clay layers, water laid till, Marchand?										
72-74								36	23	41	
83-84								33	24	43	
87-89	Till, Senkiw?										
								63	28	9	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone,
Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW5

LOCATION NE-LSD16-S14-T4-R10
Elevation 1270 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-95	Sand, fine to medium grained										
8-9								73	9	17	
20-40								84	8	7	

NUMBER FW6
Poor sample recovery

LOCATION NW-LSD12-S22-T4-R11
Elevation 1210 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-27	Sand, fine grained										
27-43	Till, Roseau										
38-39	19	68	14		11	39	50				
43-48	Sand, fine grained										
48-58	Interbedded sand, silt, and till, Roseau?										
58-68	Till, Roseau?										
58-59	16	62	22		14	31	45				
63-64	17	61	22		16	28	44				

NUMBER FW13

LOCATION NW-LSD13-S2-T8-R7
Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-4	Sand, medium grained										
4-6	Clay										
6-22	Till, Steinbach										
6-9	21	67	12	17							
10-15	19	67	14	18							
22-27	Gravel, auger broken.										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW17

LOCATION NE-LSD16-S29-T4-R6
Elevation 940 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-3	Gravel										
3-9	Sand, fine grained										
9-10	Clay										
10-15	Till, Marchand										
10-12	43	42	15	17	12	47	59	(light layer)			
10-12	42	41	17	19	10	39	49	(dark layer)			
13-15	41	42	17	20	13	45	58				
15	Boulders hole abandoned										

NUMBER FW19

LOCATION LSD13-S30-T1-R5
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-3	Gravel										
3-12	Till, Senkiw										
3-5					16	27	43				
5-10	56	34	10		10	29	39	51	19	29	
10-12	59	34	7		10	29	39				
13-15	57	32	11		10	28	38				
15-55	Sand, fine grained										
15-20					9	30	39				
35-40					7	32	39				
40-45					8	31	38				
45-50					8	31	38				
50-55					6	31	37				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone,
Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW21

LOCATION LSD14-S31-T10-R7
Elevation 850 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do T	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-9	Silt										
0-5	9	75	16		20	45	64	32	20	49	
5-9	4	83	13		19	47	66				
9-25	Till, Steinbach										
9-13	35	52	13		20	36	56	43	30	27	
15-20	29	60	11		15	39	44	48	32	19	
20-25	28	63	9		16	26	42	51	22	26	
25-33	Silt										
	9	81	10		12	34	46				
33-39	Till, Marchand										
33-35	46	48	6		17	35	52	45	15	40	
35-39	46	48	6		20	37	57	30	24	41	

NUMBER FW23

LOCATION LSD1-S35-T10-R10
Elevation 930 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do T	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-5	Sand, coarse grained										
5-18	Sand, fine grained										
18-30	Till, Stienbach										
18-20	23	52	25		31	31	62				
20-25	24	50	26		34	28	62				
25-30	37	45	18		28	31	59				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW26 — LOCATION NW-LSD13-S21-T2-R6
Elevation 960 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Sand, fine grained										
3-10	Till, Marchand										
3-5	45	42	14		11	39	50				
5-10	43	41	17		11	37	48	38	11	50	
10-15	Till, Roseau										
	33	47	20		11	43	54				
16-18	Sand and gravel										
18-20	Till, Roseau										
	44	41	15		11	44	55	36	23	40	
20-47	Sand, fine grained										
20-25	66	30	4		4	23	27				
25-30	66	30	4		3	16	19				
30-40	59	40	1		2	15	16				
40-47	55	38	7		5	30	35				
47-65	Till, Stuartburn										
50-55	36	49	15		7	25	32				
55	36	50	14		7	23	30	41	20	38	
55-57	35	52	13		8	25	33	43	18	38	
56-57	boulder										
60-65	35	51	14		6	27	33	44	16	39	
65	35	52	13								

NUMBER FW27 — LOCATION SE-LSD1-S30-T2-R7
Elevation 970 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-21	Sand, fine grained										
0-5					6	28	34				
5-10	75	23	2		6	30	36				
10-16					3	23	26				
21-33	Interbedded sand, silt, clay, and organic										
21-25	8	83	9		5	25	30				
25-33	62	32	6		5	26	31				
33-36	Till, Marchand										
	45	44	11		11	32	43				
36-42	Sand, fine grained										
42-59	Till, Marchand										
42-45	45	43	12		13	32	45	42	16	41	
45-50	47	40	13		12	31	43	41	13	44	
59-75	No samples, sand?										
75-85	Silt										
	17	78	5		7	29	36				

SUMMARY OF LABORATORY DATA

NUMBER FW40 LOCATION NE-LSD16-S29-T5-R7
Elevation 960 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-6	Sand and gravel										
6-30	Till, Marchand										
6-10	39	46	15		12	43	55				
10-15	45	41	14		16	40	56				
15-19	51	36	13		15	38	53	42	20	38	
19-22	Sand, poorly sorted										
					13	39	52				
22-25	47	38	15		15	38	53				
25-30	42	40	18		14	41	55	29	14	56	
30	Boulder, hole abandoned										

NUMBER FW41 LOCATION NE-LSD16-S27-T5-R7
Elevation 970

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-9	Till, Marchand										
0-5	35	47	18	25	11	30	41	79	6	15	
5	Sand clast										
	55	35	10								
5-9	54	34	12	14	11	25	36	81	1	18	
9-11	Sand, fine grained										
	63	31	6	7	4	25	29				
11-15	Silt										
	37	45	18	18	11	24	36				
15-27	Clay										
	1	33	66	79							
27-31	Till, Roseau										
	20	51	29	41				81	7	12	
31-37	Silt, sandy, some gravel near top										
35-37	26	65	9	12				75	7	18	
37-40	Till, Roseau										
	28	58	14	18				76	7	17	
40-65	No samples, sand with some silt layers?										
65-75	Till, Senkiw										
65-70	55	35	10	13				81	5	14	
70-75	40	46	14	19				61	18	21	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW30

LOCATION SW-LSD4-S21-T2-R7
Elevation 980 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-8	Till, Roseau										
0-5	39	44	17	22	17	38	55	35	18	46	
5-8	45	41	14		11	36	47	44	21	36	
8-11	Sand, medium grained										
8-10	91	9	0								
11-18	Sand, fine grained										
	70	28	2								
18-32	Sand and gravel										
15-20	92	6	2								
20-25	92	6	2								
25-32	92	7	1								
32-35	Till, Senkiw										
	49	41	10		10	30	40	51	7	41	0.5Sh

NUMBER FW31

LOCATION SW-LSD4-S34-T10-R11
Elevation 935 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do T	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-30	Till, Steinbach										
0-5	33	49	18		24	26	50	32	53	15	
5-11	29	50	21		27	28	55				
11-15	23	52	25		32	28	60	26	60	14	
15-20	25	50	25		29	28	57	30	52	17	
20-25	29	43	28		25	26	51	37	36	27	0.4Sh
25-30	24	47	29		22	28	50	39	27	34	0.1Sh
30-45	Till, Marchand										
30-35	36	44	20		24	27	51	41	26	33	
35-40	33	53	14		24	29	53	38	28	34	
40	Sand layer, thin										
	51	40	9								
40-55	Till, Roseau										
40-45	33	47	19		27	29	56	27	30	43	
45-50	40	41	19		28	28	56	29	36	35	
55-68	Till, C.										
55-58	34	45	21		20	32	52	39	37	34	
58-65	29	50	21		22	30	52	28	16	56	
65-68	32	48	20		19	32	51	35	29	36	
68-75	Sand, coarse grained										
70-75								55	41	5	

SUMMARY OF LABORATORY DATA

NUMBER FW32

LOCATION LSD14-S35-T10-R10
Elevation 890 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do T	Cb	Cr	Ls	Ds	Other
0-62	Sand, fine grained										
62-66	Silt										
66-72	Sand and gravel										
72-75	Till, B										
	29	53	18		11	18	29	81	10	9	

NUMBER FW33

LOCATION SE-LSD1-S5-T10-R8
Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-13	Sand, fine grained										
13-24	Gravel, sandy										
24-43	Sand, fine grained										
43-48	Gravel, sandy										
48-51	Sand, poor sample										
51-59	Gravel, sandy										
59-76	Sand, poor sample										
76-79	Till, Marchand										
(a)	40	42	18								
(b)	38	42	20		17	21	38	31	31	38	

NUMBER FW34

LOCATION LSD13-S21-T8-R7
Elevation 860 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
0-12	Till, Steinbach										
0-5	49	40	11	16							
7-10	46	42	12	16				45	27	28	
12-15	Sand, fine grained										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW36 — LOCATION NW-LSD5-S24-T2-R4, Elevation 860

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
						T					
0-5	Sand and gravel										
	92	7	1								
5-40	Till, Sonkiw										
5-10	54	35	11		12	34	46				
10-15	51	37	12		12	36	48	41	19	39	
15-20	51	36	13		10	38	48				
20-25	51	36	13		11	37	48	40	18	42	
25-30	57	31	12		11	29	40				
30-35	55	32	13		11	29	40	52	23	23	
35-40	57	31	12		12	28	40				
40-95	Sand, fine grained										
40-45	72	26	2								
45-55	55	43	2								
55-70	88	10	2								
70-80	91	7	2								
80-90	89	8	3								
90-95	75	20	5								

NUMBER FW37 — LOCATION SE-LSD2-S8-T2-R5, Elevation 930 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
						F					
0-6	Sand, fine grained										
6-50	Till, Sonkiw										
6-10	66	24	10		12	30	42	51	14	34	
10-15	65	24	11		11	29	40				
15-20	73	19	8		10	31	41	45	13	42	
20-25	73	17	10		15	31	46	44	13	42	
25-30	68	20	12		16	29	45				
30-40	68	20	12		12	33	45				
40-50	71	18	11		15	31	46	43	15	41	0.4Lig
50-65	Sand, fine grained										
50-60	90	7	3								
65-69	Silt										
	19	74	7		5	38	43				
69-76	Clay										
	4	33	63		4	7	11				
76-83	Sand, fine grained										
83-85	Silt										
	5	67	28		6	21	27				

SUMMARY OF LABORATORY DATA

NUMBER FW38 — LOCATION NE-LSD9-S17-T5-R5
Elevation 880 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-13	Till, Marchand										
0-5	38	43	19	23				35	12	53	
5-9	41	44	15	19				43	12	45	
9-10	46	37	17	21				26	12	61	0.6Lig
10-14	Silt										
10-13	6	66	28	41							
14-16	Sand, fine grained										
16-18	Silt										
18-20	Sand, finod grained										
20-37	Silt, minor sand and clay layers										
25-30	3	81	16	20							
35-37	3	80	17	20							
37-45	Sand, minor silt layers										
40-45	53	39	8	10							
45-90	Sand, fine grained										
55-60	54	43	3	4							
70-75	89	8	4	4							

NUMBER FW39 — LOCATION SW-LSD4-S29-T6-R5
Elevation 925 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
						T					
0-13	Sand, fine grained										
13-31	Clay										
25-30	0	8	92	97							
31-37	Till, Marchand										
31-35	30	59	11		7	30	37	44	11	44	0.8Wood
35-37	38	49	13		9	29	38	46	10	43	1.4Wood
37-46	Silt										
	8	58	34		8	22	30				
46-51	Sand, fine grained										
					5	21	26				
51-75	Till, Roseau										
51-55	16	63	21		14	23	37				
55-60	21	65	14		8	21	29	46	8	46	
60-65	21	65	14		8	21	29	43	15	42	
65-70	30	57	13		8	22	30	47	11	42	0.5Lig
70-75	35	50	15		9	22	31	52	10	37	0.5Lig

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW40

LOCATION NE-LSD16-S29-T5-R7
Elevation 960 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-6	Sand and gravel										
6-30	Till, Marchand										
6-10	39	46	15		12	43	55				
10-15	45	41	14		16	40	56				
15-19	51	36	13		15	38	53	42	20	38	
19-22	Sand, poorly sorted										
					13	39	52				
22-25	47	38	15		15	38	53				
25-30	42	40	18		14	41	55	29	14	56	
30	Boulder, hole abandoned										

NUMBER FW41

LOCATION NE-LSD16-S27-T5-R7
Elevation 970

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-9	Till, Marchand										
0-5	35	47	18	25	11	30	41	79	6	15	
5	Sand clast										
	55	35	10								
5-9	54	34	12	14	11	25	36	81	1	18	
9-11	Sand, fine grained										
	63	31	6	7	4	25	29				
11-15	Silt										
	37	45	18	18	11	24	36				
15-27	Clay										
	1	33	66	79							
27-31	Till, Roseau										
	20	51	29	41				81	7	12	
31-37	Silt, sandy, some gravel near top										
35-37	26	65	9	12				75	7	18	
37-40	Till, Roseau										
	28	58	14	18				76	7	17	
40-65	No samples, sand with some silt layers?										
65-75	Till, Senkiw										
65-70	55	35	10	13				81	5	14	
70-75	40	46	14	19				61	18	21	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW42

LOCATION NW-LSD13-S1-T6-R7
Elevation 975 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-35	Sand, fine grained										
10-20	89	2	9		2	12	14				
20-25					2	12	14				
30-35	54	34	12		3	14	17				
35-40	Silt										
	2	90	8		2	21	23				
40-50	Interbedded sand, silt, and clay										
50-70	Till, Scnkiw										
50-55	58	34	8		6	26	32	73	6	21	
55-60	63	30	7		6	26	32	74	6	20	
60-65	62	30	8		7	26	33	60	10	30	
70-90	Silt										
70-75					4	29	33				
75-80	26	65	9		5	29	34				
80-85					4	26	30				
85-90	26	68	6		4	28	32				

NUMBER FW43

LOCATION NE-LSD14-S17-T5-R8
Elevation 1000 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	Sand and gravel										
2-5	Clay										
5-40	Till, Marchand										
5-10	46	43	11	16							
10-15	52	38	10	13				36	16	48	
25-30	43	43	14	19				34	17	49	
35-40	40	45	14	20							

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone,
Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW44

LOCATION SW-LSD4-S26-T5-R8
Elevation 1000 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Sand, fine grained										
3-6	Sand and gravel										
6-13	Sand, fine grained										
6-10	71	26	3		4	23	27				
13-17	Sand, medium to coarse grained										
17-25	Sand, medium grained										
25-59	Sand, fine grained										
30-40	84	14	2					55	15	30	
40-50					3	28	31				
50-59					5	26	31				
59-65	Till, Senkiw										
	66	23	11		18	28	46	68	10	22	

NUMBER FW45

LOCATION SE-LSD1-S10-T5-R8
Elevation 1010 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Sand and gravel										
3-5	Silt										
5-18	Till, Marchand										
5-10	40	41	19								
10-15	30	53	17					25	42	33	
18	Boulders, hole abandoned										

NUMBER FW46

LOCATION NE-LSD16-S15-T4-R8
Elevation 1030 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-13	Till, Marchand										
0-5	45	40	15					41	20	39	
5-10	51	34	15								
10-13	49	36	15								

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW47

LOCATION NW-LSD16-S8-T4-R8
Elevation 1[illegible]15 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-17	Sand, fine grained										
0-5	96	3	1								
5-7	88	11	1		8	32	40				
7-10	39	46	11		4	30	34				
10-13	41	46	14		4	31	35				
20-23	Clay										
	0	15	85		1	4	5				
23-25	Silt										
	15	57	28		16	40	56				
25-30	Till, Marchand										
	39	44	17		14	46	60	38	17	45	
30-45	Till, Roseau										
30-35	33	46	21		17	40	57	34	23	43	
35-40	32	46	22		18	37	55	30	24	46	
40-45	30	46	24		15	40	55				
45-75	Till, Stuartburn										
45-50	46	41	13		14	43	57				
50-55	41	42	17		11	42	53	35	17	48	
55-60	42	41	17		10	42	55	32	15	53	
60-65	41	42	17		14	40	54	34	18	48	
65-70	43	40	17		15	39	54	38	15	47	
70-75	44	40	17		16	37	53				

NUMBER FW48

LOCATION SE-LSD1-S16-T4-R6
Elevation 930 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-25	Till, Marchand										
0-5	45	44	11		9	42	51				
5-10	44	48	8		7	40	47	36	12	52	
10-15	39	44	17		13	42	55				
15-20	40	43	17		11	43	54				
20-25	39	49	12		10	40	50				
25	Boulders, hole abandoned										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm, Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW49

LOCATION LSD15-S30-T6-R9
Elevation 1025

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	T	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Sand											
3-20	Till, Steinbach											
3-5	55	26	19		14	20	34					
5-10	50	35	15		15	18	33					
10-15	55	31	14		15	16	31		63	23	13	
15-20	55	30	15		17	15	32		62	24	14	
20-50	Till, Senkiw											
20-25	62	24	14		12	16	28		70	17	13	
25-30	62	27	11		12	17	29		68	17	15	
30-35	62	27	11						75	10	15	
35-40	60	29	11		15	18	33					
40-45	58	29	13		17	16	33		66	19	15	
45-50	57	30	13		16	16	32		65	18	16	

NUMBER FW50

LOCATION NW-LSD13-S29-T6-R8
Elevation 930 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	T	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-22	Silt and fine sand											
15-22	29	66	5		10	23	33					
22-26	Clay											
26-45	Till, Steinbach											
26-30	29	53	18		31	34	65		31	13	56	
30-34	26	54	20		25	36	61		26	25	49	
34-35	22	58	20		22	36	58		26	33	41	
35-40	22	56	22		24	37	61		25	34	41	
40-45	25	54	21		24	35	59		28	28	44	
45-50	Till, Marchand											
	34	49	17		18	36	54		41	16	43	
50-70	No sample, sand or till											
70-75	Till, Marchand											
	38	48	14		18	40	57		36	14	50	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone,
Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW51

LOCATION SE-LSD4-S25-T6-R6
Elevation 885 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
					T					
0-3	Sand, medium grqined, a few pebbles									
3-6	Silt									
6-35	Till, Steinbach									
6-8	33	49	18				35	18	46	1.0Lig
8-15	30	47	23				35	10	53	2.0Lig
15-20	34	49	17				36	12	52	
20-25	32	51	17	13	23	36	38	10	52	
25-30	28	58	14	8	21	29	44	11	45	
30-35	28	58	14	7	22	29	38	16	46	
35-65	Till, Marchand									
35-40	30	59	11	8	21	29	45	20	35	0.3Lig
40-45	29	59	12				42	16	42	
45-50	31	58	11	8	22	30	44	16	40	0.3Lig
50	32	56	12	7	22	29	55	10	35	
55-60	33	55	12	8	21	29	48	10	41	1.0Lig
60-65	34	54	12	9	21	30	50	11	38	1.0Lig
65-78	Sand, fine grained									
78-82	Silt									
82-87	Till, Roseau									
82-85	39	46	15	29	22	52	27	38	35	0.3Lig
85-87	30	49	12	28	22	50	26	35	39	0.3Lig

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW52

LOCATION NE-LSD16-S21-T6-R5
Elevation 830

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F&T	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-5	Till, Steinbach										
	21	59	20		13	36	49F				
5-17	Silt										
5-10	7	73	20		14	38	52T				
10-15	3	76	22		15	38	53T				
15-17					12	43	55F				
17-95	Clay				all by F						
23-25					9	29	38				
25-30					11	31	42				
30-35					11	30	41				
35-40	11	43	46		9	30	39				
40-45	13	44	43		10	32	42				
50-60					10	32	42				
60-70					10	32	42				
70-75					12	18	30				
75-80					10	16	26				
80-90	2	31	67		9	17	26				
90-95	5	35	60		10	18	28				

NUMBER FW53

LOCATION NE-LSD14-S19-T6-R6
Elevation 845 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do T	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-4	Till, Steinbach										
2-4	4	77	19		18	41	59	28	16	56	
4-5	Sand										
5-17	Till, Marchand										
5-7					25	7	32	64	10	26	
7-10	49	41	0		26	7	33	63	6	30	
10-17	37	45	18		15	34	49	41	13	46	
17-57	Sand, fine grained										
57-75	Clay										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW54 — LOCATION SE-LSD3-S20-T7-R8
Elevation 960 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-4	Disturbed										
4-5	Sand, fine grained										
5-30	Silt										
10-15	24	69	7		1	17	18				
23-27	2	59	38		11	31	42				
30-35	Interbedded sand, silt, and clay										
35-40	No sample, sand?										
40-42	Till, Steinbach										
	31	53	16		8	31	40	33	15	32	

NUMBER FW55 — LOCATION SW-LSD13-S22-T3-R11
Elevation 1200 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-13	Sand, medium to fine grained										
13-43	Sand, fine grained										
43-50	Silt or water laid till										
40-45	13	54	33		26	33	59				
45-50					24	30	54				
50-80	Till, Roseau										
50-55	27	49	24		14	32	46	45	20	35	
55-60	30	47	23		14	35	49	35	28	36	
60-65	23	54	23		14	31	45	40	19	41	
65-70	35	45	20		13	36	49	44	12	44	0.1Lig
70-75	30	53	17		10	29	39	42	15	43	0.1Lig
75-80	23	62	15		8	29	37	51	13	36	0.4Lig
80-95	Silt										
80-85					7	28	35				
85-87	13	71	16		9	24	33	50	25	24	1.0Lig
87-95	Silt										
					7	26	33				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW56

LOCATION NE-LSD16-S12-T5-R10
Elevation 1175 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
0-10	Silt										
5-10	24	64	12					62	23	15	
10-20	Interbedded till, Roseau, and silt										
10-15	32	48	20	T				63	17	20	
15-20	31	51	18	T				62	11	27	0.2Lig
20-25	Interbedded till, Roseau, and sand										
	30	55	15	T				60	12	28	0.2Lig
25-80	Poor sample recovery, stratified sediment?										
25-30	17	78	5								
30-35	30	64	6								
35-40	30	58	12					60	10	30	
40-80	Sand, fine grained										
80-85	Till, B										
	24	64	12					88	4	8	

NUMBER FW58

LOCATION WC-S16-T3-R13
Elevation 1175 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
						F					
0-60	Till, Roseau										
0-5	13	62	25		21	33	54				
5-10	26	51	23		17	34	51	36	28	36	
10-15	26	51	23		20	30	50				
15-20	26	48	26		19	31	50				
20-25	26	51	23		19	32	51				
25-30	27	50	23		17	32	49	39	32	29	
30-35	26	50	24		18	32	50				
35-40	26	49	25		18	32	50				
40-45	28	50	22		21	31	52				
45-50	27	51	22		20	32	52				
50-55	27	50	23		19	31	50				
55-60	26	49	25		19	31	50	35	33	30	2.0Sh
60					21	29	50				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW59 — LOCATION SE-LSD9-S36-T7-R9
Elevation 1025

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-13	Till, Steinbach										
0-4	33	36	31								
4-5	48	32	20		19	26	45				
5-10	35	37	28		18	22	40	49	17	34	
10-13	37	36	27		18	24	42				
13-16	Sand, fine grained										

NUMBER FW60 — LOCATION NE-LSD16-S35-T7-R9
Elevation 1000 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	Sand, fine grained										
2-5	Silt										
5-17	Interbedded sand, silt, and clay										
17-26	Till, Steinbach										
17-20	27	58	14					26	21	53	
20-25	28	57	15								
26-40	Sand, medium grained										
40-48	Sand, fine grained										
48-55	Silt										
55-85	Sand, fine grained										
85-95	Sand, coarse grained										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0,002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW62

LOCATION SW-LSD1-S21-T7-R8
Elevation 975 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-15	Till, Steinbach										
0-5	38	48	14		16	43	59				
5-10	40	44	16		14	42	56	34	25	41	
10-15	36	46	18		20	39	59	34	26	40	
15-25	Sand, fine grained										
15-20	55	32	13		14	34	48				
20-25	66	26	8		9	24	33				
25-50	Till, Marchand										
25-30	42	43	15		10	25	35				
30-35	43	42	15		9	23	32	48	10	42	
35-40	45	41	14		8	23	31				
40-45	45	42	13		9	25	34	50	15	35	
45-50	45	42	13		8	23	31				
50-65	Till, Roseau										
50-55	27	61	12		8	20	28	55	12	32	0.6Wood
55-60	33	55	12		5	20	25				
60-65	26	63	11		5	22	27	59	12	28	0.4Wood
65-85	Sand										
65-70	57	35	8		5	23	28				
70-75	37	55	8		4	21	25				
75-80	50	43	77		5	21	26				
85-90	Silt										
	37	57	6		4	29	33				

NUMBER FW63

LOCATION LSD16-S14-T10-R9
Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-6	Sand, medium to coarse grained										
6-8	Sand, fine grained										
8-10	Sand, medium to coarse grained										
10-40	Sand, fine grained										
10-20	98	1	1	1							
30-40	82	13	5	6							
40-47	Silt										
45-47	18	53	24	33							
47-55	Till, B										
50-55	38	44	18	27				87	6	7	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dQlostone.

SUMMARY OF LABORATORY DATA

NUMBER FW64 — LOCATION SW-LSD2-S22-T10-R9, Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-20	Till, Steinbach										
0-5	62	29	9	11							
5-10	64	28	8	11				44	30	26	
10-20	32	52	16	23				33	30	37	

NUMBER FW65 — LOCATION SE-S18-T11-R9, Elevation 870 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Sand, medium to coarse grained										
3-5	Sand, fine grained										
5-10	Till, Steinbach										
	33	56	12	18							
10	Boulders, hole abandoned										

NUMBER FW66 — LOCATION SW-LSD13-S18-T11-R9, Elevation 870 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-10	Sand, coarse to fine grained										
10-20	Sand, coarse grained										
20-22	Silt										
22-37	Sand, coarse grained										
37-50	Sand, fine grained										
50-64	Silt										
	36	61	3	4	2	13	15				
64-68	Till, B										
	25	58	17	23	6	23	29	70	16	14	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW67

LOCATION NW-LSD13-S6-T11-R9
Elevation 790

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-23	Clay										
0-5	1	10	89								
5-10	1	26	73								
10-15	1	18	81								
15-20	1	7	92								
20-23	2	9	89								
23-25	Till, Steinbach										
	37	50	13					16	50	34	

NUMBER FW68

LOCATION LSD14-S12-T12-R6
Elevation 810 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-10	Sand, fine grained										
10-18	Till, Steinbach										
10-15	28	56	16					22	21	57	
15-18	29	55	16					18	20	62	
18-22	Silt										

NUMBER FW71

LOCATION SE¼LSD3-S21-T9-R8
Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-6	Sand, fine grained										
6-8	Clay										
8-15	Till, Steinbach										
8-9	32	56	12	21							
10	27	59	14	23							
10-15	30	53	17	19							
15	Boulder, hole abandoned										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW75

LOCATION SE-LSD1-S19-T9-R7
Elevation 830 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-11	Till, Steinbach										
0-5	16	60	24	35	15	47	62				
5-7	29	51	20	25	14	49	63				
7-10	19	50	31	37	17	35	52				
11-33	Interbedded till, Steinbach, and stratified drift										
11-15	18	82	0	48	17	35	52				
15-20	12	54	34	42	20	36	56 T				
20-25	15	53	32	39	19	35	54 T				
25-30	8	56	36	42	19	34	53 T				
33-46	Till, Steinbach										
33-35	20	69	11	14	10	50	60				
35-40	32	56	12	14	12	44	56	20	32	43	
40-46	34	53	13	19	21	42	63				

NUMBER FW76

LOCATION NC-LSD14-S20-T9-R9
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-25	Till, Steinbach										
0-5	26	62	12	18	10	50	60				
5-10	27	60	13	18	12	50	62				
10-15	36	50	14	20	20	38	58				
15-20	35	49	16	22	24	37	61	39	26	35	
41	45	14	20	16	37	53					
25-36	Sand, medium to fine grained, a few silt layers										
25-30	56	38	6	9	8	25	33				
30-35	7	69	24	32	25	24	49				
36-40	Sand, fine grained										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW77

LOCATION S1/2-LSD6-S5-T7-R11
Elevation 1100 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
				F							
0-6	Sand, fine grained										
6-8	Gravel, sandy										
8-50	Sand, medium grained										
10-20								81	18	11	
40-50					4	29	33				
50-65	Clay										
50-55					1	6	7				
60-65					1	7	8				
65-76	Sand, grading downward into silt										
65-70	45	46	9		7	34	41				
70-76	52	41	7		7	33	40				
76-85	Till, C										
76-80	25	52	23		18	32	50	35	28	37	
80-85	20	54	26		12	36	48	31	22	47	
85-100	Interbedded sand, silt, and clay										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW78

LOCATION SW-LSD9-S11-T3-R4
Elevation 840 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	Sand, fine grained										
2-100	Till, Senkiw										
2-5	57	34	9		8	30	38	54	23	23	
5-10	58	33	9		8	28	36	53	23	24	
10-15	60	31	9		8	29	37				
15-20	58	32	10		9	28	37				
20-25	60	30	10		11	29	40				
25-30	58	30	12		12	29	41				
30-35	57	31	12		12	30	42				
35	56	32	12		12	30	42	48	25	27	
35-37	59	29	12		14	30	44				
37-40	60	28	12		13	30	43				
40-45	58	29	13		14	30	44				
45-50	58	30	12		11	31	42	49	21	30	
50-55					10	30	40				
55-60	59	28	13		10	31	41				
60-65	61	29	10		13	30	43				
65-70	56	34	10		12	28	40				
70-75	59	30	11		11	31	42				
75-80	59	31	10		13	30	43				
80-85	56	32	12		12	29	41				
85-87	58	31	11		13	29	42				
87-90	57	32	11		13	30	43				
90-93	59	29	12		12	29	41				
93-97	59	29	12		12	32	44				
97-100	58	30	12		12	33	45	43	22	35	
100	60	28	12		13	31	44				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW79

LOCATION NE-LSD1-S12-T3-R4
Elevation 875 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-5	Sand, medium to fine grained, some pebbles										
5-13	Till, Stienbach										
5-8	29	54	17		15	52	67	27	7	66	
8-10	32	56	12	21							
10	27	59	14	23							
10-13	30	53	17	19							
13-18	Gravel										
18-23	Interbedded sand and silt										
23-24	Organic, wood rich layer										
24-35	Interbedded sand and silt										
35-40	Till, Stuartburn										
35	36	46	17		9	40	49	25	12	63	
35-40	37	46	16		8	38	46	30	15	55	0.4Lig
40-46	Poor sample recovery, interbedded till and sand?										
46-58	Till, Woodmore										
46-48	30	46	24		11	51	62	25	16	59	
48-50	27	49	24		12	50	62	26	19	55	
50	26	49	25		12	54	66	27	16	57	
50-58	29	48	23		13	38	51	43	13	44	0.4Lig
58-75	Till, Rosa										
58-65	33	46	21		12	37	48	42	18	40	0.3Lig
65-67	32	50	17		10	38	48	41	15	44	0.4Lig
67-70	31	50	19		11	39	50	46	12	42	
70-73	30	51	19		12	36	48	43	9	48	
73-75	32	49	19		11	39	50	40	12	48	0.4Lig
75	32	49	19		12	38	50	36	14	50	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone,
Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW80 LOCATION C-LSD9-S7-T3-R5 (ford)

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Road fill										
3-3.25	Organic, fine grained										
3.25-15	Till, Woodmore										
4-5	31	50	19		15	48	63				
5-7	35	45	20		15	48	63	27	18	55	
7-10	38	43	19		15	47	62	29	17	54	
10-13	15	50	35		13	35	48	40	11	49	
13-15	16	51	33		14	31	45	40	10	50	
15-27	Silt										
15-17	5	51	44		10	22	32	40	16	44	
17-20	7	49	44		18	37	55				
20-25	4	64	32		15	41	56	44	19	37	
25-27	7	71	22		14	41	54				
27-70	Till, Rosa										
30-35	32	46	22		13	37	50				
35-37	34	47	19		12	38	50	42	13	44	
37-40	34	45	21		12	39	51				
40-43	31	47	22		12	35	47	44	15	41	
43-47	33	48	19		11	37	48				
47-50	31	47	22		12	36	48	43	12	45	
50-55	33	48	19		12	42	54	41	14	45	
55-60	27	48	25		12	34	46				
60-63	28	48	24		12	36	48	45	12	42	
63-67	30	49	21		12	35	48				
67-70	32	48	21		10	36	46	43	13	43	0.3Lig

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWB1 — LOCATION NE-LSD14-S6-T7-R10
Elevation 1070 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-5	Sand, medium grained, a few gravel layers										
5-23	Sand, fine grained										
10-15	94	3	3								
15-23	80	10	10								
23-24	Silt										
24-26	Sand, fine grained										
26-26.5	Peat lens or layer										
26.5-30	Interbedded sand, silt, and clay										
30-35	Interbedded silt and clay										
35-45	Clay, a few silt layers										
35-40	1	16	83		1	6					
40-45	29	48	23		5	16	21				
45-55	Till, Roseau										
45-48					12	35	47				
48-50	53	38	9		8	42	50	41	13	45	
50-53	49	40	11		9	44	53	38	12	44	
53-55	51	39	10		8	45	53				

NUMBER FWB2 — LOCATION NW-LSD13-S34-T10-R7
Elevation 865 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-25	Till, Steinbach										
1-3	46	40	14	20							
3-5	26	56	18	27							
5-10	44	48	8	10							
10-15	46	46	8	10							
15-17	41	49	10	16							
17-20	39	51	10	16							
20-25	38	50	12	17							
25	39	47	14	23							
25	Boulders to numerous hole Abandoned										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER PW-1

LOCATION [illegible]

Elevation [illegible] ft

DEPTH (ft)	TEXTURE (%) (<2 mm) Sand	Silt	Clay	CARBONATE (%) (<0.063 mm) Cc	Do	Tc	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds
0-2	Disturbed								
2-4	Sand and silt								
4-?	Clay								
?-21	Fill (weathered)								
8	41	[illegible]	16	28	19	[illegible]	[illegible]	[illegible]	[illegible]
8-10	41	[illegible]	9	19	3	4			
10	40	51	9	29	31	58	14	38	28
10-13	32	50	18	28	17	61	[illegible]	67	20
13-15	28	51	21	29	29	48		57	19
17-21	34	52	24	22	29	51	[illegible]	43	16
21-37	Fill (weathered)								
21-23	45	43	12	18	38	58	35	19	31
23-25	47	41	12	[illegible]	37	52	19	14	19
25	52	32	11	18	38	54	29	31	40
25-27	41	42	17	21	18	51			
27-30	42	44	14	21	36	57	32	11	37
30-33	38	47	15	19	40	59			
33-37	47	38	15	22	38	60	[illegible]	15	66
37-50	Fill [illegible]								
37-40	35	50	15	18	42	58			
40	19	63	18	21	40	61	14	38	48
40-43	28	55	17	22	37	59	11	30	59
43-47	36	46	18	24	21	45	11	65	24
47-50	36	48	16	24	22	46	34	37	29
50-55	Fill								
50-52	22	55	23	25	22	47	45	37	18
52-55	20	57	23	24	21	45			
55	21	57	22	24	15	39	45	38	18

Sand=2-0.063mm. Silt=0.063-0.002mm. Clay=<0.002mm. [illegible] Cc=calcite, Do=dolomite, Tc=total carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

SUMMARY OF LABORATORY DATA

NUMBER FW92

LOCATION NW-SW-S14-T160-R43
Minnesota
Elevation 1070 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other Sh
0-20	Till, Marchand										
3-4	39	45	16	21							
5-6	39	45	16	21				41	14	44	1.0
12-14	40	44	16	21				44	16	39	1.
14-16	40	41	19	23							
19-20	38	42	20	23				39	13	46	2.
20-40	Till, Roseau										
25-27	42	42	16	18				30	16	52	2
27-28	39	40	21	24				35	12	50	2
30-31	38	44	18	22				32	13	53	2
38-40	39	41	20	23				37	11	45	7
41-70	Gravel and sand, Senkiw-like										
41-45								53	18	29	
51-56								53	18	29	
70-73	Till?										
73-116	Silt, fine sand near base.										

NUMBER FW93

LOCATION NW-SW-S31-T164-R47
Minnesota
Elevation 960 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-18	Sand, fine grained										
18-19	Clay with wood fragments										
19-22	Clay										
22-56	Till, Senkiw										
27-29	52	37	11					91	4	5	
41-44	53	36	11					92	3	5	
54-56	52	37	11					91	5	4	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW94

LOCATION NE-LSD16-S9-T3-R4
Elevation 810

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
0-6	Fill										
6-26	Clay										
26-30	Till, Roseau										
26-27	31	54	15	20				37	9	54	
27-28	38	48	14	20							
29-30	46	40	14	18							
30-78	Till, Senkiw										
38-40	50	35	15								
41-43	51	35	14	18				45	28	27	
54-56								44	29	27	
58-60	53	34	13	18							
63-67	54	34	12	18				47	24	29	
75-76								36	31	34	
78-118	Clay										
118-136	Till, Stuartburn										
118-120	41	41	18					39	17	43	0.1Lig
122-124	40	40	20					45	16	38	0.9Lig
124-126	39	40	21					40	15	45	
127-129	40	39	21					40	17	42	0.2Lig
132-134	40	43	17					36	18	46	
135-136	40	42	18					42	13	45	0.1Lig

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW96

LOCATION NW-LSD13-S34-T10-R8
Elevation 885 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc.	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-1	Peat										
1-6	Sand, medium to fine grained										
6-18	Clay										
18-44	Till, Steinbach										
20-22	33	53	14	15	16	43	59	29	21	50	
22-23	Gravel										
23-24	30	53	17	18	24	38	62	21	33	46	
38-40	33	50	17	18	27	36	63	23	39	38	
42-44	31	52	17	18	25	36	61	22	35	43	
44-50	Silt										
47-50	4	73	23	24	32	32	64				
50-65	Poor recovery, sand?										
65-70	Sand, fine grained										
70-75	Till, Marchand										
	39	51	10	10	14	25	39	43	37	19	
75-130	Sand, fine to medium grained										
80-90	82	17	1	1							
110-120	89	9	2	2							
120-125								55	29	16	
130-145	Till, A										
130-135	78	20	2	2	8	26	34	51	32	17	
135-140	78	20	2	2	9	26	35	51	35	14	
140-145								29	55	16	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW97 LOCATION SW-LSD4-S4-T10-R11
Elevation 960 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-8	Till, Steinbach										
3-5	61	29	10	12				86	8	6	
5-7	62	29	10	11				91	5	4	
8-90	Sand, fine grained										
90-91	Silt										
91-96	Till, C										
92-93	27	51	22	29				25	21	54	
94-96	26	51	23	30				19	25	56	
96-105	Clay										
105-116	Till, B										
105-107	27	43	30	39				75	21	20	0.5Sh
109-112	32	41	27	35				73	21	6	0.7Sh
114-115	32	42	26	37				77	19	2	0.8Sh
116-122	Poor sample recovery, sand?										
122-128	Till, A										
124-123	60	32	8					86	12	2	

NUMBER FW98 LOCATION NW-LSD13-S9-T9-R12
Elevation 970 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	Gravel										
2-16	Till, Steinbach?, Marchand?										
4-5	45	44	11	16							
10-11	41	47	12	14							
12-14	47	41	12	14							
16	Boulders to numerous hole abandoned										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW99

LOCATION LSD2-S16-T9-R12
Elevation 970 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-5	Fill										
5-9	Till, Steinbach?, Marchand?										
5-9	40	47	14	19	22	35	57				
10-38	Till, Senkiw										
11-12	65	31	4	6	4	9	13				
14-15	72	23	5	5	3	5	8				
20-23	65	27	7	9	6	15	21				
23-26	69	25	6	9	7	14	21				
29-32	70	23	7	8	6	16	22				
33-36	65	28	7	9	7	14	21				
38-56	Sand, coarse to medium grained										
56-73	Till, Semkiw										
71-73	68	27	6	8	2	4	6				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW100

LOCATION NE-LSD6-S1-T3-R6
Elevation 965 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do F	Cb	Cr	Ls	Ds	Other
0-10	Till, Marchand										
4-6	40	43	17	20	10	43	53	38	14	52	
7-9	40	43	17	20	11	42	53				
10-21	Till, Roseau										
10-11	33	47	19	27	13	43	56	28	23	49	
13-14	29	49	21	28	15	44	59	29	22	49	
15-16	29	50	21	28	13	43	56				
18-19	24	49	27	35	13	40	53	28	27	45	
20-21	21	50	29	38	14	37	51	29	27	44	
21-33	Gravel, sandy										
33-40	Sand, fine grained										
40-68	Silt										
52-54	12	82	6	7							
68-70	Sand, fine grained										
	58	25	17	21	10	27	37				
70-100	Silt										
100-106	Clay										
106-115	Sand, fine grained										
115-116	Till, Senkiw?										
	60	33	7	9	5	27	32	23	30	47	
116-154	Poor recovery										
116-140	Two till samples										
	27	47	26	33	14	22	36	14	58	28	
	33	42	25	32	16	25	41	11	54	35	
154-156	Silt										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW101

LOCATION NW-LSD13-S4-T4-R5
Elevation 895 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
0-116	Till, Senkiw										
6-8	61	27	11	14				54	22	24	0.1Lig
35-36	56	32	12	13				46	21	28	
60-65	60	28	12	13				53	21	25	0.3Lig
95-100	58	31	11	11				49	21	28	
102-106	49	38	12	13				50	20	30	0.1Lig
114-116	42	45	13	16				36	15	50	0.1Lig
116-156	Till, Rosa										
120-125	31	54	15	19				38	14	48	
130-135	24	63	14	17				39	11	49	0.1
140-145	24	63	13	16				38	13	50	0.1Lig
154-156	24	62	14	18				38	12	50	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS3 — LOCATION SW-LSD4-S24-T8-R7, Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	Sand, gravelly										
2-7	Till, Steinbach										
3	35	49	16	22							
6	32	52	16	22				27	18	55	

NUMBER FWS4 — LOCATION SE-LSD1-S23-T8-R7, Elevation 905 ft

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Sand, coarse grained, gravelly										
3-12	Till, Steinbach										
4	61	31	8								
6	58	34	8					49	21	30	
12	57	39	4								

NUMBER FWS6 — LOCATION SE-LSD1-S24-T8-R7, Elevation 915 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-10	Till, Steinbach										
	32	52	16								
10-11	Silt										

Sand=2-0.063mm, Silt=0.063-0,002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS7 | LOCATION SW-LSD2-S20-T8-R8
Elevation 955 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-5	Till, Steinbach										
	34	52	47								
	35	52	48	18				32	19	49	
5-8	Sand, fine grained										

NUMBER FWS8 | LOCATION SW-LSD4-S21-T8-R8
Elevation 950 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-15	Till, Steinbach										
5	31	53	16	23							
10	35	47	18	25				35	24	41	
13	37	48	15	25				29	24	47	
14	34	48	18	27							

NUMBER FWS10 | LOCATION C-LSD3-S3-T10-R7
Elevation 910 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	Sand, fine to medium grained										
2-10	Interbedded clay, silt, and till, Steinbach										
	T 28	52	20	28							
10-15	Interbedded gravel and sand, kame delta										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS11 — LOCATION SW-LSD4-S19-T4-R5
Elevation 800 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	U1: sand, fine grained										
3-6	U2: till, Steinbach										
2	32	50	18	24							
6-6.5	U3: clay, rythmically bedded										
6.5-14	U4: till, Steinbach										
2	34	46	20	26							
4	31	49	20	27							
6	35	50	15	19				48	13	38	
8	35	50	15	19							

NUMBER FWS14 — LOCATION NE-LSD5-S8-T3-R5
Circus Section center
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
						F					
0-6	U1 sand, gravel at base										
6-10	U2 sand, fine grained										
10-14	U3: sand, coarse grained										
14-17	U4: pond and flood plain deposits										
	38	51	11		6	27	33				
17-19	U5: deformed lower part of U4										
19-22	U6: sand, fine grained, silt near base										
22-24	U7, till, Tolstoi										
	26	55	19		11	42	53				
24-25	U8: gravel										
25-35	U9: till, Stuartburn										
26	41	51	8		11	37	48				
30	38	47	15		12	36	48	41	11	48	0.1Lig
34	42	44	14		14	36	50	38	12	50	
35-35.2	U10: organic, fine grained										
35.2-36	U11: till Woodmore										
	28	52	20		14	48	62	30	14	56	

Sand=2-0.063mm, Silt=0.063-0.[illegible]2mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS.[illegible] LOCATION [illegible]-LSD2-S20-T[illegible]-R[illegible]
Quarantine Section
Elevation [illegible] ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
						P					
0-3	U1 sand, gravelly										
	93	4	3								
3-14	U2 till, Sonkiw										
3	70	23	7		11	13	24				
6	70	23	7		11	13	24	[illegible]	[illegible]	13	
9	66	25	9		10	14	24				
12	68	24	8		9	15	24	77	13	10	

NUMBER FWS19 LOCATION LSD9-S15-T8-R10
Elevation 1000 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2	U1: sand, gravelly										
2-6	U2: till, Steinbach?										
	74	21	6	6							
6-12	U3: sand, fine grained, a few gravel layers										

NUMBER FWS22 LOCATION SW-LSD9-S11-T3-R4
Big Bend Section
Elevation 850 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
						P					
0-5	U1: till, Steinbach										
5	16	57	27		22	47	69				
5-25	U2: till, Sonkiw										
7	62	24	14		14	26	40	56	22	22	
12	60	24	16		12	26	38				
17	58	28	14		12	25	37				
22	61	28	11		12	26	38	53	23	24	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

[illegible] OF LABORATORY DATA

NUMBER FWB3[illegible] LOCATION [illegible]-LSD1[illegible]-[illegible]7-T[illegible]-R[illegible]
[illegible] Section
Elevation [illegible] ft

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-10	U1 till [illegible]										
3	[illegible]	37	13	15	9	42	51	44	13	43	
6	[illegible]	3[illegible]	14	17	10	38	48	49	11	40	
9	[illegible]	33	14	16	13	38	51	42	10	48	
10	41	41	18	22	13	45	[illegible]				
10-14	U2: sand, fine grained										
14-15	U3 clay										
16-21	U5, 6, 7 pond and flood plain deposits										
U5	6	61	33		9	20	29				
U7	24	53	23		6	16	22				
21-22	U8: sand and gravel										
22-23	U9: silt										
23-29	U10: till, Tolstoi										
	30	58	12		8	22	30	47	8	45	
29-39	slump										

NUMBER FWB25 LOCATION NW-LSD16-S29-T9-R11
Elevation 1200 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
	Horizontal wedge of till, Roseau, overlain, underlain and abutted on one end by fine grained sand.										
till	23	52	25	35				32	32	36	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

[illegible]

[illegible]

NUMBER [illegible]   LOCATION LSD10-[illegible]-T4-R[illegible]
Elevation [illegible]140 ft

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	U1 sand, gravelly										
3-6	U2 till, Marchand										
	44	41	15	18				40	15	39	
	41	43	16	19				44	11	45	
6-10	U3: silt and/or water laid till										
	7	72	20	26				50	15	35	
10-12	U4: sand, fine to medium grained										
12-15	U5: till, water laid, Marchand?										
	21	54	25	34				45	12	43	

NUMBER FW829   LOCATION LSD9-S21-T8-R7
Elevation 870 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-4	U1: gravel, sandy										
4-5	U2: till, Steinbach										
	48	42	10		22	43	65				
5-7	U3: sand, fine to coarse grained										
7-9	U4: till, Steinbach										
	28	51	21		28	37	66	27	33	40	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS41

LOCATION SW-LSD6-S7-T3-R5
Beaver Dam Section
Elevation 875 ft.

DEPTH (ft)		TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3		U1. sand, fine grained										
3-4		U2· gravel										
4-8		U3· till, Senkiw										
2		63	26	11		11	28	39				
4		59	30	11		9	31	40	52	23	25	
8-30		U4 & 5: interbedded sand, silt, and minor clay										
	U4					6	25	[illegible]				
5	U5					4	25	27				
10		18	75	8		3	23	30				
33-36		U8: pond and flood plain deposit										
1		3	63	34		3	40	43				
2		2	69	28		5	41	46				
3		33	47	20		5	37	42				
36-42		U9· sand, medium to coarse grained in upper part, interbedded with till? in lower part										
	T	29	57	14		5	34	39	46	16	38	
42-52		U10: till, Stuartburn										
1		27	57	16		5	24	29				
3		27	57	16		5	23	28	43	18	39	
5		28	56	16		5	25	30	41	16	43	
7		31	54	15		5	24	29	45	16	39	
9		31	53	16		5	25	30	43	17	40	
52-60		Slump covered										
60-62		Till, Woodmore										
		30	51	19		13	50	63	30	17	53	

NUMBER FWS42

LOCATION NW-LSD16-S35-T2-R5
Skeleton Section
Elevation 935 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-8	Till, Roseau										
2	33	45	22		16	34	50				
4	34	46	20		14	38	52	35	9	56	
6	33	45	22		14	34	48				
8	35	44	21		14	36	50	38	11	51	
8-12	Sand, fine to medium grained										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FW34

LOCATION C-LSD16-S5-T3-R5
Shooting Section
Elevation 915 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay F	Cc	Do	Cb	Cr	Ls	Ds	Other
0-18	U1: till, Senkiw										
4	61	30	9		10	31	41	51	27	22	
6	60	31	9		11	30	41				
8	59	30	11		10	32	42				
10	58	31	11		10	29	39				
12	57	31	12		11	30	41				
14	57	31	12		11	30	41	57	21	22	
16	37	50	13		9	42	51	37	17	46	
18	28	57	15		9	41	50				
18-20	U2: gravel										
20-22	U3: till, Senkiw										
					7	40	47				
22-23	U4: Clay										
					9	22	31				
23-26	U5: pond and flood plain deposit										
					6	26	32				
26-28	U6: gravel										

NUMBER FWS35

LOCATION C-LSD11-S4-T3-R5
Deer Section
Elevation 915 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay F	Cc	Do	Cb	Cr	Ls	Ds	Other
0-2	U1: sand, fine grained										
2-3	U2: gravel										
3-9	U3: interbedded clay and till, Steinbach										
	T 49	45	6								
9-19	U4: till, Senkiw										
4	63	29	8		4	36	40				
6	54	36	10		9	35	44				
8	59	34	7		4	34	38	60	20	20	
10	58	33	9		8	32	40				
19-44	U5: sand upper part, silt and clay lower 1/3										
	6	21			C 6	21	27				
					St 9	23	32				
					S 4	22	26				
44-50	U6: till, Stuartburn?										
1	43	50	7		8	41	49				
3	40	51	9		8	40	48	40	18	[illegible]	
5	33	58	9		88	40	48	40	17	43	
7	31	58	11		9	41	50	36	18	46	

SUMMARY OF LABORATORY DATA

NUMBER FWS38

LOCATION SW-LSD8-S8-T3-R5
Silence Section
Elevation 900 ft.

DEPTH (ft)		TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-2		U1: sand, fine grained										
2-4		U2: clay										
4-7		U3: gravel										
7-13		U4: loess?										
2		13	81	6		1	23	24				
4		11	81	8		4	22	26				
13-22		U5,6,&7: pond and flood plain deposits										
	U5	9	76	15		5	26	31				
	U6		98	23		8	30	38				
0.5	U7	1	83	15		1	16	17				
1		1	84	15			17	17				
1.5		2	80	18		2	19	21				
2		3	78	19		2	26	28				
2.5		6	75	19		4	28	32				
22-24		U8: gravel										
									51	6	43	
									38	16	46	
24-27		U9: silt										
		1	89	20		8	45	53				
27-29		U10: till, Tolstoi										
1		24	56	20		12	43	55	31	13	56	
2		30	57	13		11	44	55	26	9	65	
29-44		U11 & U12: till, Stuartburn, U11 upper water laid part										
2	U11	41	52	7		10	43	53	41	13	46	
3		43	50	7		10	42	52	42	15	43	0.1Lig
4		40	54	6		9	44	53	36	15	49	
0.5	U12	43	40	17		12	36	48				
2		47	37	16		13	36	49				
4		42	42	16		12	34	46	44	15	41	
6		43	41	16		13	32	45	40	17	43	0.1Lig
8		43	45	12		12	35	47	41	15	44	0.3Lig

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS36

LOCATION NE-LSD9-S4-T3-R5
Fishing Section
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
						F					
0-2	U1: sand, fine grained										
2-3	U2: gravel										
3-6	U3: till, Roseau										
1	39	45	16		10	45	55	43	14	43	
3	42	43	15		7	46	53				
	See written description for depths below this										
	Till, middle part of Senkiw										
2	55	28	17		11	22	33				
4	56	27	17		11	21	32				
6	61	26	13		8	25	33	62	16	22	
8	59	28	13		9	24	29				
10	62	26	12		9	24	33	67	14	19	
12	62	27	11		6	21	29				

NUMBER FWS37

LOCATION NE-LSD5-S8-T3-R5
Mouse Section
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm)				CARBONATE (%) (-0.063 mm)			VERY COARSE SAND (%) (2-1 mm)			
	Sand	Silt	Clay	Clay	Cc	Do	Cb	Cr	Ls	Ds	Other
						F					
0-3	U1: sand, fine grained										
3-6	U2: gravel and sand (filling low area)										
3-6	U3: till, Senkiw (adjacent to low)										
6-11	U4: silt										
11-13	U5: pond and flood plain deposit										
13-17	U6: deformed till, Tolstoi, and gravel										
G								35	17	48	
T								37	14	49	
17-19	Slump covered										
19-28	U7: interbedded silt, sand, and till, Stuartburn										
T								44	15	41	
T								43	15	42	

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS39

LOCATION SW-LSD12-S18-T3-R5
Circus Section east
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-1	U1: sand, fine grained										
1-4	U2: till, Senkiw										
1	42	45	13		8	33	41	56	17	27	
3	36	51	13		6	27	33				
4-5	U3: silt										
5-8	U4: gravel										
8-11	U5: pond and flood plain deposit										
	27	63	10		6	25	31				
11-14	U6: gravel										
14-18	U7: interbedded sand, silt, and till, Tolstoi										
T	21	64	15		7	37	44				
18-20	U8: till, Tolstoi										
1	24	51	25		10	44	54				
2	25	51	24		10	44	54	30	8	62	
20-29	U9: till, Stuartburn										
2	38	52	10		11	38	49				
4	44	48	8		10	40	50	40	15	45	0.3Lig
6	46	41	13		10	36	46	43	19	38	
8	44	43	13		10	35	45	40	19	41	
29-31	U10: sand, fine grained										
31-32	U11: clay and clay over peat										
32-34	U12: till, Woodmore										
1	31	50	9		14	48	62	25	19	56	

NUMBER FWS40

LOCATION SE-LSD9-S7-T3-R5
Circus Section west
Elevation 900 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	U1: sand, fine grained										
3-4	U2: gravel										
4-14	U3: sand, fine grained becoming coarser in lower half										
14-17	U4: pond and flood plain deposit										
17-19	U5: sand, gravelly near the top										
19-26	U6: upper part; interbedded sand, silt and till Tolstoi										
T	20	54	26	34				36	9	56	
T	24	58	18	26				26	5	69	
T	29	50	21	27				23	8	69	
	U6: lower part; till, Stuartburn										
								39	15	46	
	41	43	16					39	12	49	

SUMMARY OF LABORATORY DATA

NUMBER FWS41

LOCATION SW-LSD6-S7-T3-R5
Beaver Dam Section
Elevation 875 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	U1: sand, fine grained										
3-4	U2· gravel										
4-8	U3: till, Senkiw										
2	63	26	11		11	28	39				
4	59	30	11		9	31	40	52	23	25	
8-30	U4 & 5: interbedded sand, silt, and minor clay										
U4					6	25	[illegible]				
5 U5					4	25	27				
10	18	75	8		3	23	30				
33-36	U8: pond and flood plain deposit										
1	3	63	34		3	40	43				
2	2	69	28		5	41	46				
3	33	47	20		5	37	42				
36-42	U9: sand, medium to coarse grained in upper part, interbedded with till? in lower part										
T	29	57	14		5	34	39	46	16	38	
42-52	U10: till, Stuartburn										
1	27	57	16		5	24	29				
3	27	57	16		5	23	28	43	18	39	
5	28	56	16		5	25	30	41	16	43	
7	31	54	15		5	24	29	45	16	39	
9	31	53	16		5	25	30	43	17	40	
52-60	Slump covered										
60-62	Till, Woodmore										
	30	51	19		13	50	63	30	17	53	

NUMBER FWS42

LOCATION NW-LSD16-S35-T2-R5
Skeleton Section
Elevation 935 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-8	Till, Roseau										
2	33	45	22		16	34	50				
4	34	46	20		14	38	52	35	9	56	
6	33	45	22		14	34	48				
8	35	44	21		14	36	50	38	11	51	
8-12	Sand, fine to medium grained										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS44 — LOCATION LSD14-S30-T4-R10
Waxwing Section
Elevation 1250 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-1	U1· sand, fine to medium grained										
1-2	U2: gravel										
2-5	U3: till, Roseau										
	16	60	24	34	17	35	52	45	23	32	
	24	55	21								

NUMBER FWS45 — LOCATION NE-LSD14-S31-T4-R15
Ford Section
Elevation 870 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-6	Till, Steinbach										
2	23	59	18	25	12	37	49	48	12	40	
4					12	39	51				
6	19	61	20					41	14	44	
6-6.5	Clay										
6.5-9	Till, Steinbach										
	21	61	18	25	11	39	50				
9-13	Till, Marchand										
11	42	41	17	20	9	37	46	46	12	41	
13	41	44	15	19							

NUMBER FWS46 — LOCATION NE-LSD15-S32-T2-R5
Elevation 915 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	U1: till, Roseau										
	38	44	18	22				37	19	44	
3-4	U3: sand dragged in between U1 and U2										
4-10	U2: till, Senkiw										
10-11	U3: sand, fine to medium grained										

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

SUMMARY OF LABORATORY DATA

NUMBER FWS47

LOCATION NW-LSD16-S27-T11-R8
Elevation 840 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-3	Clay										
3-9	Till, Steinbach										
	30	55	15	21							

NUMBER FWS49

LOCATION LSD12-S20-T10-R11
Elevation 965 ft.

DEPTH (ft)	TEXTURE (%) (-2 mm) Sand	Silt	Clay	Clay	CARBONATE (%) (-0.063 mm) Cc	Do F	Cb	VERY COARSE SAND (%) (2-1 mm) Cr	Ls	Ds	Other
0-4	Till, Steinbach										
	36	47	17		35	20	55				

Sand=2-0.063mm, Silt=0.063-0.002mm, Clay=-0.002mm, Clay=-0.004mm
Cc=calcite, Do=dolomite, Cb=carbonate, Cr=crystalline, Ls=limestone, Ds=dolostone.

Appendix I

Description of Test Holes on Which No Laboratory Analyses Were Run

NUMBER FW7 LOCATION SE-LSD16-S10-T8-R7

Elevation 910 ft.

DEPTH	DESCRIPTION
0-5	Bouldery gravel
5-14	Till; Steinbach?; sandy silt; light brownish gray (2.5Y 6/2 wet; Munsell Soil Color Chart, 1954); clasts abundant, hole abandoned.

NUMBER FW8 LOCATION SW-LSD4-S35-T8-R7

Elevation 880 ft.

DEPTH	DESCRIPTION
0-8	Sand; coarse grained; upper part grayish brown (2.5Y 5/2 wet), lower gray (2.5Y N5/ wet).
8-12	Clay; silty; dark grayish brown (2.5Y 4/2 wet); colour banded.
12-22	Till; Steinbach?; silty; grayish brown (2.5Y 5/2 wet).
22-45	Sand; medium grained; light brownish gray (2.5Y 6/2 wet), well sorted.

NUMBER FW9 LOCATION SE-LSD4-S28-T8-R5

Elevation 795 ft.

DEPTH	DESCRIPTION
0-8	No sample
8-18	Clay; silty; massive; some obscure colour banding; a few small, light coloured, silty, clasts; olive gray (5Y 4/2 wet).
18-23	Clay; silty; dark olive gray (5Y 3/2 wet); some thin silty layers, many fragmented; some light coloured, silty clasts.

FW9 continued

23-33	Clay; silty; dark olive gray; obscurely colour banded; some small, light, angular, silty and till-like clasts.
33-48	Clay; silty; very dark gray (5Y 3/1 wet); thin colour banding; no small clasts.
48-63	Clay; silty; black (5Y 2/1 wet); massive to colour banded; small till clasts present throughout; concentration and size of the clasts increases with depth; one layer, composed entirely of clasts, truncates the underlying clay at an angle.
63-70	Till; Steinbach; silty sand; abundant granules and pebbles; light brownish gray (2.5Y 6/2 wet); no fragments of clay.

NUMBER FW10 — LOCATION C-S16-T8-R11

Elevation 1025 ft.

DEPTH	DESCRIPTION
0-10	Sand; fine to medium grained; pale brown (10 YR 6/3 wet).
15-25	Sand; medium to fine grained; grayish brown (2.5 Y 5/3 wet).
25-45	Sand; medium grained; olive gray (5Y 5/2 wet).
45-80	Sand; coarse to medium grained; olive gray; few pebbles but the proportion increasing with depth.

NUMBER FW11 — LOCATION E1/2-S15-T8-R10

Elevation 1025 ft.

DEPTH	DESCRIPTION
0-35	Sand; medium to fine grained; light brownish gray (2.5Y 5/2 wet); a few small clasts.

35-37	Sand, silty, to silt, sandy; light brownish gray.

NUMBER FW12 LOCATION SW-LSD14-S15-T8-R9

Elevation 960 ft.

DEPTH	DESCRIPTION
0-1	Sand; medium to fine grained.
1-10	Till; Steinbach?; silty; light yellowish brown (2.5Y 5/4 wet).
10-20	Sand; fine grained; dark grayish brown (2.5Y 4/2 wet); a few granules in the lower part.
20-30	Silt and find sand, interbedded; three bed types massive sand, thinly laminated sand, and thinly laminated, clayey silt.
30-70	Sand; medium grained; gray (5Y 4/1 wet), well sorted.
70-82	Silt to fine sand; gray (5Y 4/1 wet).

NUMBER FW14 LOCATION SE-LSD1-S5-T8-R7

Elevation 860 ft.

DEPTH	DESCRIPTION
0-5	Clay; silty; very dark grayish brown (2.5Y 3/2 wet); faint mottling.
5-16	Clay; silty; dark olive gray (5Y 3/2 wet); colour banded to about 10 feet.
16-20	Till; Steinbach?; clayey; very dark grayish brown (2.5Y 3/2 wet).
20-44	Till; Steinbach?; sandy silt; grayish brown (2.5 Y 5/2 wet); below 25 feet gray (5Y 5/1 wet).
44-46	Gravel; gray
46-49	Till; sandy silt; gray.
49-50	Sand; fine grained; gray.

NUMBER FW15 LOCATION LSD16-S27-T4-R9

Elevation 1240 Ft.

DEPTH	DESCRIPTION
0-10	Sand; medium grained; well sorted; olive brown (2.5Y 4/4 wet).
10-20	Sand; fine grained; light brownish gray (2.5Y 6/2 wet).
20-85	Sand; medium grained; light brownish gray; very fine grained 78-80.

NUMBER FW16 LOCATION LSD2-S29-T4-R9

Elevation 1110 ft.

DEPTH	DESCRIPTION
0-14	Sand; medium to coarse grained; well sorted; light olive brown (2.5Y 5/4 wet).
14-19	Sand; medium to coarse grained; well sorted; dark gray (5Y N4/wet).
19-23	Silt; gray.
23-30	Sand; medium to coarse grained; poorly sorted; olive gray (5Y 5/2 wet).
30-40	Sand; medium to fine grained; better sorted than above; grayish brown (2.5Y 5/2 wet).
40-50	Sand; fine grained; grayish brown.
50-70	Sand; very fine grained; grayish brown.
70-75	Silt; light brownish gray (2.5Y 6/2 wet).
75-80	Silt and clay, interbedded; gray (5Y 5/1 wet).

NUMBER FW18 LOCATION SE-LSD8-S15-T6-R7

Elevation

DEPTH	DESCRIPTION
0-2	Gravel; sandy
2-5	Till; Steinbach?; silty; light brownish gray (2.5Y 6/2 wet).
5-14	Sand; fine grained; well sorted; grayish brown (2.5Y 5/2 wet).
14-24	Sand; very fine grained; well sorted; dark gray (5Y 4/1 wet).
24-30	Silt; clayey; dark gray; a few small, black organic? fragments.
30-38	Sand and silt, interbedded; sand, fine grained, thinly laminated; a few black organic? streaks.

NUMBER FW20 LOCATION LSD4-S25-T4-R4

Elevation 870 Ft.

DEPTH	LOCATION
0-8	Sand; medium to coarse grained; light yellowish brown (2.5Y 6/4 wet).
8-14	Sand; medium to fine grained; well sorted; light yellowish brown.
14-22	Silt; sandy; dark grayish brown (2.5Y 4/2 wet).
22-40	Sand; fine grained; well sorted; olive gray (5Y 4/2 wet).
40-60	Silt and clay, interbedded; dark gray (5Y 4/1 wet); clay predominates and the proportion increases with depth.

NUMBER FW22 LOCATION SW-LSD5-S34-T10-R9

Elevation 905 ft.

DEPTH	DESCRIPTION
0-5	Sand; very coarse grained.
5-8	Silt; sandy; light yellowish brown (2.5Y 6/4 wet).
8-20	Sand; find grained; light yellowish brown.
20-26	Silt; light gray (5Y 7/2 wet); a few thin, well sorted, fine grained, sand layers.

NUMBER FW24 LOCATION EC-S8-T9-R11

Elevation 935 ft.

DEPTH	DESCRIPTION
0-8	Clay; silty; dark grayish brown (2.5Y 4/2 wet); thin colour banding.
8-18	Silt; pale yellowish brown (2.5Y 6/4 wet).
18-25	Till?; silty sand; light brownish gray (2.5Y 6/2 wet).
25-50	Silt, sand, and till, interbedded; dark gray (5Y 4/1 wet).

NUMBER FW25 LOCATION SE-S17-T8-R8

Elevation 950 ft.

DEPTH	DESCRIPTION
0-2	Gravel; sandy.
2-15	Sand; medium grained; well sorted; light yellowish brown (2.5Y 6/4 wet); below 15 feet grayish brown (2.5Y 5.2 wet).
35-65	Sand; poorly sorted; coarse to medium grained; proportion of the very coarse sand increases with depth.
65-80	Sand; medium grained; gray (5Y 5/1 wet).

NUMBER FW35

LOCATION LSD9-S7-T8-R5

Elevation 900 ft,

DEPTH	DESCRIPTION
0-3	Sand; fine grained; a few pebbles.
3-13	Sand; very fine grained; well sorted; no pebbles; light brownish gray (2.5Y 6/2 wet). A few black streak.
13-16	Sand; coarse grained; a few pebbles; some reddish brown iron staining.
16-23	Silt; massive; olive gray (5Y 5/2 wet); a few black streaks.
23-27	Poor sample recovery; mixed gravel. till?, and silt; olive gray.
27-36	Silt; sandy; olive gray (5Y 4/2 wet); some thin, medium grained sand layers; one pelecypod shell at 29-30.
36-39	Till; silty; olive gray.
39-40	Gravel; sandy.
40-72	Poor sample recovery; till?; sandy silt; gray (5Y 5/1 wet).
72-79	No sample return; possibly sand.
79-95	Till; sandy silt; dark gray (5Y 4/1 wet).

NUMBER FW57

LOCATION SW-LSD1-S24-T5-R9

Elevation 1270 ft.

DEPTH	DESCRIPTION
0-50	Sand; fine grained; well sorted; a few granules and gravel rich layers above 28 feet; a few coarse grained layers with the number increasing with depth.
50-75	Sand; coarse grained; well sorted; granule rich.

NUMBER FW61 LOCATION SE-S18-T7-R10

Elevation 1050 feet

DEPTH	DESCRIPTION
0-7	Sand; coarse grained; well sorted.
7-12	Sand; medium to fine grained; a few pebbles.
12-25	Sand; medium grained; slightly silty; light gray (2.5Y N7/wet).
25-95	Sand; fine grained; well sorted; clean; no stones; light brownish gray (2.5Y 6/2 wet).

NUMBER FW65 LOCATION SE-S18-T11-R9

Elevation 870 ft.

DEPTH	DESCRIPTION
0-3	Sand; medium to coarse grained; gravelly; carbonate pebbles predominate; light olive gray (5Y 6/2 wet).
3-5	Sand; fine grained; light olive gray.
5-7	Till; sandy; light brownish gray (2.5Y 6/2 wet); bouldery, hole abandoned.

NUMBER FW69 LOCATION SC-S22-T9-R7

Elevation 890 ft.

DEPTH	DESCRIPTION
0-20	Sand; fine grained; well sorted; a few pebbles and gravel rich layers.
20	Boulder, hole abandoned.

NUMBER FW70 LOCATION NE-S23-T9-R7

Elevation 890 ft.

0-15	Till; silty; light yellowish brown (2.5Y 6/4 wet); boulders so abundant hole abandoned.

NUMBER FW72 LOCATION C-S26-T8-R10

Elevation 1000 ft.

DEPTH	DESCRIPTION
0-5	Sand; medium to fine grained; well sorted.
5-10	Sand; medium to coarse grained; a few pebbles and gravel layers; light brownish gray (2.5Y 6/2 wet).
10-45	Sand; fine to medium grained; slightly silty; a few coarse grained layers; gray (2.5Y N6/ wet).
45-47	Till?; sandy; dark gray (5Y 4/1 wet).
47-50	Silt; sandy; softer than till; some wood chips and plant fragments.
50-80	Sand; coarse grained; abundant granules; well sorted; clean.

NUMBER FW73 LOCATION EC-S31-T8-R10

Elevation 960 ft.

DEPTH	DESCRIPTION
0-16	Gravel; sandy; carbonate pebbles predominate.
16-30	Sand; fine grained; gray (5Y 5/2 wet).

NUMBER FW74 LOCATION NE-LSD16-S21-T8-R7

Elevation 870 ft.

DEPTH	DESCRIPTION
0-7	Sand; medium grained; well sorted; a few pebbles in the top 3 feet.
7-22	Sand; medium to fine grained; some gravel rich layers.
22	Boulder, hole abandoned.

NUMBER FW 85 LOCATION S33-T8-R13

East of study area.

DEPTH	DESCRIPTION
0-3	Silt and fine sand, interlaminated; light yellowish brown (2.5Y 6/4 wet).
3-5	Silt and clay, interlaminated; light yellowish brown.
5-10	Clay; silty; interbedded with sand; fine grained; gray (2.5Y N6/wet); soft; sticky.
10-12	Clay; bluish gray (5B 6/1 wet); a few black organic? fragments.
12-23	Clay; gray (2.5Y N5/wet); soft; sticky; a few light gray silty laminae.
23-33	Sand; dirty; silty; gray.
33-37	Till?; clayey; stoney; dark gray (2.5Y N4/ wet).
37-40	Clay; silty; dark grayish brown (2.5Y 4/2 wet); some light gray silt laminae.
40-76	Clay; silty; grayish brown (2.5Y 5/2 wet), pinkish tint; massive; granules and pebbles in the lower part.
76-83	Sand; almost all feldspar and quartz fragments; may have reached granite bedrock.

NUMBER FW87 LOCATION LSD15-S35-T4-R4

Elevation 830 ft.

DEPTH	DESCRIPTION
0-3	Till; Steinbach?; silty; light yellowish brown (2.5Y 6/4 wet).
3-23	Sand; medium grained; grayish brown (2.5Y 5/2 wet); clean; well sorted.
23-29	Sand; silty; gray (2.5Y N6/wet); a few clay layers.
29-30	Till?; silty; stoney; dark gray (5Y 4/1 wet).
30-34	Clay; silty massive; very dark gray (5Y 3/1 wet).
34-38	Till' sandy; very dark gray.
38-44	Silt; massive; very dark gray.
44-55	Till; sandy; dark greenish gray (5GY 4/1 wet).
55-70	Poor sample recovery; mainly sandy till but some clay and silt.
70-75	Till; sandy; dark gray (5Y 4/1 wet).
75-80	Clay; silty; thin laminated; a few silt laminae.

NUMBER FW95 LOCATION SW-S11-T6-R10

Elevation 1125 ft.

DEPTH	DESCRIPTION
0-7	Sand; gravelly; light brownish gray (2.5Y 6/2 wet).
7-28	Sand; medium to fine grained; clean; light brownish gray.
28-29	Silt; grayish brown (2.5Y 5/2 wet).

29-80	Sand; medium to fine grained; a few thin silt layers and pebbles; grayish brown.
80-110	Sand; fine grained; gray (2.5Y N5/wet); a few small lignite and wood fragments; 105 feet a pocket of organic material.
110-118	Silt to very fine sand; gray.
118-160	Sand; fine grained; gray; no wood fragments.

Appendix J

Mean and Standard Deviation Values for Grouped Data

	FWS41 Vita Fm.	FWS39 St. Malo Fm.	FW81 Hazel Fm.
Trees	%	%	%
Picea	71.6	51.6	65.9
Pinus	17.6	32.0	11.0
Betula	2.0	4.1	2.2
Populus	-	-	3.3
Carpinus/Ostrya	1.0	-	-
Shrubs			
Alnus	-	0.8	-
Salix	-	-	3.3
Herbs			
Ericaceae	-	1.6	-
Gramineae	-	1.6	4.4
Tubuliflorae	-	-	2.2
Ambrosieae	1.0	0.8	-
Artemisia	-	4.1	1.1
Chenopodiineae	1.0	1.1	1.1
Sarcobatus	-	0.8	-
Leguminosae	-	0.8	-
Selaginella densa	-	0.8	-
Equisetum	1.0	-	-
Pteridophyta	2.0	-	-
Polypodiaceae	1.0	-	-
Unidentified	2.0	1.6	4.4
Aquatics			
Cyperaceae	3.0	1.6	31.9
Typha	-	0.8	-
Shpagnum	1.0	110.7	2.2

Analyses done by R.J. Mott, Geological Survey of Canada

Table K-1. Results of Palynological analyses.

Sample grouping	Cr % M /SD	Ls % M /SD	Ds % M /SD	Cb % M /SD	Cr/Cb M /SD	Ls/Ds M /SD	N	samples used test hole, section(S) surface(T)
Steinbach till								
Cross section EE'	26 /6.7	57 /7.0	17 /2.3	74 /6.8	0.37/0.12	3.4 /0.68	6	31,64,83
Highway number 1	32 /3.9	20 /4.2	47 /6.7	67 /3.2	0.48/0.08	0.45/0.16	7	76,86,53,57 S8 S29
DD'	31 /5.2	21 /8.5	47 /6.7	68 /5.3	0.46/0.12	0.48/0.24	22	50,51,53,62,84
Total	30 /5.5	27 /16.	42 /13.	69 /5.5	0.45/0.12	0.99/1.2	34	
RRP margin	47 /3.3	23 /8.5	32 /8.3	55 /3.0	0.87/0.09	0.83/0.50	8	21 34,94,S11,S45
Red River Plain	19 /2.3	34 /15	46 /13	80 /4.5	0.24/0.04	0.86/0.57	3	67,68,65
Marchand till								
Cross section EE'	35 /5.4	29 /6.7	36 /4.6	65 /5.1	0.50/0.13	0.81/0.28	11	21,31,33,83
DD'	46 /5.4	14 /3.4	40 /5.7	54 /5.7	0.89/0.22	0.35/0.12	21	50,51,53,62,84
CC'	41 /5.5	13 /3.4	45 /4.9	58 /5.8	0.72/0.18	0.30/0.09	11	38,39,40,43
BB'	40 /5.9	14 /2.9	46 /5.7	60 /6.1	0.63/0.16	0.31/0.09	11	3,46,47,48,S28,S45
AA'	38 /2.7	14 /2.9	47 /4.3	61 /3.6	0.63/0.08	0.30/0.08	10	26,27,100,S32 T73-1,2,3,45
Total	41 /6.6	16 /6.8	43 /6.8	59 /6.7	0.72/0.21	0.41/0.24	63	
DD' to EE' combined	42 /6.0	13 /3.1	44 /6.1	57 /6.3	0.76/0.20	0.32/0.10		
Roseau till								
Cross section EE'	29 /3.5	34 /6.3	37 /8.7	71 /3.2	0.40/0.07	1.0 /0.48	6	31,83
DD'	36 /7.9	30 /5.5	34 /4.3	64 /8.0	0.58/0.20	0.88/0.15	3	51 84
CC'	34 /2.6	21 /1.5	44 /2.5	65 /3.4	0.53/0.07	0.49/0.03	4	89
BB'	36 /6.7	23 /6.9	40 /4.1	63 /6.6	0.59/0.16	0.58/0.30	14	2,3,47,55
AA'	30 /2.5	22 /3.8	47 /3.1	69 /2.6	0.44/0.05	0.44/0.11	8	28,29,30,100,T317
Total	34 /6.0	26 /7.3	40 /6.5	66 /6.2	0.52/0.15	0.67/0.31	35	
Southeast samples	40 /4.5	17 /3.9	43 /4.0	60 /1.7	0.66/0.05	0.42/0.14	5	81,T556,T574,T578
Senkiw till								
Cross section DD'	71 /4.5	15 /3.2	14 /2.1	29 /4.5	2.5/0.57	1.1 /0.22	7	49,S17
CC'	70 /8.1	10 /4.8	21 /5.1	31 /8.1	2.5/1.0	0.43/0.22	6	41,42,44
AA' east	82 /8.1	7 /2.0	10 /5.6	17 /7.2	5.7/3.7	0.82/0.40	3	28,T551
Roseau River	53 /6.1	22 /3.4	25 /4.1	47 /6.1	1.1 /0.32	0.89/0.16	24	78,94,101,S22,S33 S34,S35,S36,S41
AA'	46 /4.5	20 /5.0	33 /7.3	53 /4.7	0.89/0.17	0.68/0.29	15	37,38
Total east	70 /7.8	12 /4.9	18 /7.6	30 /7.3	2.5 /0.88	0.74/0.41	17	AA'(E),CC',DD'
Total west	50 /5.3	21 /4.5	/6.6	/6.3	1.0 /0.30	0.81/0.24	39	AA'(W),Rom. R.
Tolstoi till								
Roseau River	28 /4.6	8 /1.6	64 /5.3	72 /4.4	0.41/0.09	0.12/0.03	5	S38,S39,S40
Stuartburn till								
Roseau River	41 /2.4	16 /2.2	43 /3.7	59 /2.7	0.69/0.08	0.37/0.08	26	94,S14,S23,S35 S38 S39,S40,S41
East of Rom. R.	43 /1.7	15 /4.4	42 /3.9	57 /1.9	0.75/0.36	0.36/0.14	6	3,26
Total	41 /2.4	18 /2.7	43 /3.7	59 /2.7	0.70/0.07	0.37/0.09	32	
Woodmore till								
Roseau River	27 /2.3	17 /1.9	56 /2.0	73 /2.5	0.38/0.05	0.30/0.04	6	79,S14,S39,S41
Rosa								
	42 /2.8	13 /1.9	45 /3.4	58 /3.4	0.78/0.09	0.29/0.06	19	79,80,88 101

Cr. - crystalline, Ls - limestone, Ds - dolostone, Cb - total carbonate, N - number of samples
M - mean, SD - standard deviation

Table J-2. Mean and standard deviation values for the grouped data on the very coarse sand lithology (2 to 1mm. fraction).

Sample grouping	Cc M	Cc SD	Do M	Do SD	Cb M	Cb SD	Cc/Do M	Cc/Do SD	N	Samples used
Steinbach till										test hole, section(s), surface(T)
Cross section EE'	25	/5.1	31	/3.9	56	/5.9	0.83	/0.21	19	21,23,31,83,96
DD'	21	/4.0	39	/3.8	60	/2.3	0.55	/0.15	20	50,53,62,84,T404,T621
Total	23	/5.0	35	/5.6	58	/4.8	0.68	/0.23	39	
Red R. Plain margin	13	/3.3	43	/5.7	56	/6.9	0.31	/0.08	9	75,79,S45,T621
Marchand till										
Cross section EE'	20	/3.0	35	/4.4	55	/3.3	0.59	/0.16	12	21,31,83
DD'	15	/1.5	36	/3.3	51	/3.6	0.42	/0.06	29	50,53,84
CC'	14	/1.5	40	/1.9	54	/1.5	0.36	/0.05	6	40
BB'	13	/2.3	41	/4.3	54	/4.4	0.31	/0.08	14	2,3,17,47,48
AA'	11	/1.0	40	/6.3	51	/5.2	0.29	/0.07	9	27,100,T73-1,3,65
Total	15	/3.3	38	/4.7	53	/4.1	0.40	/0.13	70	
Roseau till										
Cross section EE'	23	/3.9	31	/8.5	54	/6.7	0.82	/0.31	7	31,83
DD'	22	/4.3	29	/4.6	51	/1.8	0.80	/0.31	8	51,84
BB'	16	/2.2	40	/4.8	56	/6.4	0.41	/0.05	14	3,47,55, S44, T317
AA'	12	/2.7	42	/3.0	54	/3.2	0.29	/0.08	14	29,30,81,100
Total	17	/5.4	37	/7.3	54	/5.2	0.52	/0.29	43	
Senkiw till										
Cross section DD'	13	/2.8	15	/1.6	28	/3.9	0.81	/0.15	9	49,S17
CC'	7	/0.6	26	/0.6	33	/1.8	0.25	/0.02	3	42
Roseau River	10	/2.3	29	/2.9	39	/3.4	0.36	/0.09	58	78,S22,S33,S34,S35,S16,S39,S41
AA' (west)	11	/2.1	30	/4.4	41	/6.0	0.38	/0.09	22	19,28,30,36,37
AA' (east)	7	/1.2	22	/1.5	29	/0.6	0.31	/0.08	3	28
Total	11	/2.6	28	/5.3	39	/5.8	0.40	/0.16	95	
Tolstoi till										
Roseau River	11	/1.0	44	/0.5	55	/0.8	0.25	/0.02	4	S38,S39
Stuartburn till										
Roseau River	11	/2.1	38	/3.3	49	/2.5	0.28	/0.07	19	79,S14,S35,S39
East of Roseau R.	13	/2.0	41	/1.9	54	/1.9	0.32	/0.06	10	3,47
Total	11	/2.4	39	/3.1	50	/3.4	0.30	/0.07	29	
Woodmore till										
Roseau River	13	/2.3	48	/5.6	61	/4.7	0.29	/0.08	7	79, S14,S39,S41
Rosa till										
Roseau River	12	/0.8	37	/1.9	49	/2.0	0.31	/0.03	17	79,80

Cc=calcite, Do=dolomite, Cb=total carbonate

Table J-3. Mean and standard deviation values for the grouped data on the fine matrix carbonate composition of the tills (-0.063 mm. fraction).

Appendix K Biota Identified in Drift Samples

	FWS41 Vita Fm.	FWS39 St. Malo Fm.	FW81 Hazel Fm.
Trees	%	%	%
Picea	71.6	51.6	65.9
Pinus	17.6	32.0	11.0
Betula	2.0	4.1	2.2
Populus	-	-	3.3
Carpinus/Ostrya	1.0	-	-
Shrubs			
Alnus	-	0.8	-
Salix	-	-	3.3
Herbs			
Ericaceae	-	1.6	-
Gramineae	-	1.6	4.4
Tubuliflorae	-	-	2.2
Ambrosieae	1.0	0.8	-
Artemisia	-	4.1	1.1
Chenopodiineae	1.0	1.1	1.1
Sarcobatus	-	0.8	-
Leguminosae	-	0.8	-
Selaginella densa	-	0.8	-
Equisetum	1.0	-	-
Pteridophyta	2.0	-	-
Polypodiaceae	1.0	-	-
Unidentified	2.0	1.6	4.4
Aquatics			
Cyperaceae	3.0	1.6	31.9
Typha	-	0.8	-
Shpagnum	1.0	110.7	2.2

Analyses done by R.J. Mott, Geological Survey of Canada

Table K-1. Results of Palynological analyses.

On the following pages are reproduced the reports by L.D. Delorme and L.L. Kalas, Canada Center For Inland Waters, on samples from the Vita Formation.

OSTRACODA

Only one sample contained ostracodes - FWS 34.

Ostracoda

FWS 34

Candona candida	(Muller), 1776	11
Candona compressa	(Koch), 1838	4
Candona distincta	Furtos, 1933	4
Candona inopinata	Furtos, 1933	2
Candona paraohioensis	Staplin, 1963	2
Candona rawsoni	Tressler, 1957	18
Candona sigmoides	Sharpe, 1897	2
Cyclocypris ampla	Furtos, 1933	4
Cyclocypris serena	(Koch), 1838	2
Cyclocypris sharpei	Furtos, 1933	6
Cypridopsis vidua	(Muller), 1776	7
Ilyocypris bradyi	Sars, 1890	20
Limnocythere itasca	Cole, 1949	3
Limnocythere sp.		4

Interpretation

The sediment was deposited in an intermittent stream located within a mixed forest association. The mean annual temperature was about 1.19°C (range -9.5 to 6.6°C) and the total annual precipitation was 17.7 inches (range 9.1 to 39.6 inches).

4 OF/DE 4

FWS 34

Gyraulus parvus (Say), 1824	28	
Gyraulus deflectus (Say), 1817	2	
Valvata tricarinata (Say), 1817	10	
Valvata sincera helicoidea Dall, 1905	13	
Lymnaea arctica Lea, 1864	15	
Lymnaea parva Lea, 1841	58	
Pisidium compressum Prime, 1855	8	
Pisidium ventricosum Prime, 1851	15	
Pisidium casertanum Poli, 1795	8	
Sphaerium nitidum Clessin, 1876	4	
Catinella vermetta Say, 1829	8	
Pupilla muscorum (Linne), 1758	1	fragment
Discus cronkhitei (Newcomb), 1865	1	

Bryophyta remains (Contaminations)

Most frequent molluscs recovered from this section are aquatic species limited to the semipermanent and permanent water bodies with extant muddy shores and overbank deposits. Terrestrial species restricted to a small number of individuals are commonly found along stream banks, living under logs or in and on the litter of broad-leaf trees. Their presence with the aquatic species indicate transportation by the stream during periods of floods and burial further downstream in an oxbow lake or thaw lake area with dense submerged vegetation.

REPORT 73-31

L. L. KALAS

FOSSIL MOLLUSCS FROM ROSEAU RIVER AREA

FWS 38

Catinella vermetta Say, 1829	35
Vertigo modesta (Say), 1824	7
Vertigo alpestris Alder, 1838	5
Discus cronkhitei (Newcombe), 1865	6 + eggs
Vallonia pulchella (Müller), 1774	1
Agriolimax hyperboreus (Westerlund), 1876	1
Columella alticola (Ingersoll), 1896	1 fragment.
Rodentia	tooth

The habitat suggested by the exclusive terrestrial molluscs fauna is an open slightly moist grassland or tundra, possibly on river flood plain or close to it. Species also suggests that tundra or grassland merged with a dwarf coniferous forest with some broad-leaf trees. There is indication that some logs and leaf litter were located along the flooded area, under which most of the species identified might find a shelter. The climatic conditions were cooler than at present in the area of Roseau River.

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Section FWS 41

Vertigo modesta (Say), 1824	10	
Vertigo alpestris	4	
Catinella vermetta Say, 1829	59	
Discus cronkhitei (Newcomb), 1865	13 + eggs	
Pupilla muscorum Linne, 1758	2	fragments
Agriolimax hyperboreus (Westerlund), 1876	6	
Lymnaea parva Lea, 1841	4	

Bryophyta remains

A great proportion of the species identified from this sample are terrestrial forms living under similar conditions as assemblage from sections 38 except *Lymnaea parva*, which is a freshwater species with semi-aquatic requirements, preferrably living on wet barren mud flats along shores of lakes or streams.

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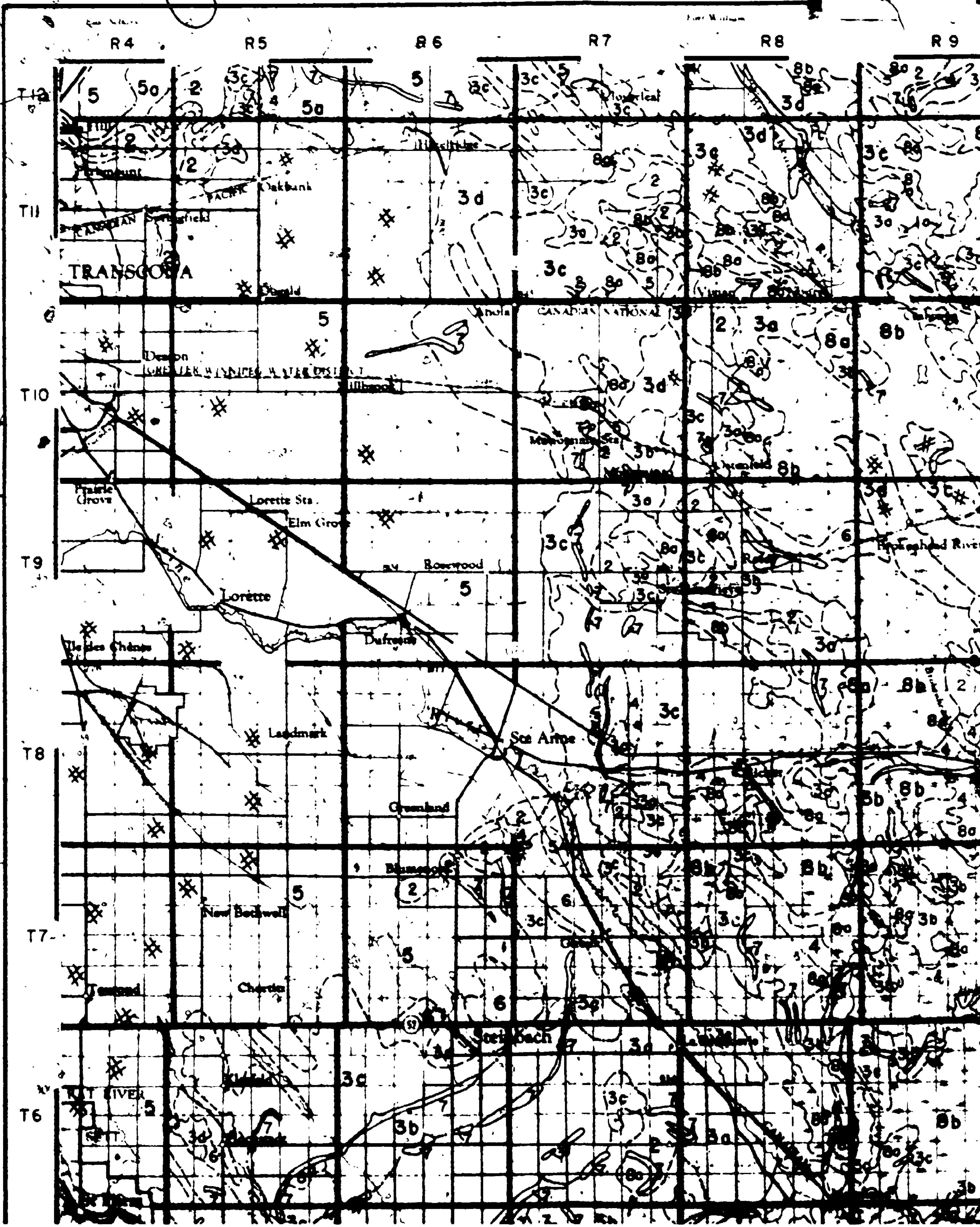
	National Research Council Postgraduate Scholarship 1972-1973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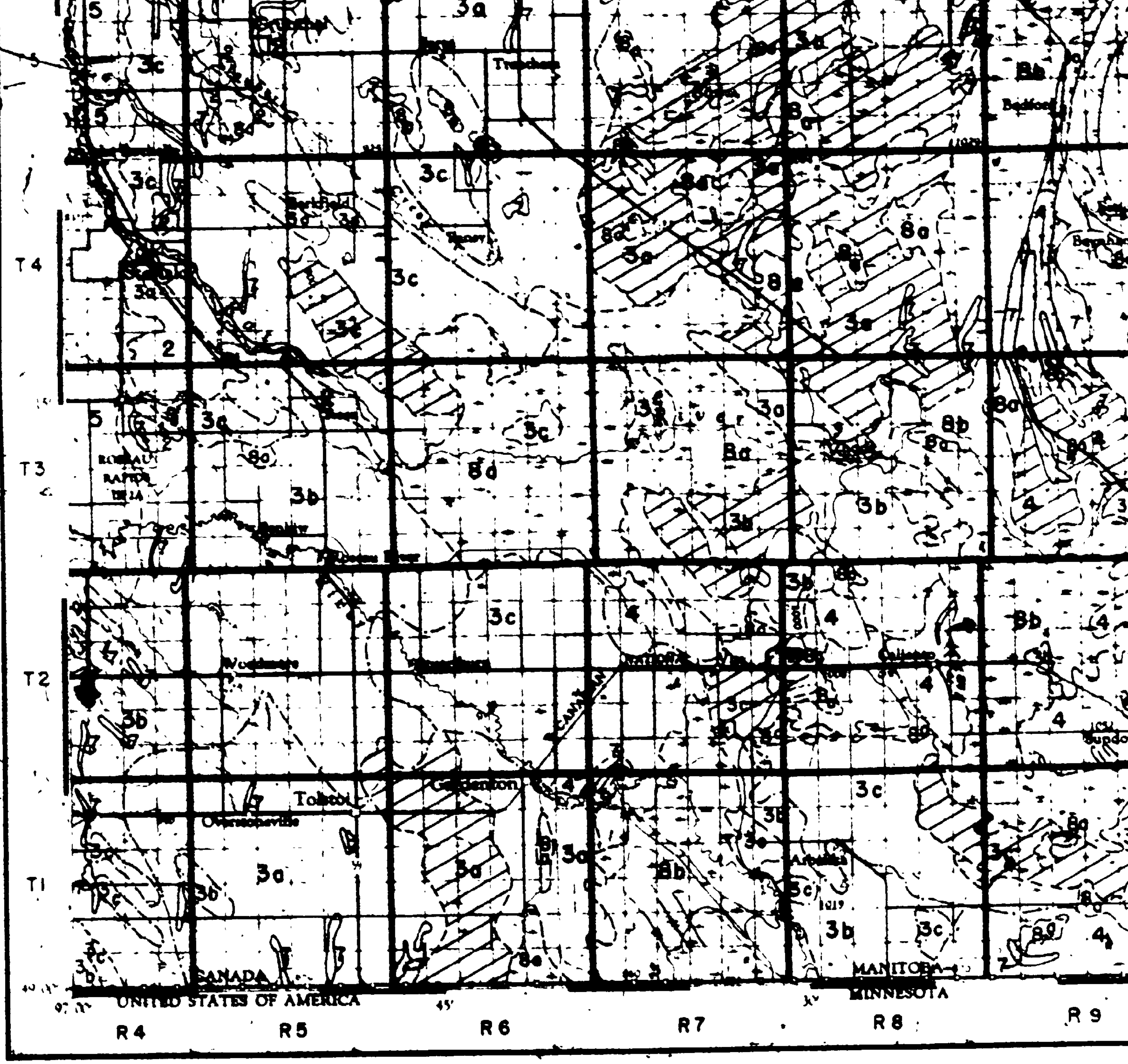
Dugald
Anola
CANADIAN NATIONAL
Deacon
GREATER WINNIPEG WATER DISTRICT
Prairie Grove
Lorette Sta.
Elm Grove
Rosewood
Lorette
Dufresne
Ile des Chênes
Landmark
Ste Anne
Greenland
Blumenort
New Bothwell
Steinbach
Kleefeld
RAT RIVER



Base-map produced by Surveys and Mapping Branch
Department of Energy Mines and Resources, printed 1967

Geology by M. M. Fenton, 1973
To accompany PhD thesis The Quaternary Geology of Part of Southeastern Manitoba, M.M. Fenton

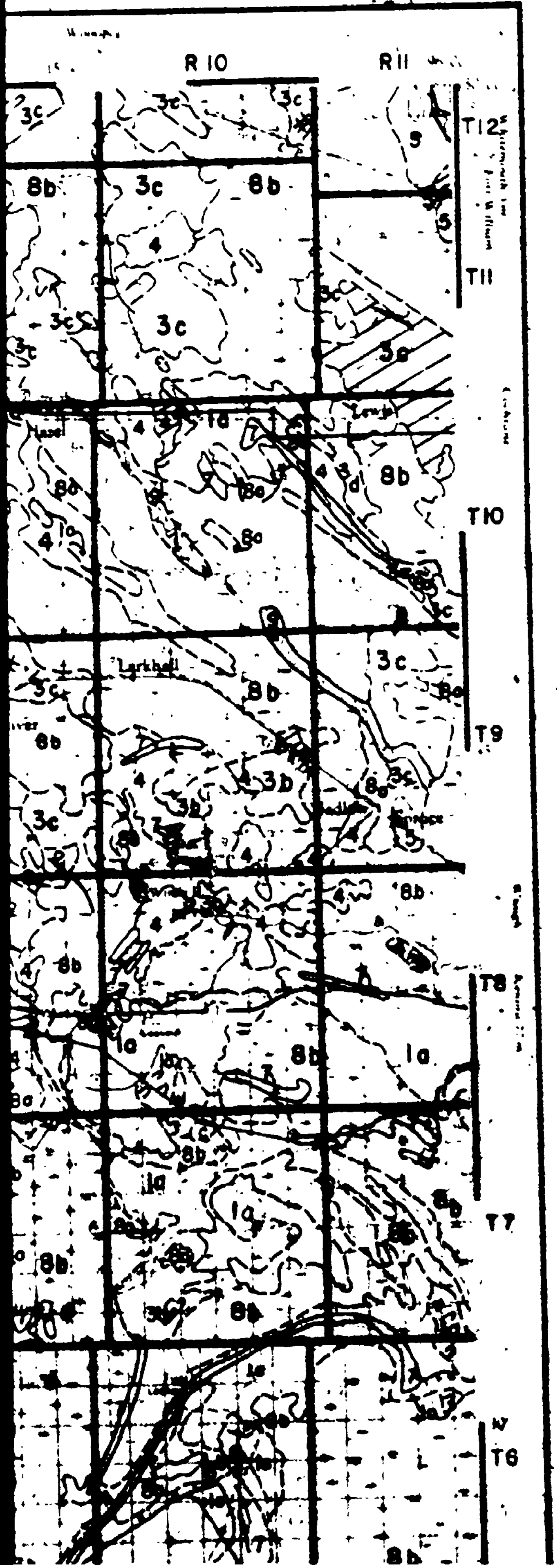
Scale 1:250,000 Échelle

Hard surface, all weather
hard surface, all weather
stabilized surface, all weather
loose surface, dry weather

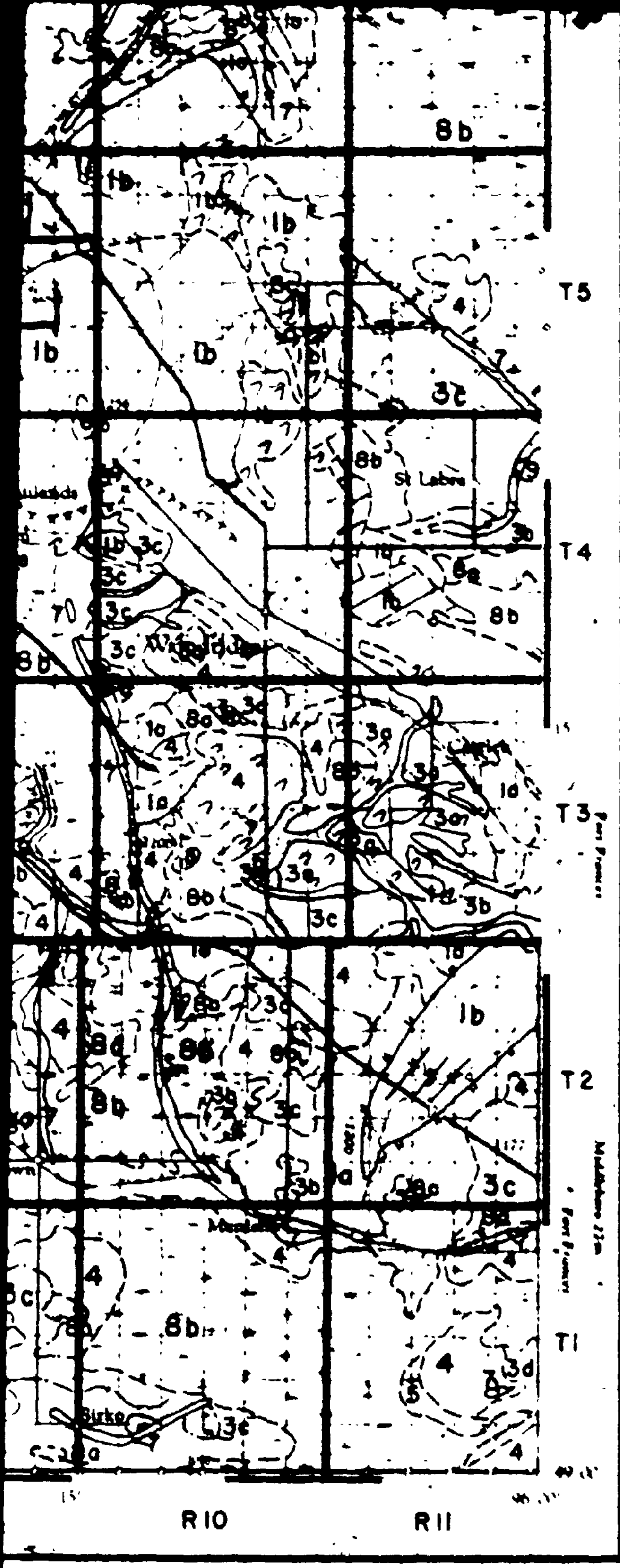
Figure 8
Quaternary Geology Winnipeg

62 H

1. 3f



	Unit	Co
9	Alluvium	Sand, silt mōderate organic l
	Organic Units	
8a	8a shallow: generally <1m (3 ft).	Fibrous sphagnu
8b	8b deep: > 1m (3ft).	Fibrous peat.
	Lacustrine Units	
7	Sand and gravel	Sand and moderate
6	Clay overlain by <1m (3 ft) of sand.	Clay: silt fine.
5	Clay: > 2m (6 ft).	Clay: silt
4	Sand: generally > 2m.	Sand: me sorted.
	Glacial Units	
	Till, partially overlain by sand to clay - 3a to d	Till: silt clasts, c
3a	3a > 90 % covered by > 2m (6 ft) of sand.	Sand. m with som the till. be abse directly sedimen
3b	3b 50 to 90 % covered by < 2m (6ft)	Sand: m gravel l



sediment.

3b	3b 50 to 90 % covered by < 2m (6ft) of sand.	Sand: med gravel lay where the Locally cl tween san
3c	3c < 50 % covered by < 2m (6 ft) of sand.	Sand: med gravel lay where sa
3d	3d > 90 % covered by < 2m (6 ft) of clay.	Clay: silty;
2	Glaciofluvial sand and gravel:	Sand and poorly to
	Glaciofluvial sand:	Sand: coa sorted.
1a	1a wave-eroded.	Sand: par boulder la lacustrine
1b	1b wave-washed.	Sand: loc

Shallow discontinuous peat cover

Discontinuous dune cover over t

Geological boundary: defined; a

Scarp: over 6m (20 ft) high; less

Photo lineament: usually a minor
Intersecting lin

omposition	Geomorphology	Origin
t, and clay stratified, e to well sorted, some layers and lenses.	Flood plains or bars; relief < 2m (6 ft).	Deposited in rivers and on adjacent bars and flood plains.
to mucky sedge, um, to reed peat. sedge and sphagnum	Plain, level to sloping (0.8-1.6 m/km, 4-8 ft/mi), 8a-also filing small depressions, relief < 1m (3ft).	Accumulation of organic material in poorly drained areas following the fall of Lake Agassiz.
d gravel: stratified, e to well sorted.	Generally indivdual ridges or hills, in some places on or adiacent to unit 1 forms subparallel ridges, relief < 4m (12 ft).	Formed by the wave and current action of Lake Agassiz.
ty, Sand: coarse to	Plain: flat, relief < 1m (3 ft).	Sand moved over clay as Lake Agassiz fell.
ty, 50 silt; clayey.	Plain: flat, sloping westward (0.8m/km, 4 ft/mi); relief < 1m (3ft).	Deposited by Lake Agassiz, generally silt shoreward of clay.
edium to fine; well	Plain: flat to undulating; partially dune covered; relief < 4m (12 ft).	Sand moved lakeward by Lake Agassiz, later aeolian reworking in some areas.
y to sandy, some calcareous.		Deposited by glacial ice.
edium to fine, often ne clay between it and Locally the till may nt and the sand rests on earlier stratified t.	Plain: flat to undulating	Sand and clay deposited

yer at the base or | 3-6 ft/mi); relief < 2m (6 ft). | ing of sand. Gravel is a lag deposit.
el sand is absent.
lay is present be-
nd and gravel.

dium to fine; a thin
yer at the base or
and is absent.

; to silt: clayey.

gravel: stratified; well sorted.	Hills and ridges. relief 4-9 m (12-30 ft).	Drift deposited at the ice margin into a proglacial lake: kame-deltas
arse to fine; well		
rtially covered by a lag; locally overlain by e deposits and till.	Plain: flat to undulating; irregular ridges where dissected by later stream erosion; relief < 4m (12 ft); partially dune covered.	Deposited between ice masses and later eroded by Lake Agassiz and then reworked by wind.
ocally till covered.	Highland: flat to ridge covered; partially scarp bordered; partially dune-covered; relief < 4m (12 ft).	

r over the deposits indicated.

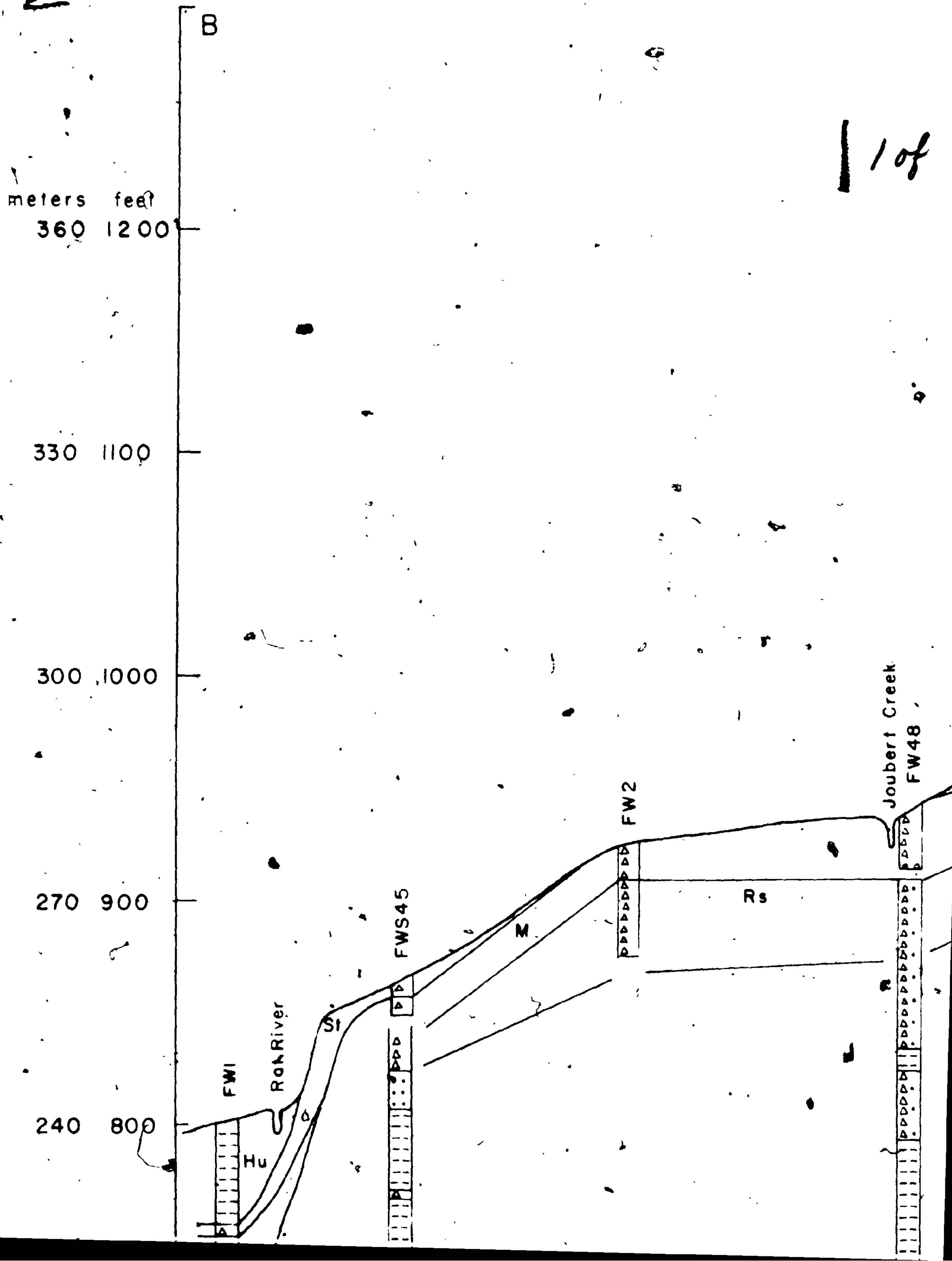
the deposits indicated.

approximate; gradational.

s than 6m (20 ft); approximate or poorly developed

or ridge or vegetation stripe;
lineaments, location approximate

6 of 6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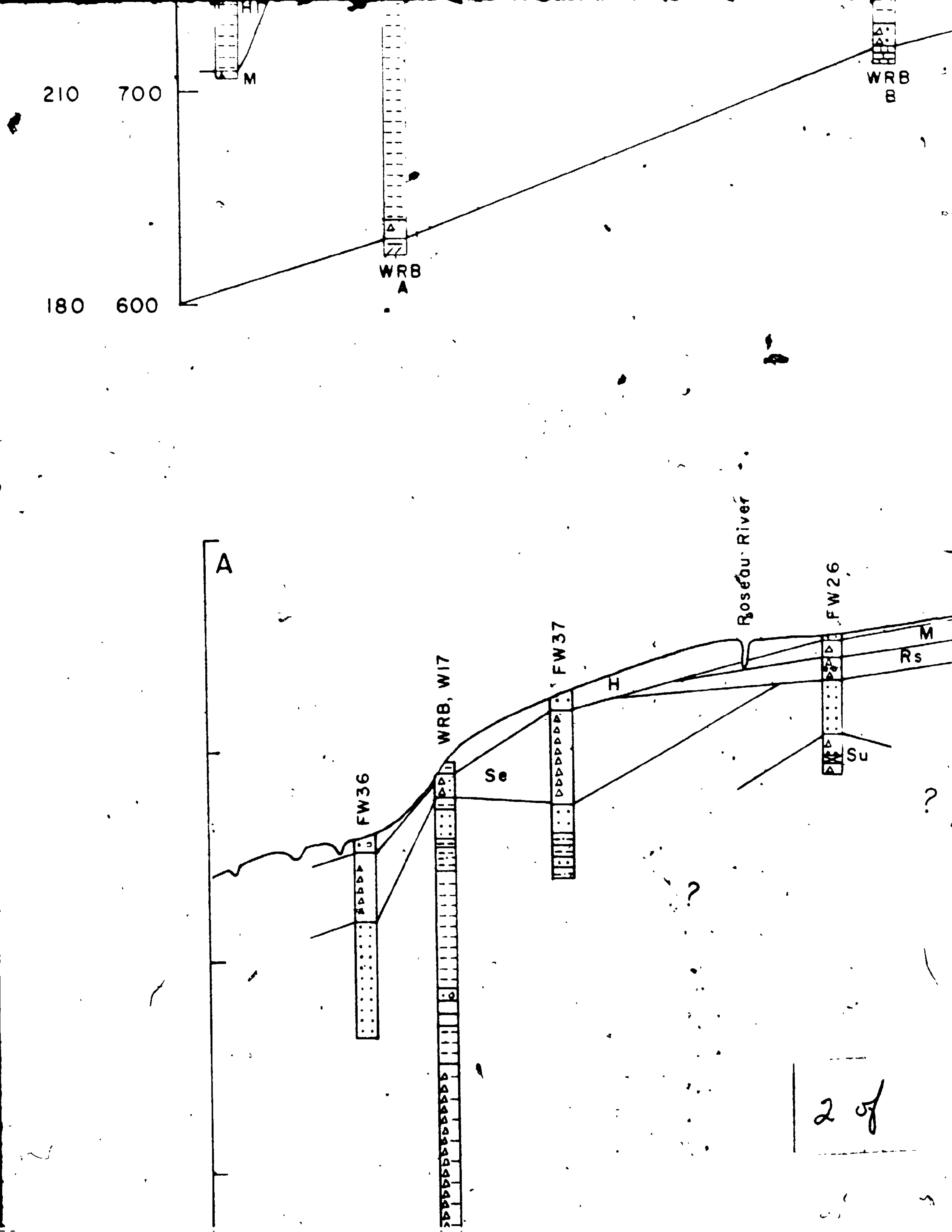

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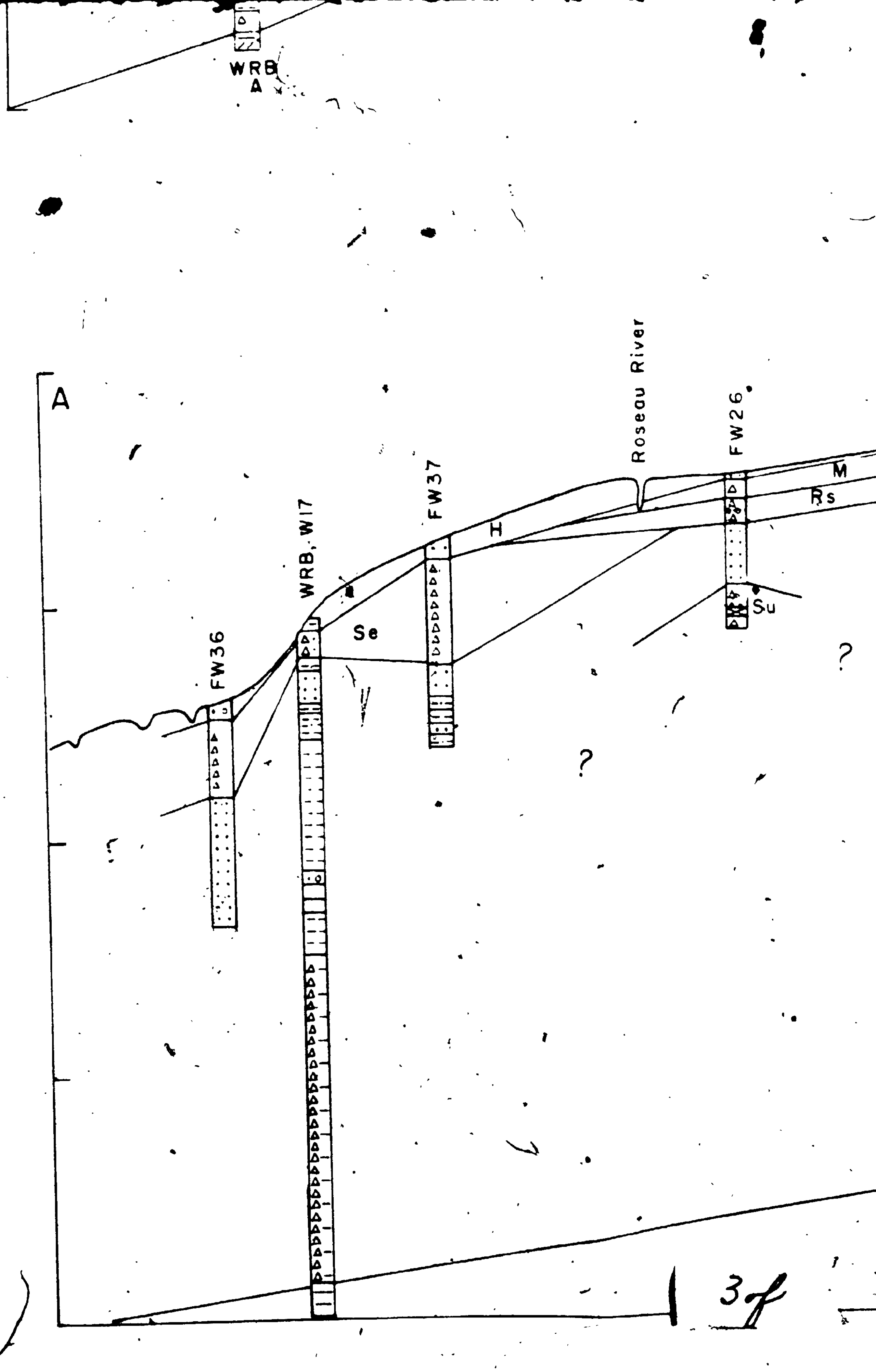

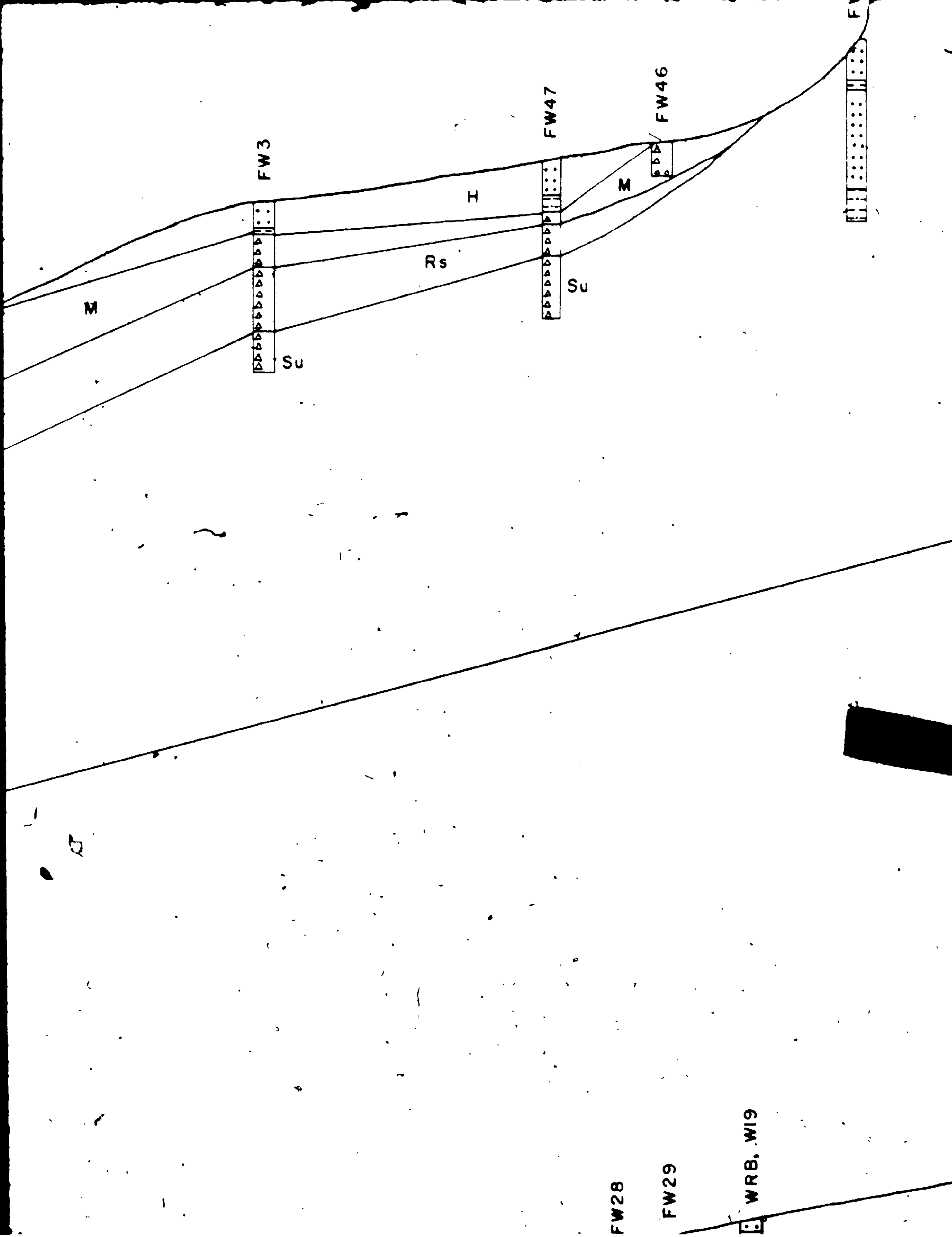
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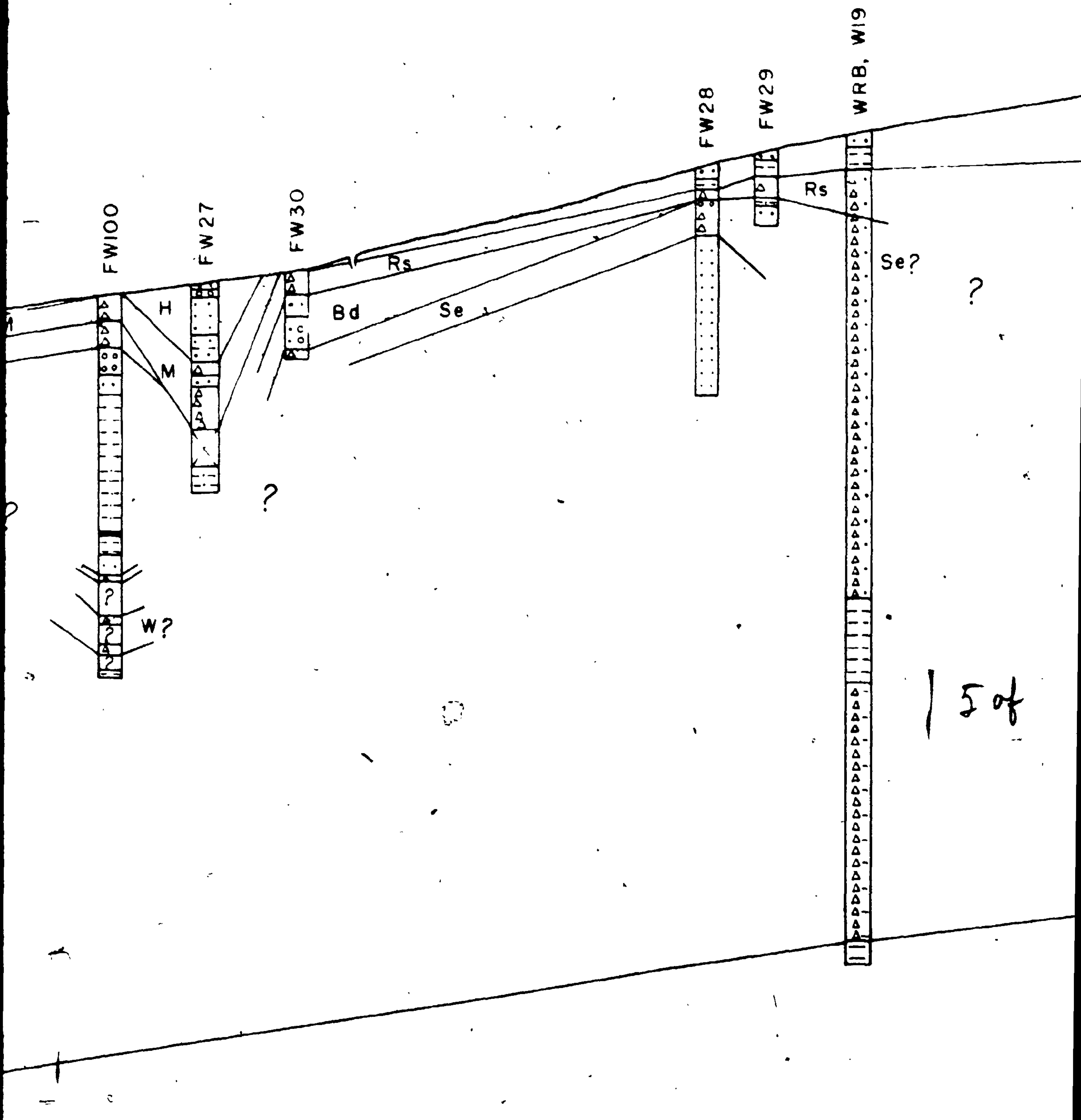
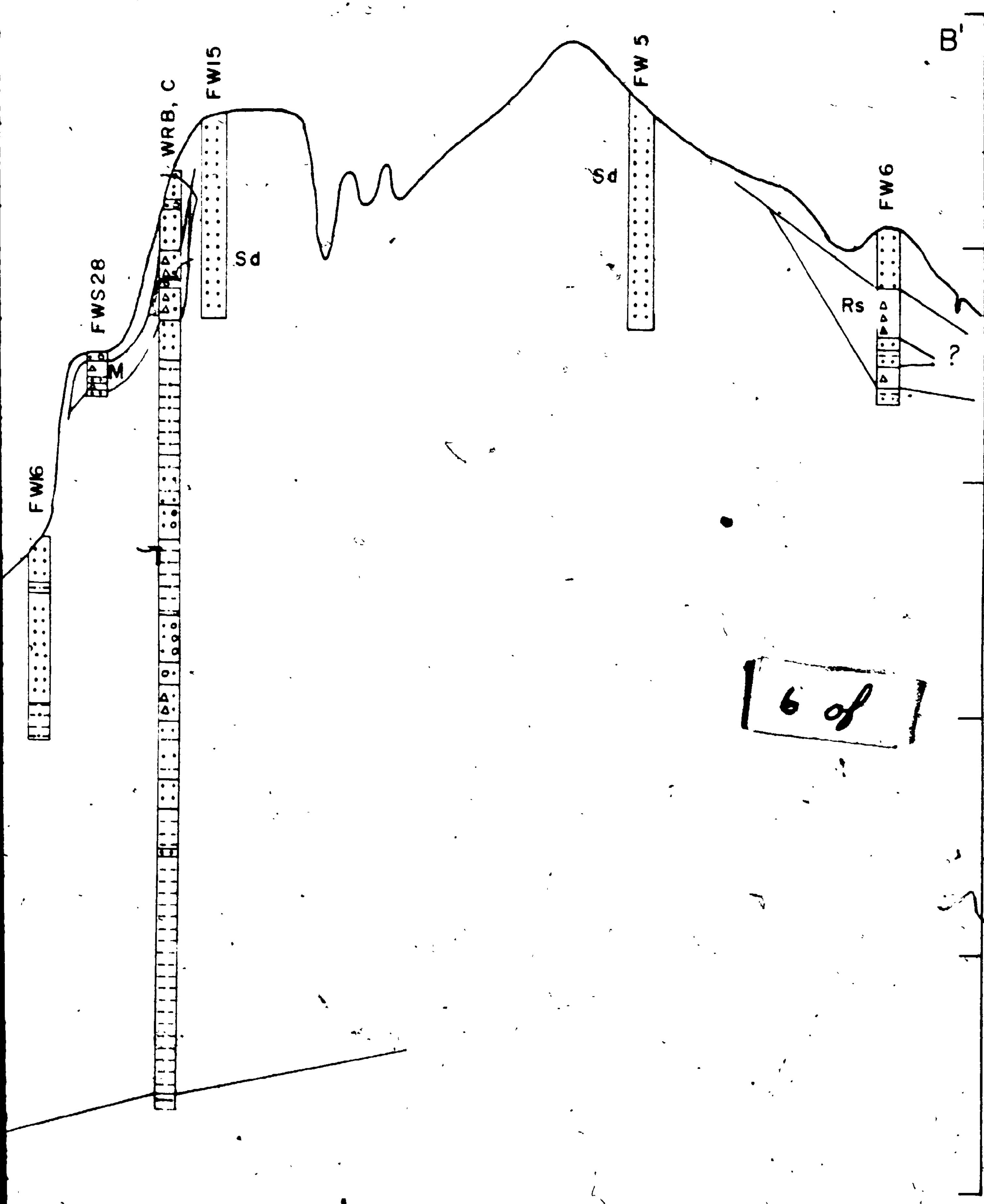
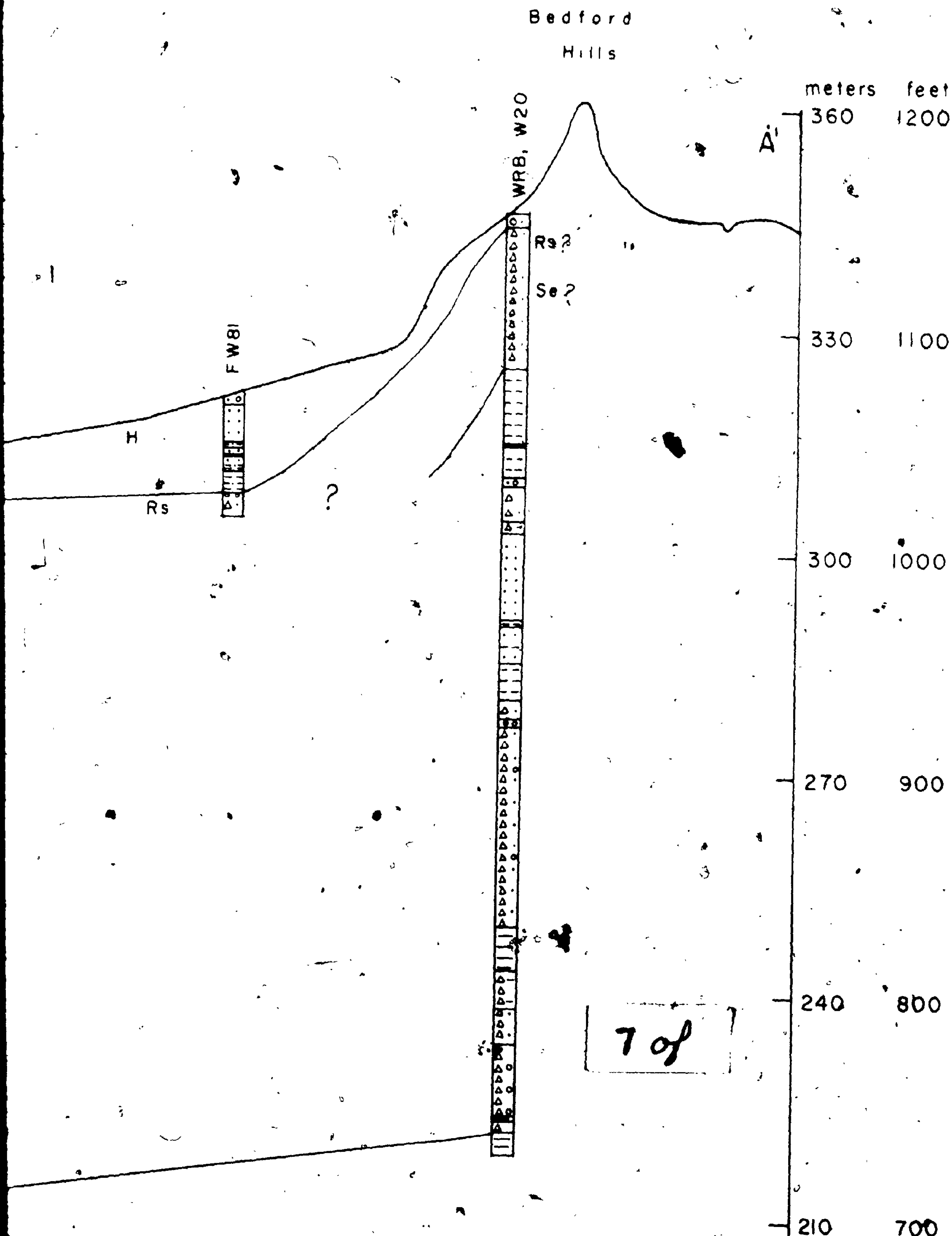


Figure 13 East west geological cross sectio

Bedford Hills




Bedford
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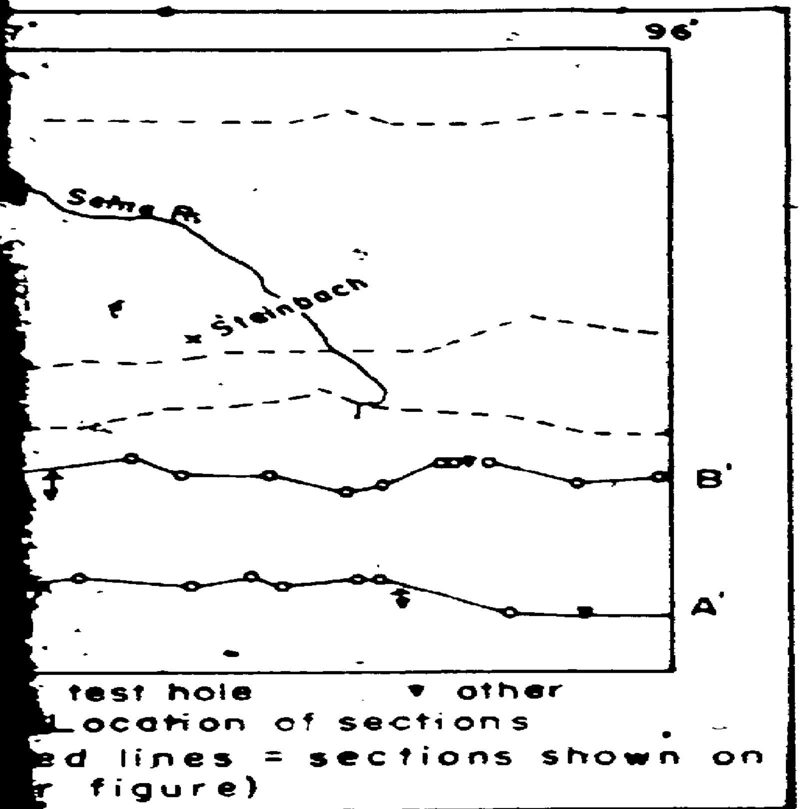
7 of



L E G E N D

Hazel Formation
- Hu upper member
- St Steinbach Member
- Hl lower member

Marchand Formation

Grunthal Formation (absent)

Roseau Formation

Bedford Formation
- Sd Sandilands San[d] Member

Senkiw Formation

Vitá Formation

Tolstoi Formation (absent)

Stuartburn Formation

St Malo Formation (absent)

Woodmore Formation

Till

Clay

Silt

8 of

W Woodmore Formation

Till

Clay

Silt

Sand

Clasts, pebbles to boulders

Shale

Carbonate bedrock

Gypsum

FW50 Test hole number 50 (auger)

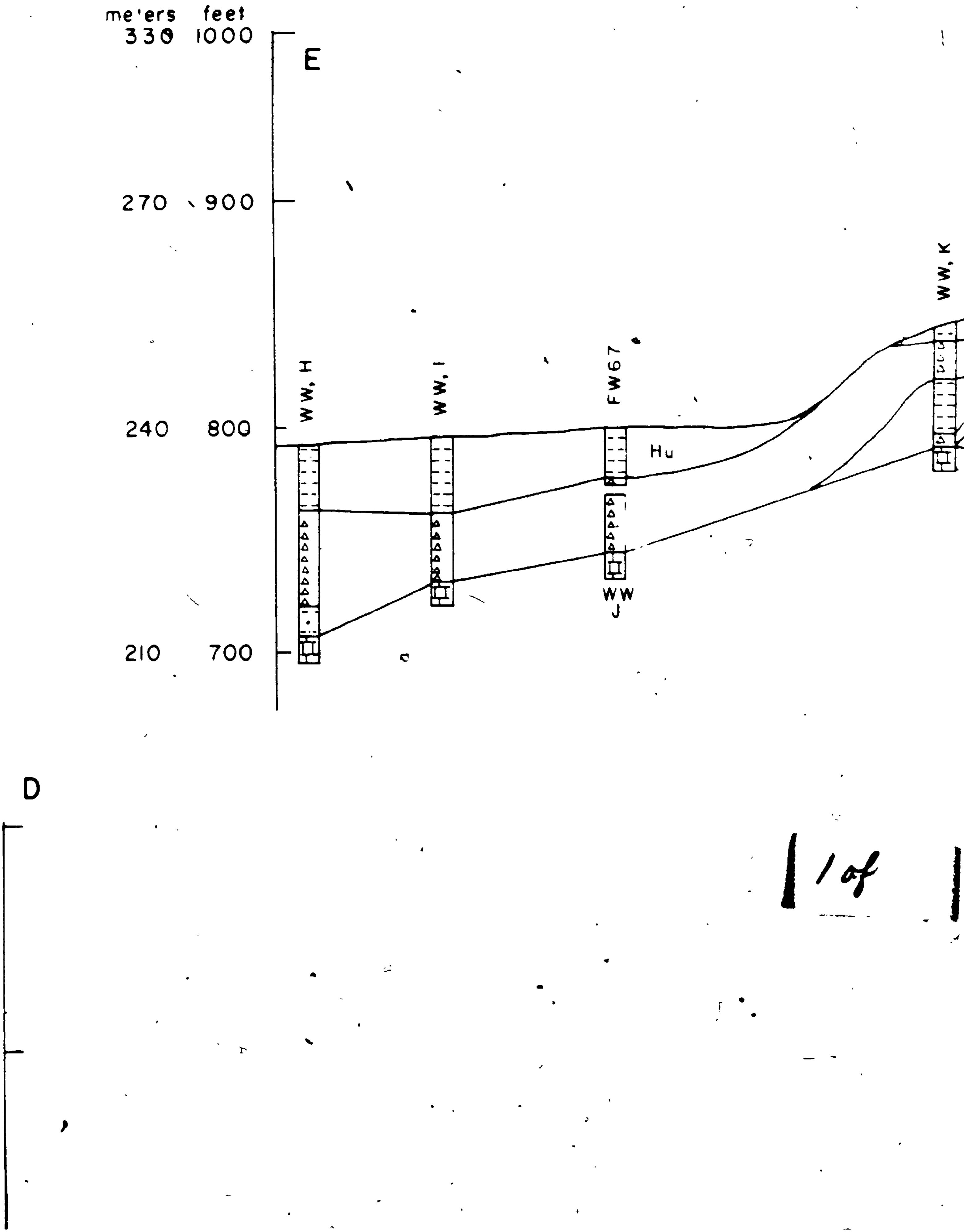
FWS28 Stratigraphic section number 28

WRB Manitoba Water Resources Branch test hole (rotary drill), W20 = hole number

WW Water well (rotary drill)

Letters A,B,C are for identification of well or hole.

Thin discontinuous deposits overlying tills nearest the surface not shown.



meters feet
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270 900
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210 700
WW, H
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Hu
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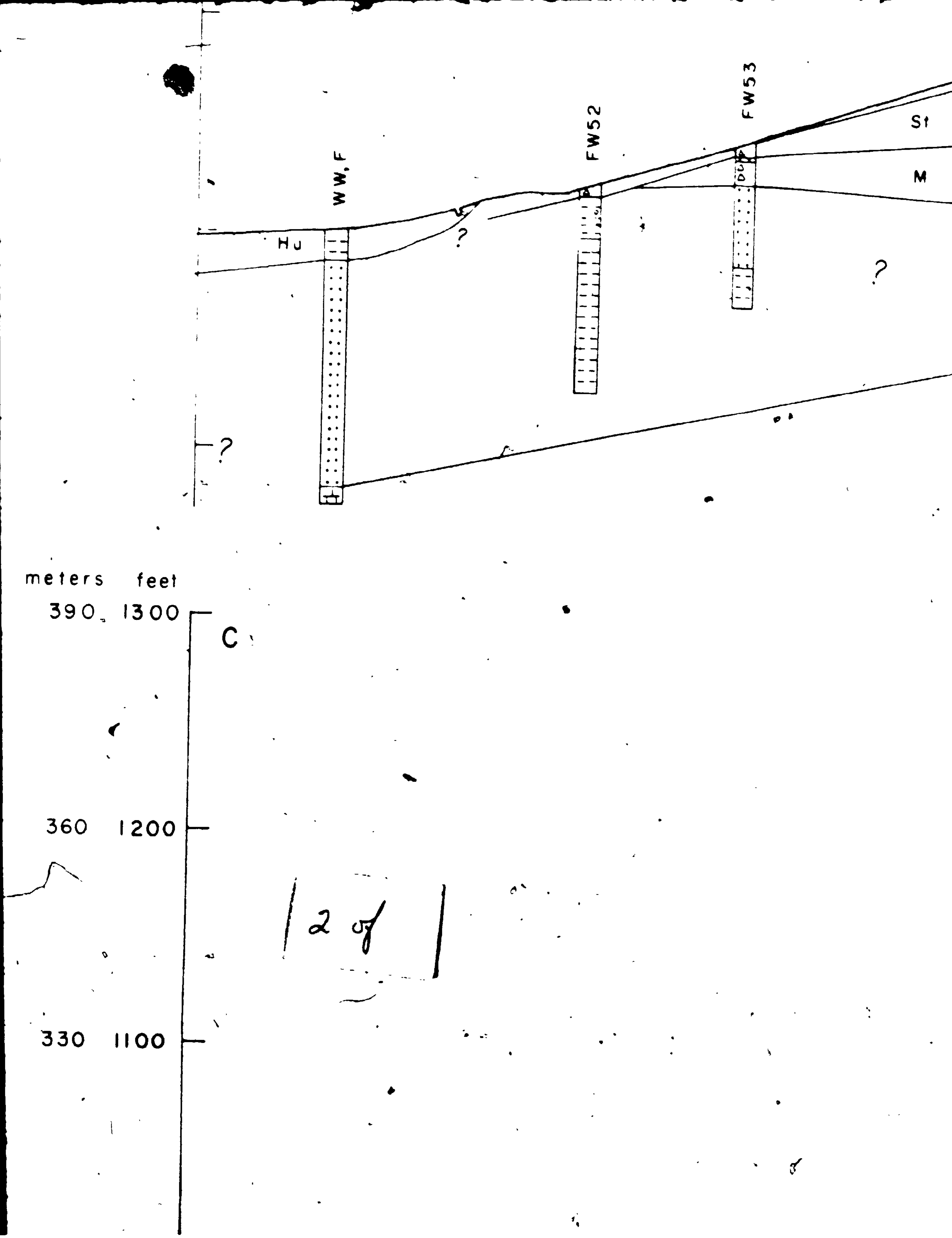
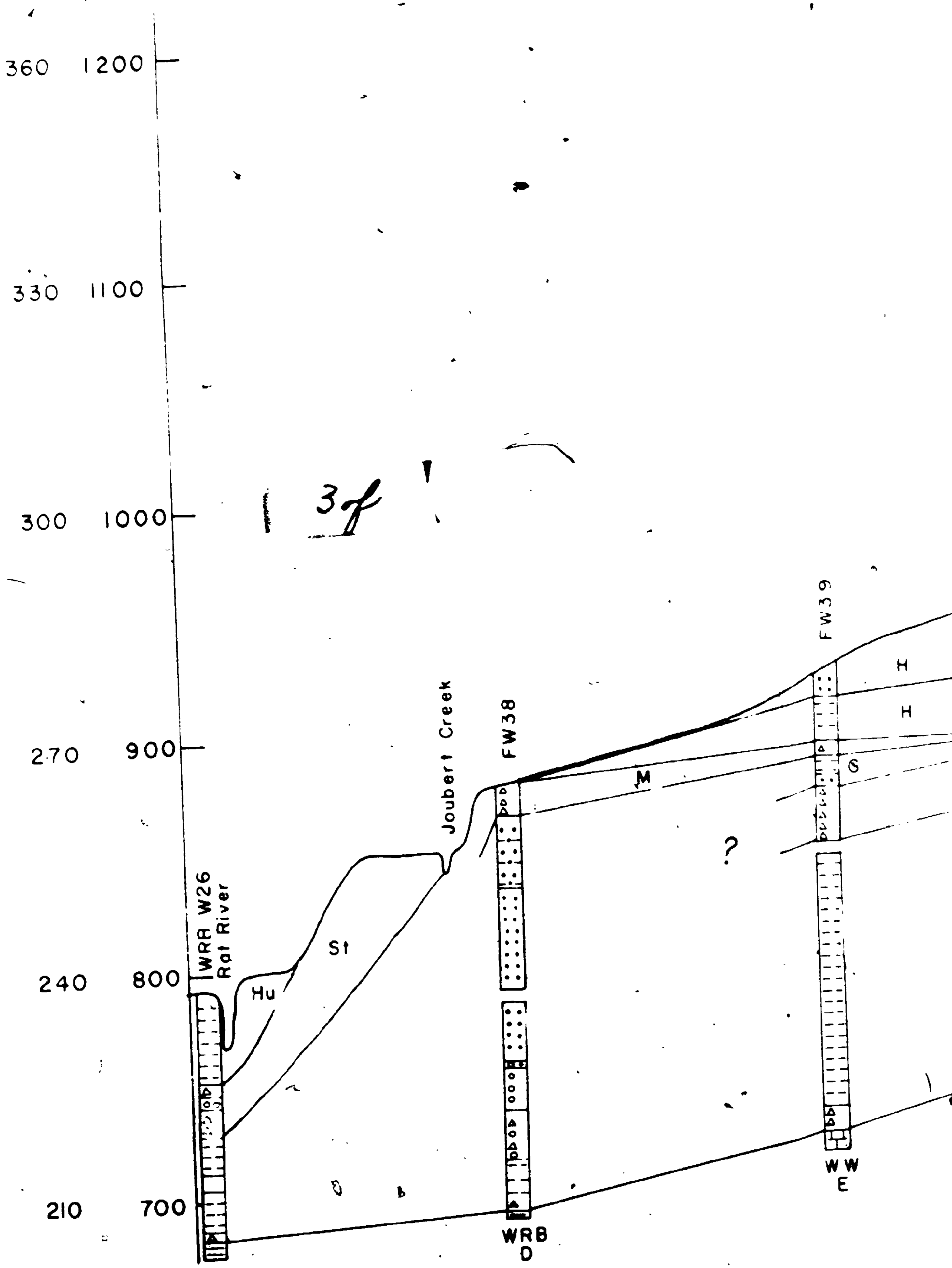
D

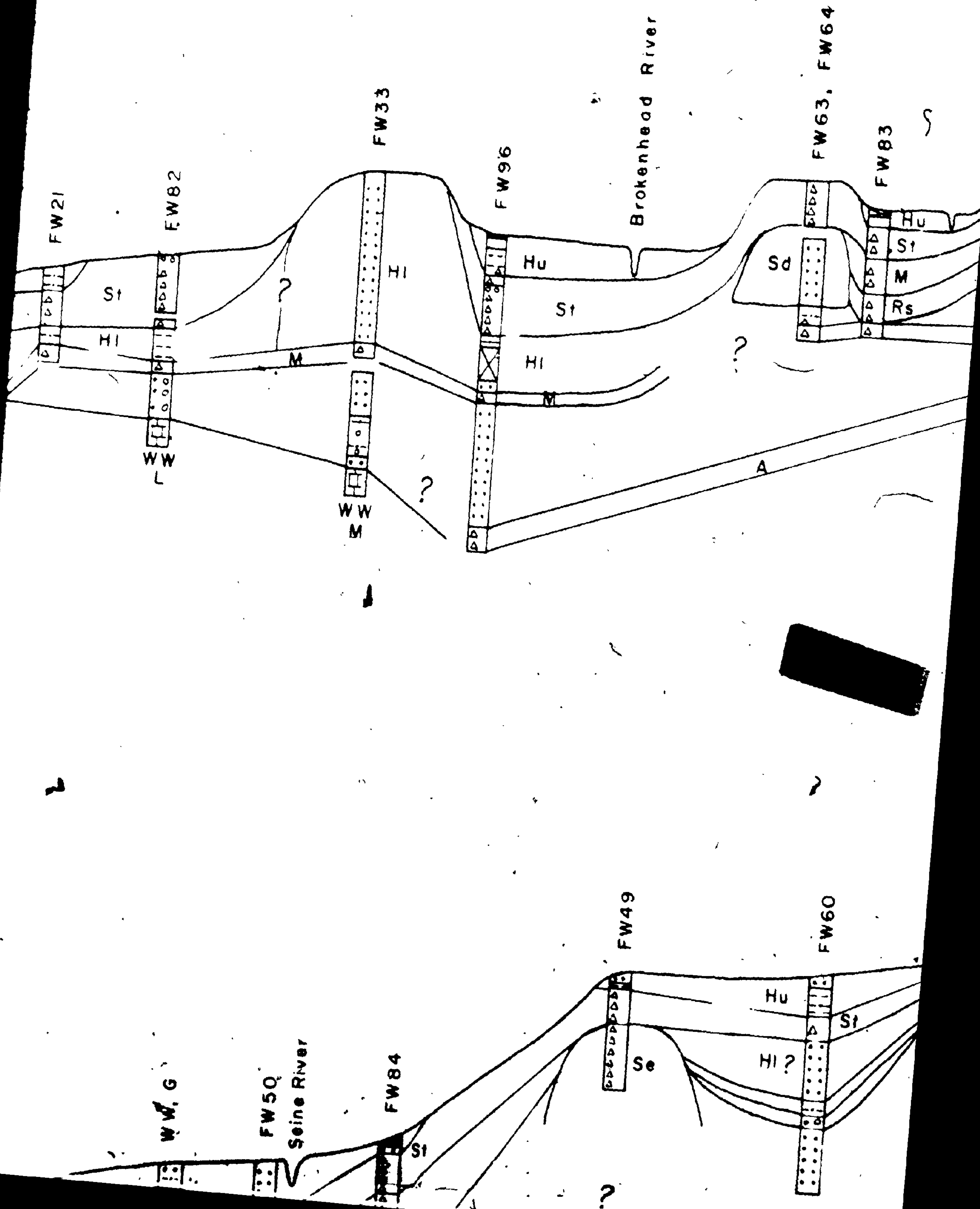
1 of 1

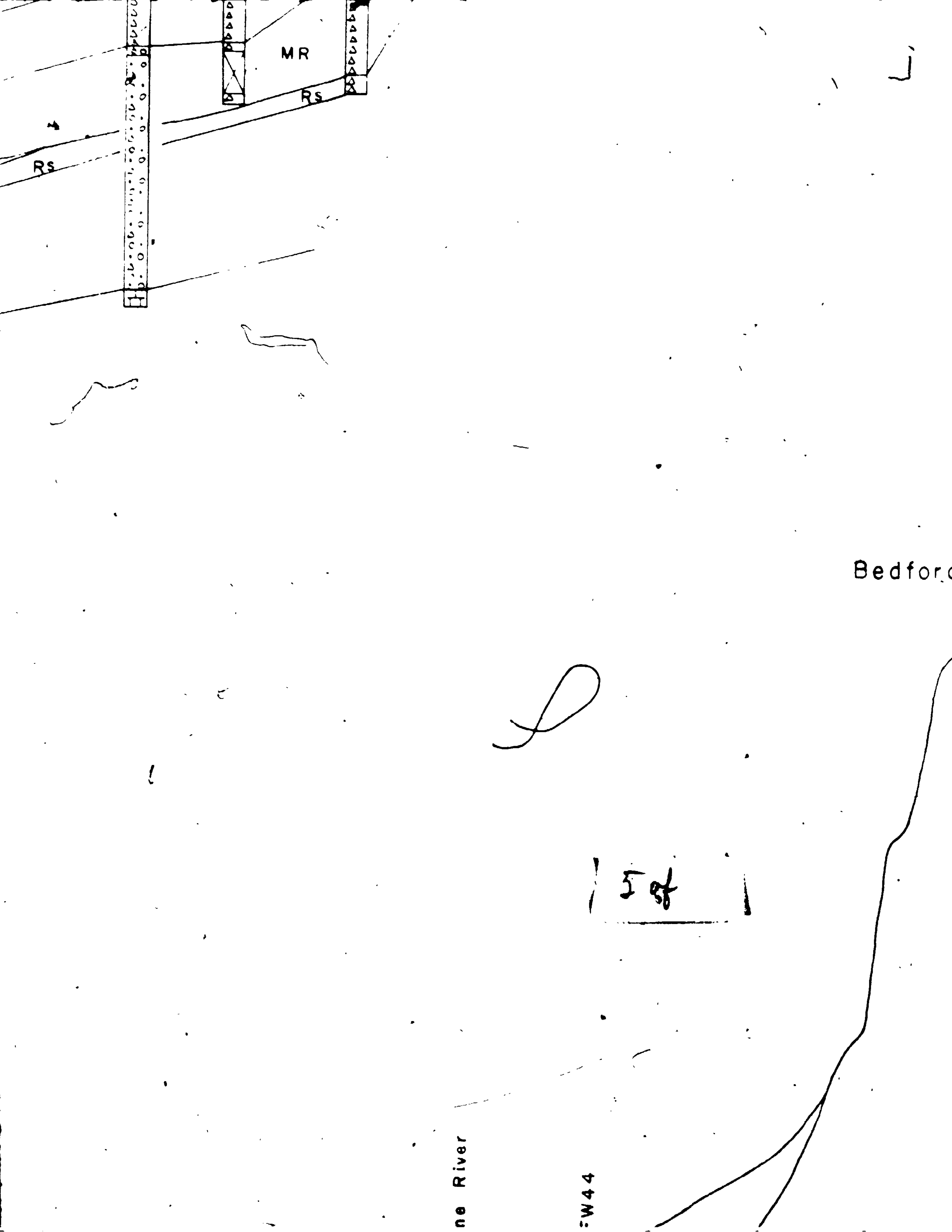

WW, F
FW52
FW53
St
M
Hu
?
meters feet
390 1300
360 1200
330 1100
C
2 of

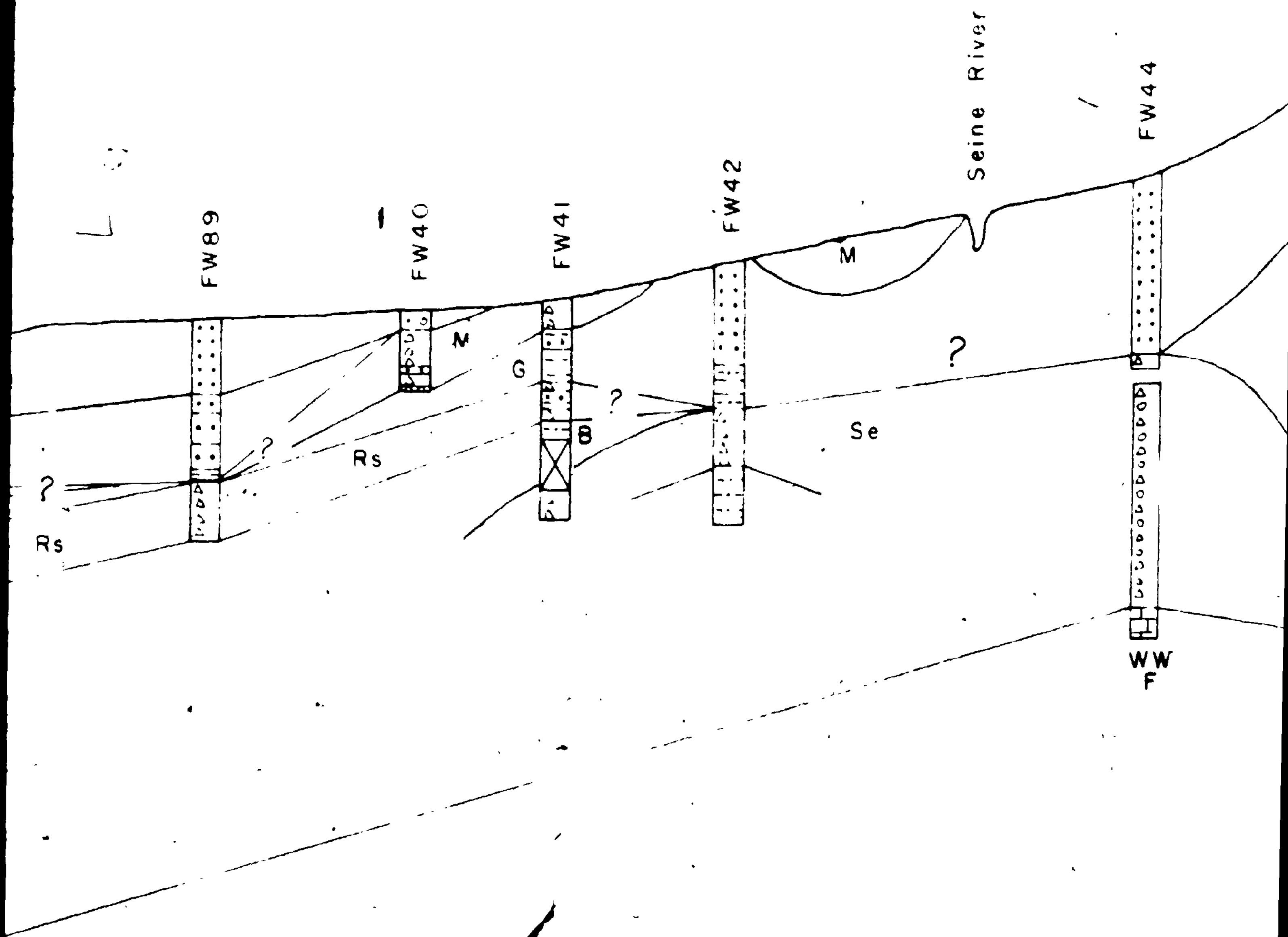


360
1200
330
1100
300
1000
270
900
240
800
210
700
3 of
WRR W26
Rat River
Hu
St
Joubert Creek
FW38
M
?
FW39
H
H
WRB
D
WW
E

Figure 14.

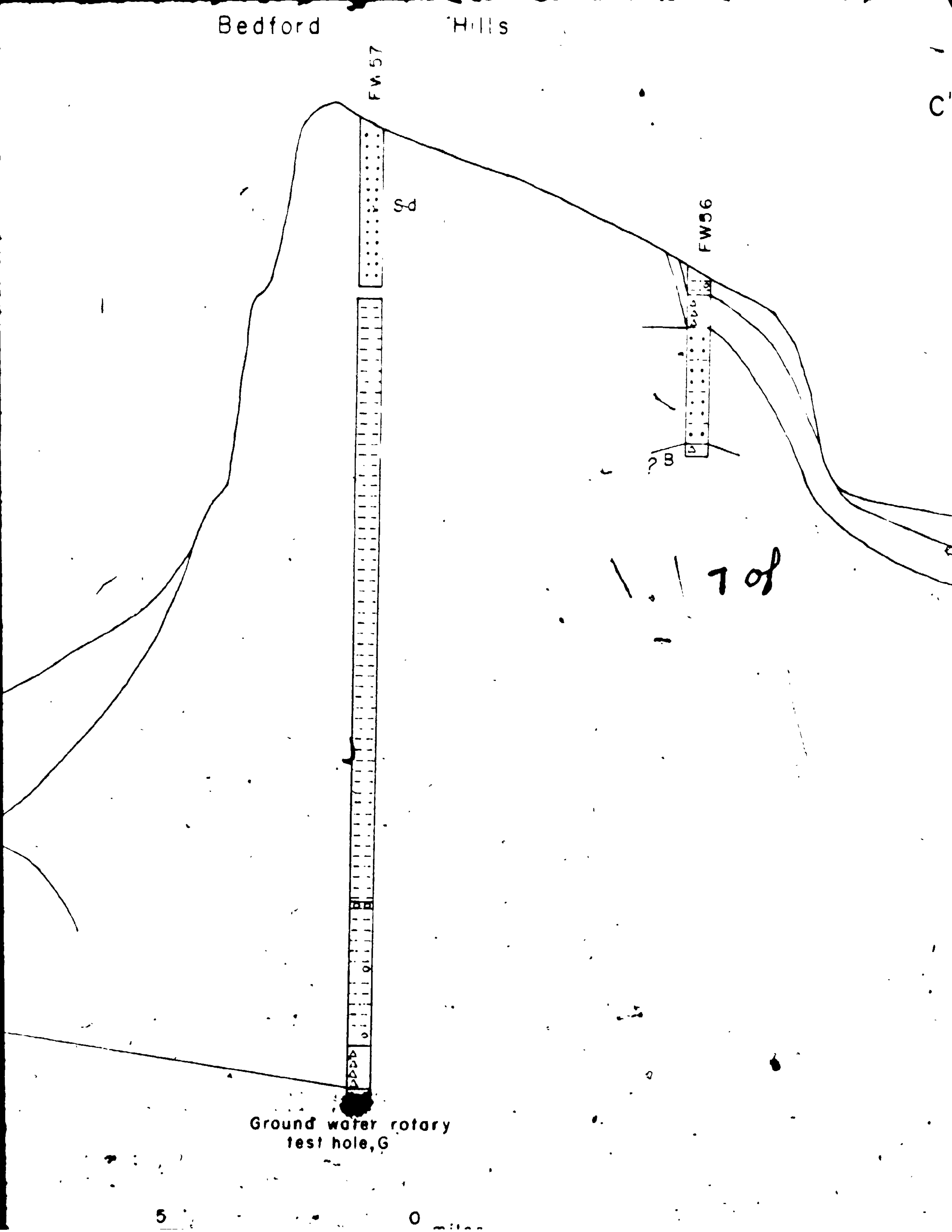

FW21
FW82
FW33
FW96
Brokenhead River
FW63, FW64
FW83
St
HI
M
HI
Hu
St
HI
M
Sd
St
M
Rs
Hu
A
WW L
WW M
?
WW, G
FW50
Seine River
FW84
St
FW49
Se
Hu
HI ?
St
FW60
?


MR
Rs
Rs
Bedfor
5 of
ne River
W44

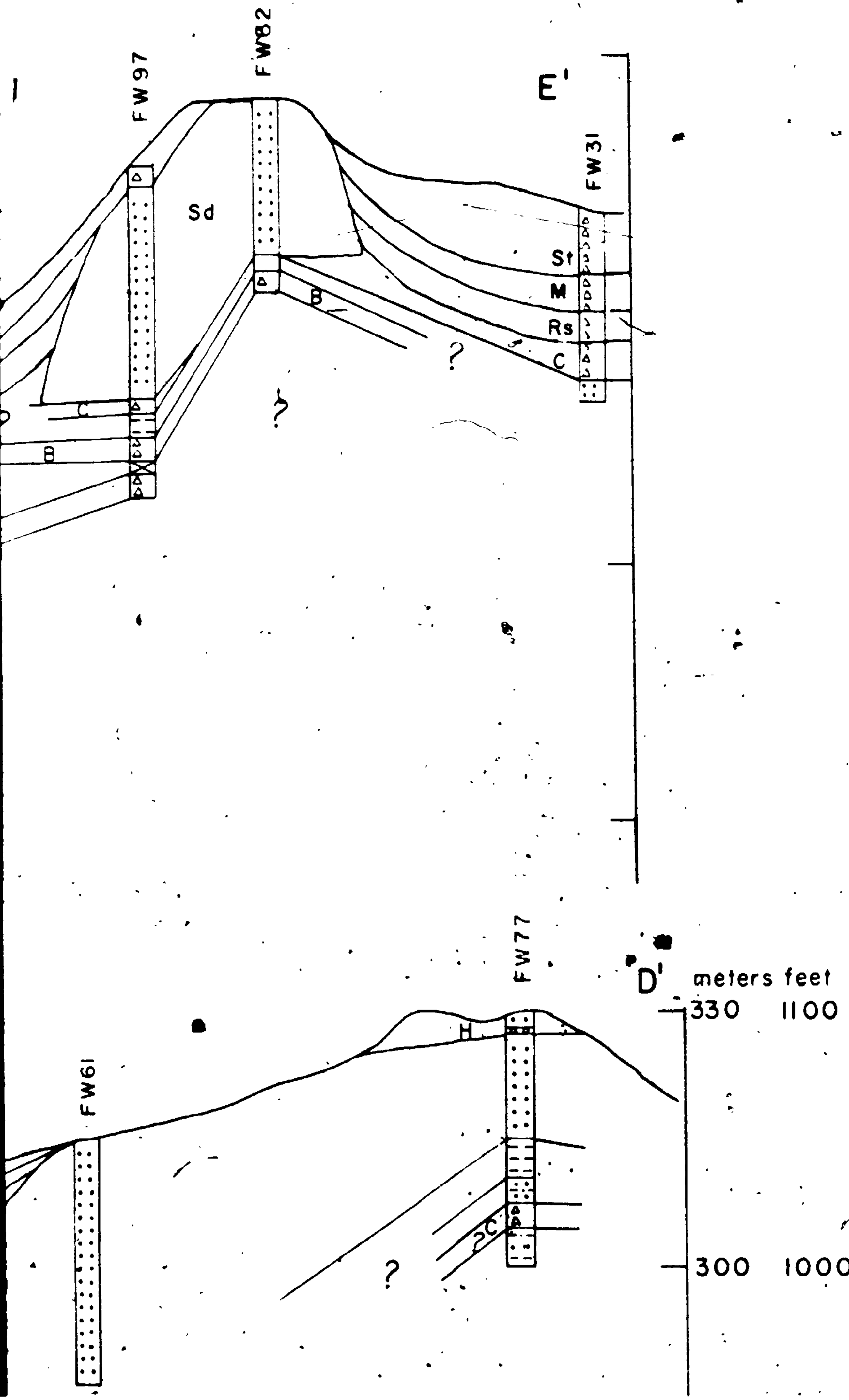


6 of

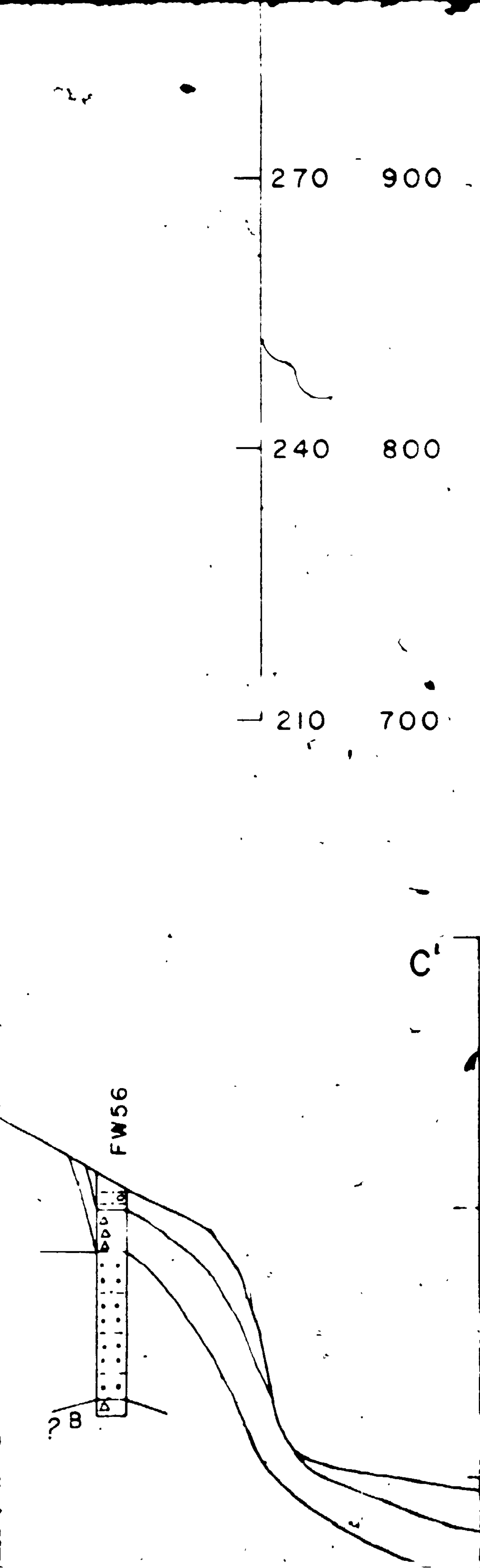
East west geological cross sections.

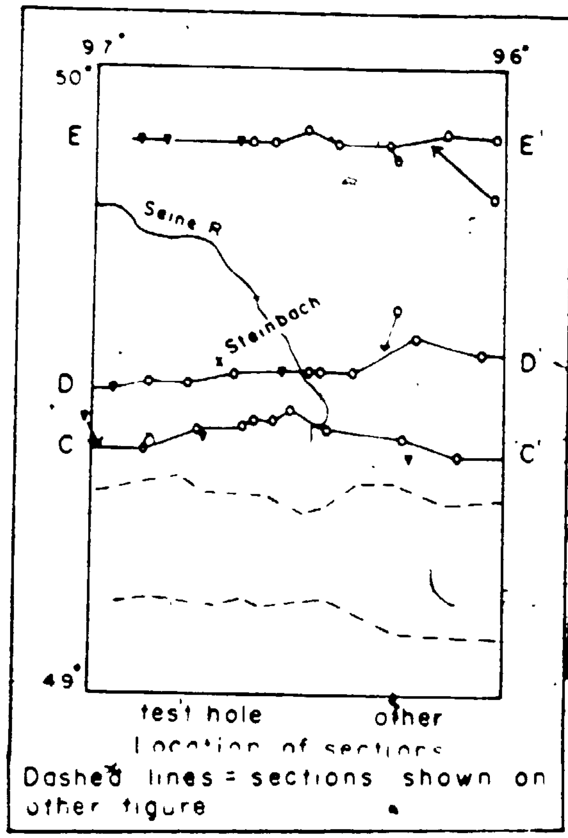


Bedford Hills
C'
FW57
S-d
FW56
?B
Ground water rotary
test hole, G
5
0


FW97
FW82
E'
FW31
Sd
St
M
Rs
C
B
?
FW77
D'
meters feet
330 1100
300 1000
FW61
H
?C

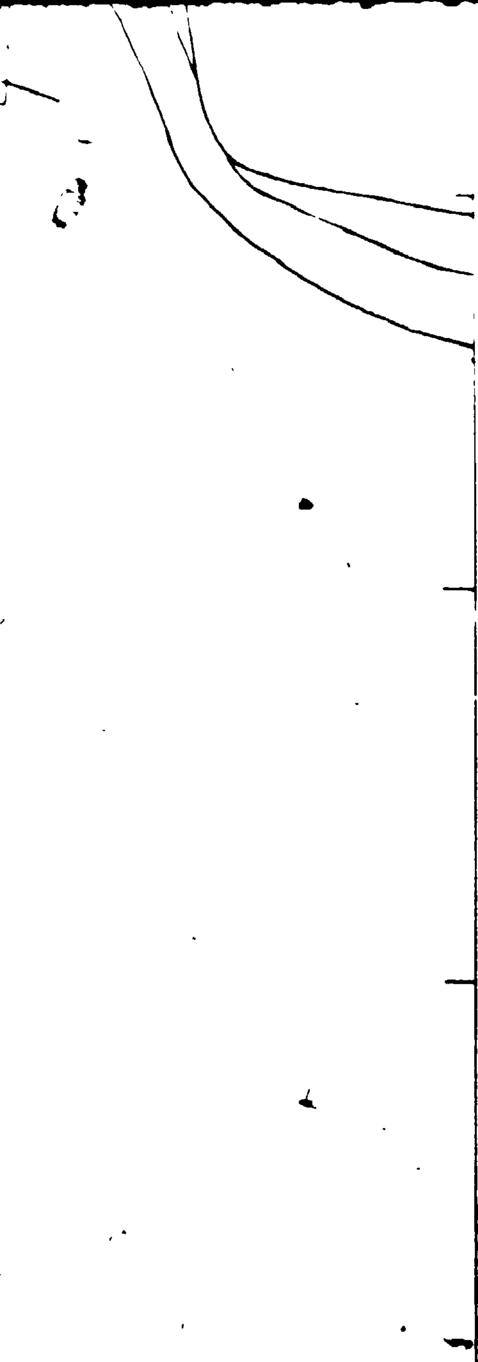
8 of





LEGEND

		Hu	upper member
H	Hazel Formation	St	Steinbach Mem
		Hl	lower member
M	Marchand Formation		
G	Grunthal Formation		
Rs	Roseau Formation		
Bd	Bedford Formation	Sd	Sandilands Memb
Se	Senkiw Formation		
C	Till C		
B	Till B		
A	Till C		



Se Senkiw Formation

C Till C

B Till B

A Till C

Till

Clay

Silt

Sand

Clasts, pebbles to boulders

Shale

Carbonate bedrock

Organic

FW50 Test hole number 50 (auger)

WRB Manitoba Water Resources Branch test hole (rotary drill), W26 = hole number

WW Water well (rotary drill)

Letters C to M are for identification of well or hole

Thin discontinuous stratified deposits overlying tills nearest the surface, not shown.

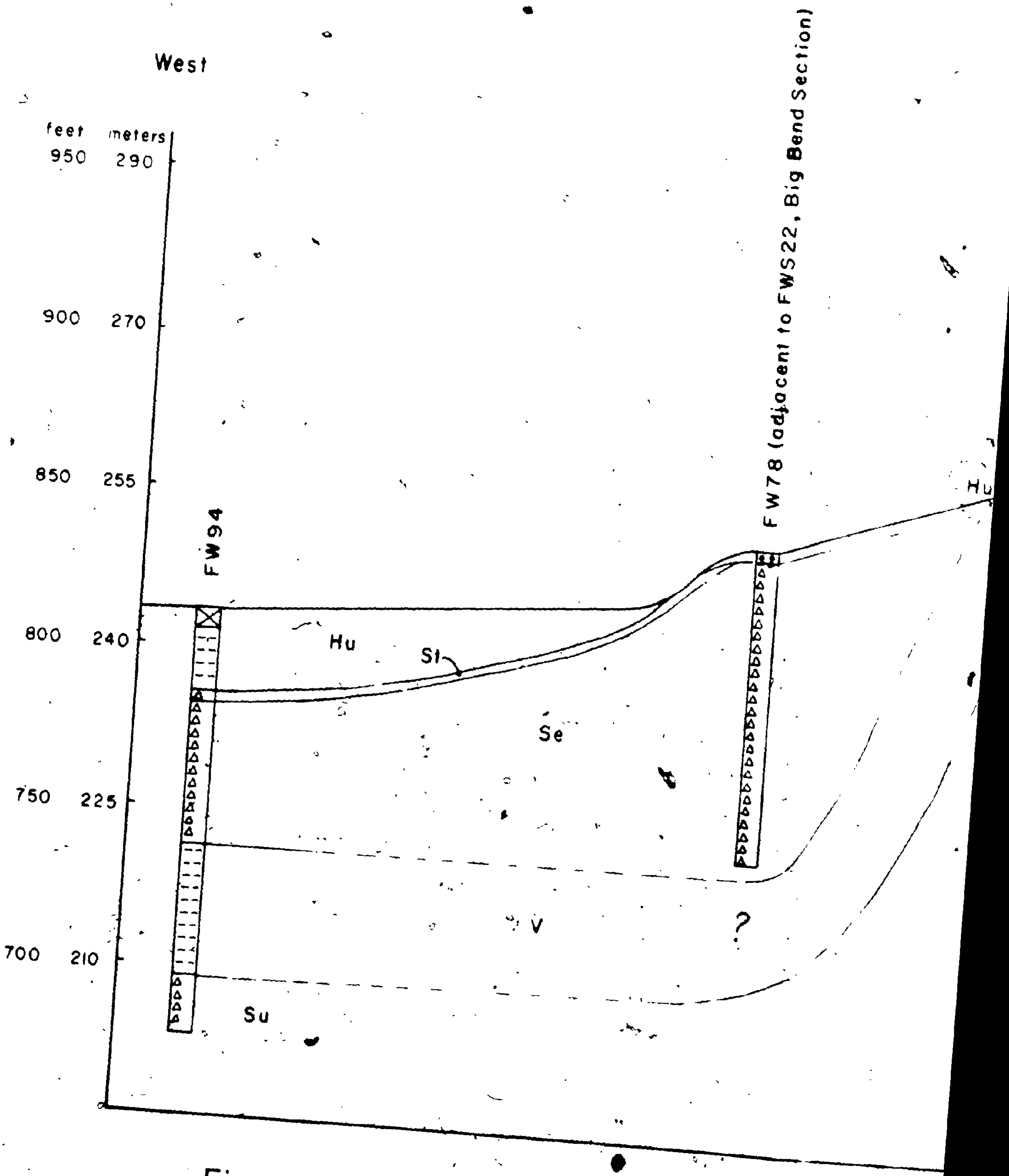
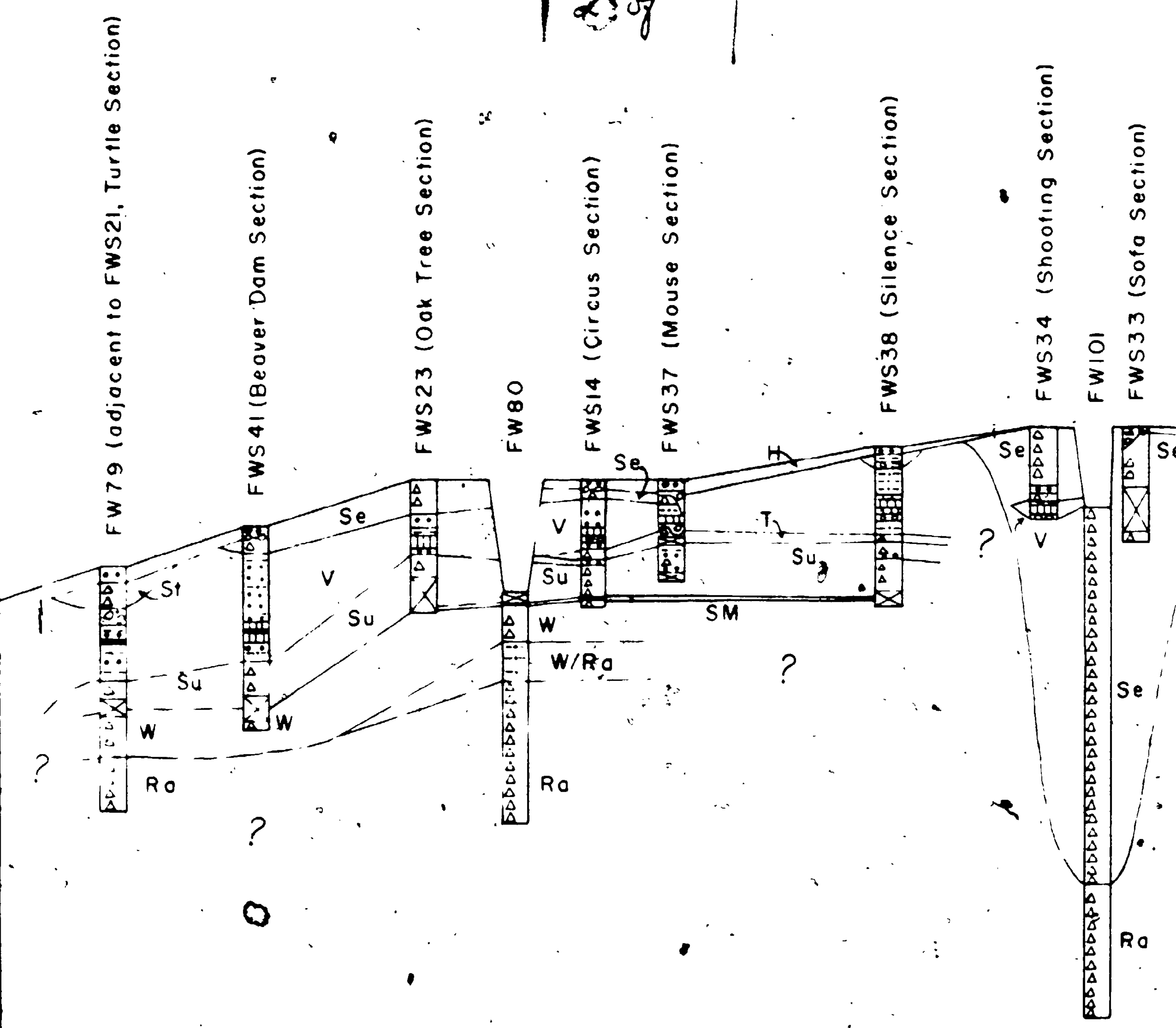


Figure 15. East-west geological cross secti



n near the western part of the Roseau River

3f

[illegible] (Sole Section)

[illegible] (Deer Section)

[illegible] (Fishing Section)

[illegible] (Skeleton Section)

H Hazel Formation

M Marchand Formation (absent)

G Grunthal Formation (absent)

Rs Roseau Formation

Bd Bedford Formation (absent)

Hu upper member

St Steinbach Member