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PAPER 75-19

LANDFORMS AND SURFACE MATERIALS AT SELECTED SITES IN A PART OF THE SHIELD - NORTH-CENTRAL MANITOBA

R.W. KLASSEN

with Appendix of testhole data and soil index properties

JEAN VEILLETTE

Energy, Mines and Resources Canada
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LANDFORMS AND SURFACE MATERIALS AT SELECTED SITES IN A PART OF THE SHIELD — NORTH-CENTRAL MANITOBA

Abstract

Selected sites along a 54-mile (87-km) stretch of roadway across a part of the Precambrian Shield are described and illustrated by stereopair airphotos and ground photos. The terrain described is typical of much of glaciated and glacial-lake inundated Precambrian Shield of north-central Manitoba. Surficial deposits are mostly varved clays that are some tens of feet thick in the flat and broadly rolling terrain of low-lying areas, and are thinly veneered or absent in the hilly terrain of higher areas. Bog and fen occur on most of the low-lying terrain. Permafrost commonly occurs a few feet below the surface of bogs and in places at a somewhat greater depth beneath the thickly wooded slopes of certain clay-mantled ridges. Road building and maintenance present certain problems unique to the discontinuous permafrost zone but they appear to be manageable. The construction and maintenance techniques used appear to provide adequate roads without unduly damaging sensitive terrain and financial resources.

Résumé

A l'aide de couples stéréoscopiques de photographies aériennes et de photos prises au sol, l'auteur décrit et illustre certains sites choisis le long d'une section de route longue de 54 milles (87 km) qui traverse une partie du Bouclier précambrien. Typique de la majeure partie du centre-nord du Manitoba, le relief décrit dans cette étude est un relief de socle précambrien qui a été recouvert à la fois par les glaciers et les lacs de barrage glaciaire. Les dépôts meubles, constitués principalement d'argiles à varves, ont une épaisseur de quelques dizaines de pieds dans les parties plates et ondulées des régions basses, et qui, dans les régions plus élevées de collines se trouvent en minces placages ou sont absents. Les tourbières et les "fen" occupent en majorité les dépressions. Le pergélisol se trouve généralement à quelques pieds sous les tourbières et à des profondeurs un peu plus grandes sous les versants très boisés de bourrelets à couverture argileuse. Certains problèmes propres à la zone de pergélisol intermittent se posent, en ce qui concerne la construction et l'entretien des routes, mais il semble bien qu'on puisse les résoudre, puisque les techniques mises en oeuvre pour la réalisation de ces travaux donnent des résultats satisfaisants, sans porter atteinte outre mesure aux terrains sensibles, ni aux ressources financières.

INTRODUCTION

Activities related to resource development in northern Canada have created a need for information about the terrain and surficial deposits of this vast region. A reconnaissance mapping project covering some 60 000 square miles in north-central Manitoba was begun by the author in 1971. Map-units were determined using airphotos at a scale of 1: 60 000 and were compiled on photomosaics at a scale of 1: 125 000 (Klassen and Netterville, 1973, 1974). Maps on a scale of 1: 250 000 are in preparation for publication. Field observations were made by a 3-man, helicopter-supported mapping party that was directed primarily towards determining (1) the general lithology and local morphology of map-units, (2) the nature and thickness of organic deposits, (3) the distribution of permafrost, and (4) the Quaternary stratigraphy of this region.

This report consists primarily of descriptions and stereopair airphoto and ground photo illustrations of selected sites that are intended to provide more detailed information on the map-units and landforms within an area typical of much of the Shield region inundated by glacial Lake Agassiz. Sites were selected primarily on the basis of their accessibility and the degree of exposure provided by fresh road-cuts. They are along the eastern segment of a new highway between Thompson and Lynn Lake, Manitoba and within an area of approximately 1000 square miles (Fig. 1) between latitudes 55°45' and 56°00', and longitudes 97°30' and 99°00' in the northeast part of the Nelson House (63 O) and the northwest part of the Sipiwisk (63 P) map-areas.

A description of the location, map-unit and landform, material, vegetation, drainage, permafrost, and terrain performance is given for each site.

Regional Setting

Physiography

The Shield in north-central Manitoba is a gently irregular, lake-dotted land surface with generally less than 50 feet (15 m) local relief. Along the western part it is gradational into higher relief bedrock hills and intervening valleys with 100 to 200 feet (61 m) of local relief. It is part of the Kazan Upland, a division of the Kazan Region part of the Canadian Shield (Bostock, 1970). The topography almost everywhere reflects the Precambrian bedrock surface that was smoothed and polished by glaciation and somewhat modified by deposition of drift. The structural elements of the bedrock are strikingly well preserved in

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hilly areas and there is a dearth of glacial fabric in this landscape. Ambrose (1964, p. 817) suggested these surfaces have undergone little change since early Paleozoic time. Certain low relief areas are dotted by streamlined, glacially built landforms, although the drift is generally thin and the landforms commonly are cored by bedrock knolls or ridges. Scattered complexes of kame hills and esker ridges, in places more than 200 feet (61 m) above the adjacent plains, are prominent glacial landforms in this region.

Climate

Cool and short summers of the subarctic climatic zone prevail in this region (Atlas of Canada, 1957). The mean annual air temperature is well below freezing, for the region lies between the 25- and 30-degree isotherms that approximately mark the southern fringe of the discontinuous permafrost zone (Brown, 1967). Annual precipitation is from 16 to 18 inches (40 to 46 cm) and about half of this falls as rain during the warmest months (June to August) and the least (about 2 inches or 5 cm) falls as snow during the coldest months (December to February).

Vegetation

The study area is within a part of the Boreal Forest region where closed stands of black spruce and ground mosses cover much of the better drained terrain. Peatlands, covered in part by open to semi-closed stands of mainly black spruce and tamarack, occur in low-lying, poorly drained areas. The area is in the transition zone from the Nelson River section of the Boreal Forest to the Northern Coniferous section that is commonly associated with jack pine and tamarack but where black spruce is also predominant (Rowe, 1972, p. 42-43). Good mixed stands of white spruce, balsam poplar, white birch, trembling aspen, and balsam fir also occur on certain well drained sites. Variation in the type and density of tree cover on the well drained sites generally reflects differences in the parent soil materials and the age of the tree cover. The low-lying, poorly drained areas contain two basic peatland types, distinguished by differences in vegetation and drainage: bog, which lies somewhat above the water table with very little standing water, and fen, which lies somewhat below the water table and is covered mostly by standing water.

Description of the Study Area

Nature of the Terrain and Surficial Deposits

The eastern part of the study area consists of broadly rolling clay-mantled bedrock ridges and knolls, separated by or lying within nearly flat to gently irregular basins (Fig. 1). Local relief seldom exceeds 75 feet (23 m) and is generally between 10 and 25 feet (3 to 7.6 m). The bedrock is mainly gneissic granite (Harrison, 1950; Quinn, 1953). Bedrock hills become more common in the central part of the area and form a hilly, irregular terrain with more than 100 feet (30 m) local relief in the western part where the bedrock is mostly sedimentary gneiss and schist, and mixed gneisses (Quinn, 1953).

Most of this area is mantled by varved clay that was deposited in glacial Lake Agassiz during final recession of the continental ice sheet. Thicknesses range from scattered patches a few feet thick in shallow depressions on bald bedrock hills to tens of feet thick in basins and valleys between hills or in low-lying areas and on broadly rolling bedrock hills. The clay commonly overlies glacially polished and grooved bedrock surfaces on the stoss (up-ice) slope of bedrock hills and patches of very hard or loose bouldery till on the steeper flanks and lee slopes. The nature and distribution of the surficial deposits underlying the clay in valley bottoms and low-lying areas in general are poorly documented as exposures and borehole data are rare. Widely scattered exposures, mainly outside this area, suggest a general succession that includes a lower compact sand and gravel, bouldery till and varved clay. The distribution of the subsurface deposits is no doubt patchy and one or all of them may be absent in a particular locality. Drift thicknesses in the low-lying areas most likely are greatest in the bedrock depressions and valleys that lie transverse to the general north-south and northeast-southwest direction of glacial movement. Maximum thicknesses, probably of the same order of magnitude as the maximum local relief, may occur locally but in general the drift thickness in the low areas is probably less than 50 feet (15 m) and ranges from 20 to 40 feet (6 to 12 m).

Two chains of hills and ridges trending north-south are the most prominent landforms in this area. They are 100 to 200 feet (30 to 61 m) above the adjacent clay basins and are composed of sand and some gravel, deposited mostly as kames and eskers along and near the glacier margin. The surfaces of these features were reworked by Lake Agassiz as indicated by abandoned beaches near the crests of the hills; this suggests other associated minor landforms are of lacustrine origin, but on the whole, the form and surface configuration of these features indicate they formed in contact with glacier ice.

Vegetation

The low-relief, rolling terrain in the eastern part is covered by closed stands of mainly black spruce and some poplar and jack pine on well drained sites. Bog and fen occur on the poorly drained lower parts over the entire area but are most extensive in the eastern part. Open stands of black spruce are common on the bogs. The higher parts of the bedrock hills and isolated kames and eskers have closed to open stands of mainly jack pine but clusters of other tree types common to the region also are present particularly where patches of clay veneer occur. Where clay covers the well drained flanks of the bedrock hills, closed stands of tall poplar, birch, and conifers are common.

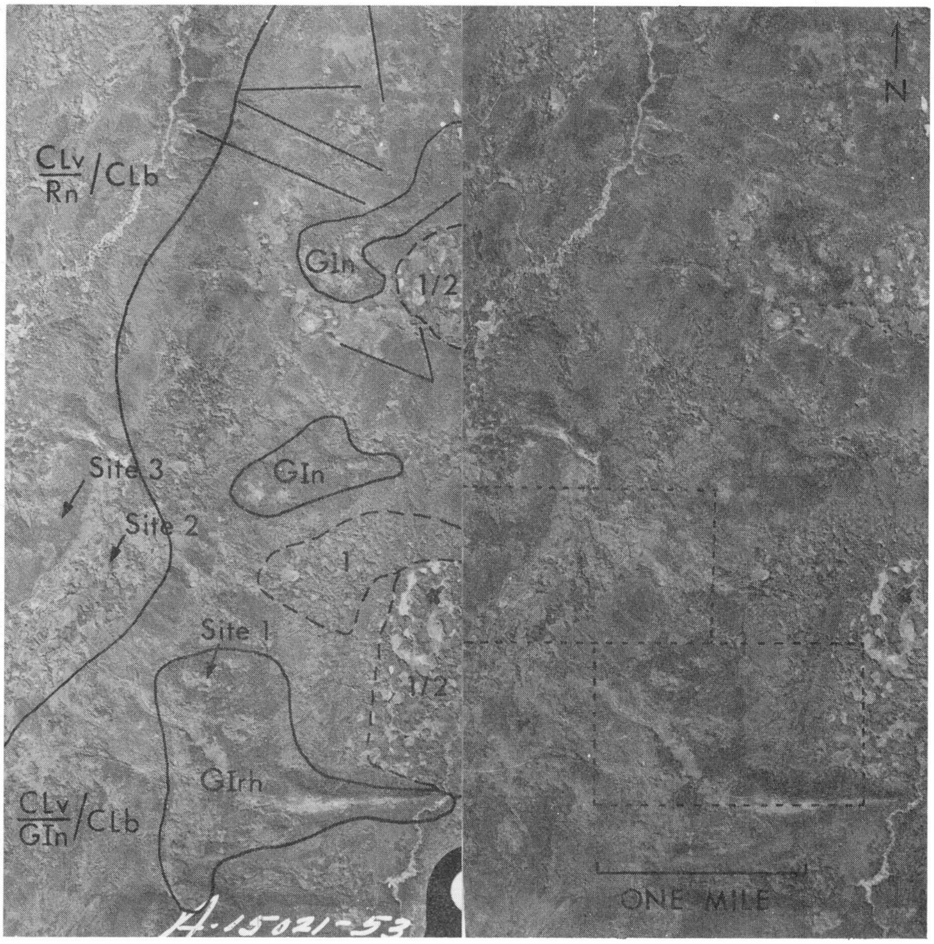

Figure 2.

Stereopair airphotos (A15021-53, 54) showing the locations of Sites 1, 2, and 3. Map-units (*see* Fig. 1) include ice-contact deposits, clay-veneered bedrock knolls, and clay basins. The rectangles outlined by dotted lines show the area covered by Figures 3 (lower) and 9 (upper). Straight lines are lineaments.

Permafrost

Permanently frozen ground occurs beneath the surface of bogs and the low-lying terrain covered by closed stands of trees and is absent mainly in the fen areas and beneath the well drained surfaces of sand, gravel, till and bedrock ridges, knolls and hills. It may occur beneath the well drained surfaces of rolling, clay-mantled hills; its presence appears to depend on the density of the tree cover, the thickness of the forest peat mat, and the slope direction. The active layer is generally less than 2 feet (.6 m) thick although in places, as on an irregular bog surface where small pools of water collect, it may extend to 4 feet (1.2 m); conversely, the higher parts shaded by clusters of trees may have permafrost beneath 6 inches (15 cm) of dry moss or peat. The total depth of permafrost varies considerably, but maximum depth is of the order of 50 feet (15 m) (Brown, 1967). The removal of the tree and peat cover results in thawing and local disappearance of permafrost in several years.

Ground ice is widespread below the bogs that typically consist of 2 to 5 feet (.6 to 1.5 m) of frozen peat separated from the underlying mineral sediments by ice lenses several feet thick. Ground ice also occurs in the underlying mineral sediments but it is most abundant in the transition from clay, devoid of organic detritus, to peat. Segregated ice crystals also can be seen throughout the peat as the moisture content is very high (*see* Appendix and Zoltai and Tarnocai, 1971, p. 124). The thickest lenses of ground ice occur beneath local hummocks (palsen), 4 to 6 feet (1.2 to 1.8 m) high, near the margins of bogs or within shallow fen. These features are the surface expression of ice lenses. The frozen clay beneath the well drained sites on clay-mantled bedrock hills contains very little segregated ground ice. Permafrost, though present, is not as apparent from casual inspection of cores as it is beneath organic terrain, and it appears to occur in areally discontinuous and relatively thin zones.

Site Descriptions

Introduction

The twelve sites described are along a 54-mile (87-km) segment of the Thompson-Lynn Lake highway between Thompson and a locality about 8 miles (13 km) beyond the Nelson House turnoff (Fig. 1). For each site, the location is given by quarter section, township, range, as well as by the approximate latitude and longitude. Descriptions of the general nature of the areal map-unit and the landform on which the site is located are given, along with a general discussion of the nature

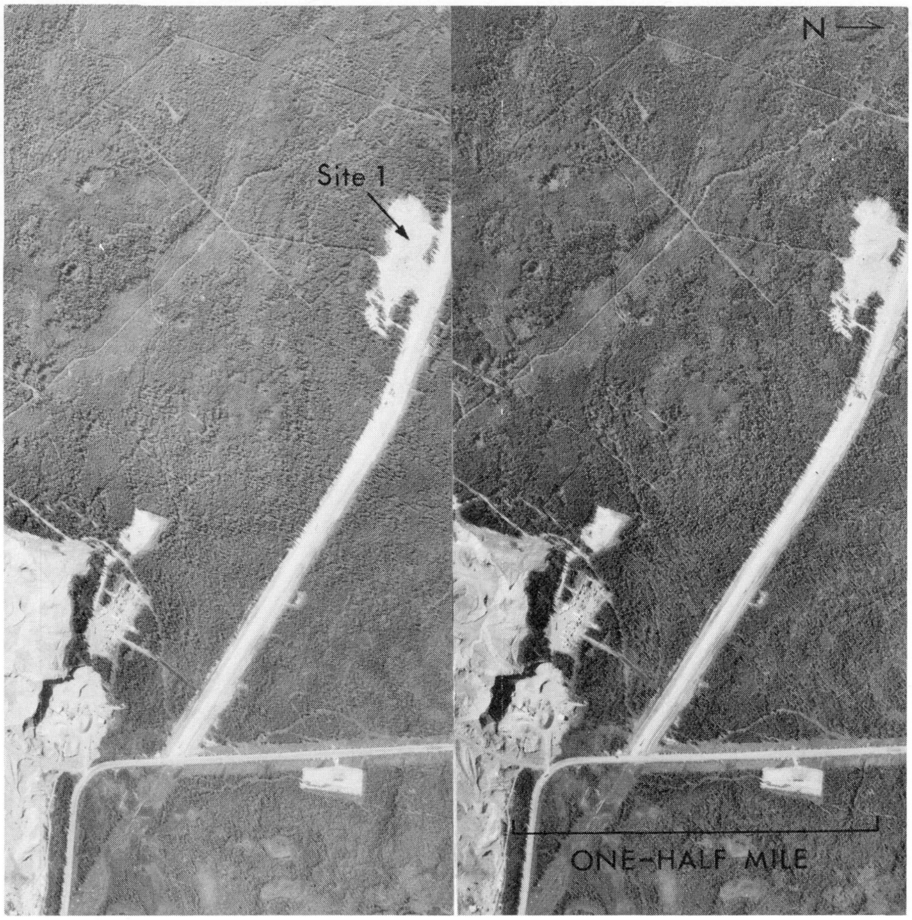

Figure 3.

Stereopair airphotos (A21910-226, 227) of the area outlined in Figure 2 showing the location of Site 1 on the side of a kame. The large gravel pit (lower left) is within the main body of the kame. The light grey tones on the higher surfaces indicate mainly poplar trees and the slightly darker grey tones on the slopes indicate mainly spruce trees.

Figure 4. Oblique aerial view of Sites 1 and 2, looking north, across the west end of the Thompson airport clearing. (GSC 163394)

Figure 5. Bouldery gravel and sand exposed in the gravel pit at Site 1. Note shovel for scale. (GSC 163330)

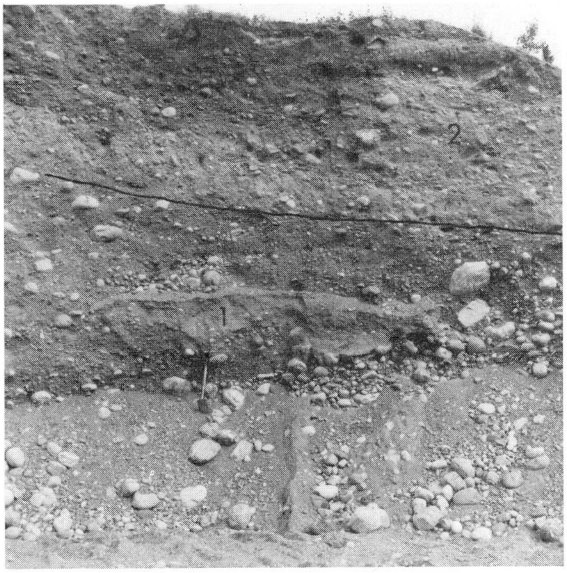

Figure 6. Bouldery gravel and sand (1) overlain by sandy ablation till (2) exposed in the gravel pit at Site 1. The bank is about 20 feet (6 m) high; note the shovel for scale. (GSC 163329)

Figure 7. Roadbed at Site 1 marks the approximate upper limit of clay overlying kame deposits. Opposite ditch is in a lacustrine clay veneer covered by mature black spruce. (GSC 163332)

of the material, vegetation, drainage, and occurrence of permafrost. Subsurface information was obtained by testhole drilling (*see* Appendix) and hand augering to depths of 10 feet. Terrain performance is discussed in terms of the stability of the materials to date as reflected by the apparent changes in the roadbed and ditches, due to vehicle traffic, mass movement, water erosion,

Figure 8. Cluster of poplar trees on left is remnant of former closed tree cover on the kame surface at Site 1. (GSC 163331)

and thawing of permafrost subsequent to construction. Stereopairs of airphotos at two scales (about 1: 60 000 and 1: 16 000), showing the site localities and the adjacent terrain, are included as figures, as are oblique airphotos taken from about 400 feet (122 m) altitude. Selected ground views also are shown in photo figures. For a detailed explanation of the map-unit symbols on the figures, the reader is referred to Figure 1.

Site 1

Location. The site is about $3\frac{1}{4}$ miles (5 km) north of Thompson in the NW $\frac{1}{4}$ sec. 29, tp. 78, rge. 3 (lat. 55° 47', long. 97°53'). *

Map-unit and Landform. Site 1 is on the side of a kame consisting of a distinctive ridge, nearly a mile long and about 150 feet (46 m) high, that widens abruptly into a bulbous lobe (Fig. 2). Much of the kame has been used as a source of gravel (Fig. 3). Site 1 includes one of the smaller pits on the outer margin of the kame (Fig. 4).

Nature of the Material. The bulk of the material in the kame is coarse gravel and sand (Fig. 5). Ablation till, composed of a poorly sorted mixture of gravel, sand and silt similar to the gravel in appearance (Fig. 6), overlies this material to a depth of 5 to 15 feet (1.5 to 4.5 m). A veneer of varved clay covers the lower slopes (Fig. 7).

Vegetation, Drainage, and Permafrost. The higher, well drained parts of the kame are covered by mature poplar trees (Figs. 3 and 8). Mixed stands of poplar

*All locations are west of the Principal Meridian.

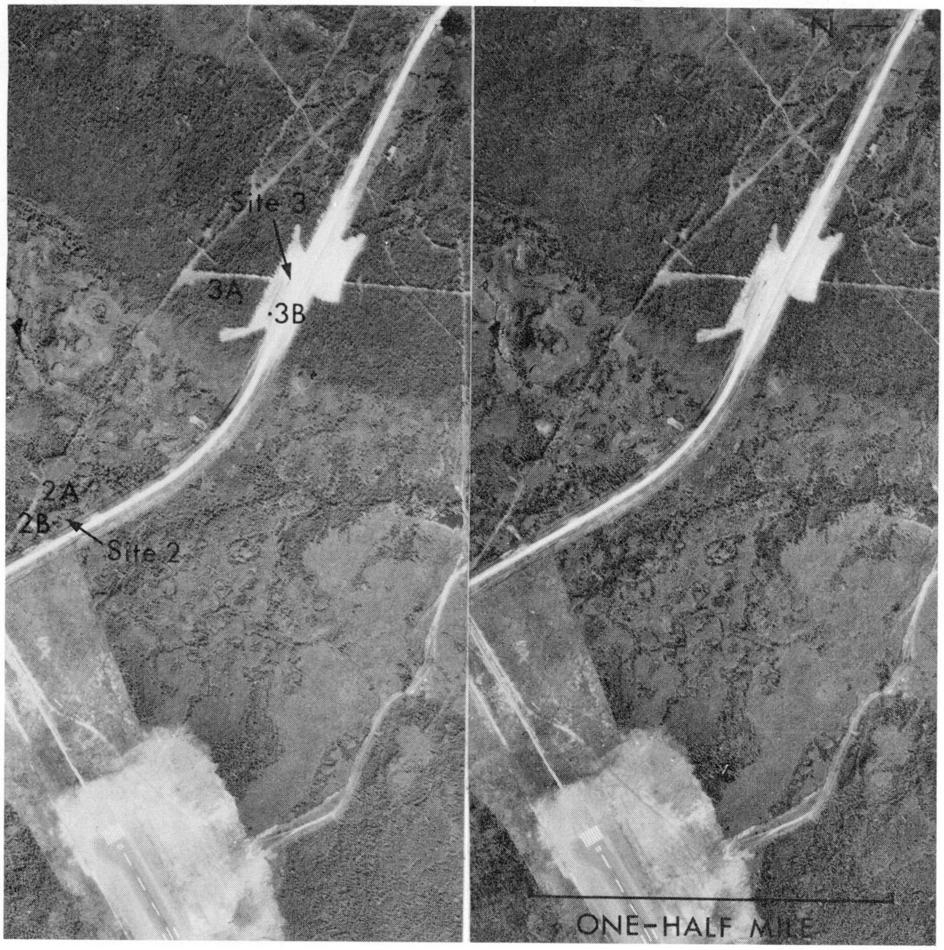

Figure 9.

Stereopair airphotos (A21910-225, 226) of the area outlined in Figure 2 showing the location of Sites 2 and 3 and Testholes 2A, 2B, 3A, and 3B. The southwest part of the Thompson airstrip appears in the lower part of the photo.

Figure 10. Vegetation (mainly black spruce) typical of the shallow bog of Site 2. Testhole 2A was drilled at about this location. (GSC 163353)

Figure 11. Fen area adjacent the bog at Site 2. Hummocks of shallow peat with tufts of grass and small shrubs are separated by pools of shallow water. (GSC 163352).

Figure 12. Roadbed across fen (1) and across edge of a low bog (2) at Site 2. View is south towards airport clearing. (GSC 163351)

Figure 14. Closed stand of spruce, jack pine, and poplar on the crest of the broad, clay-mantled bedrock ridge at Site 3. (GSC 163347)

and spruce cover the lower flanks of the kame and are gradational into spruce along the margin of the kame and the adjacent clay basin (Fig. 7). Evidence of permafrost was not found at this site.

Terrain Performance. The gentle, clay-veneered slopes provide optimum road construction and maintenance conditions and are reflected in a smooth, even road surface. The clay is easily worked and gravel

Figure 13. Oblique aerial view to the southeast of Site 3 and the Thompson airport. The borrow pits are in clay. (GSC 163395)

Figure 15. Typical tree cover of black spruce, jack pine, and poplar at Site 3. The trees are larger and more widely spaced than on the bogs. (GSC 163349)

is nearby for surfacing and maintenance. Minor clay erosion by water run-off has occurred along the roadside and steeper parts of the ditch bottom.

Site 2

Location. The site is about 3.75 miles (6 km) north of Thompson in the NW $\frac{1}{4}$ sec. 29, tp. 78, rge. 3 (lat. 55^{o} 47', long. $97^{o}54'$).

Map-unit and Landform. Site 2 is within a clay basin flat that is part of a complex-composite map-unit consisting of flat basins between broad, clay-veneered or clay-blanketed bedrock ridges and knolls (Figs. 2 and 9).

Nature of Material. Brown clay about 12 feet (3.6 m) thick with poorly defined beds and scattered organic detritus underlies about one foot of woody peat and moss (*see* Testhole 2A, Appendix). Varved clay, at least 12 feet (3.6 m) thick, underlies the massive brown clay. Varves at this locality are 1 to 2 inches (2.5 to 5 cm) thick with dark and light layers of roughly equal thickness.

Vegetation, Drainage, and Permafrost. Clusters of black spruce (Fig. 10) separated by stretches of open grassy fen (Fig. 11) characterize this type of terrain. Drainage is fair to poor. Weakly developed drainage lines are evident in places (Fig. 9). Permafrost occurs at a depth of 1 to 2 feet below the bog surface and continues to at least 23 feet (7 m) in depth (*see* Testhole 2A, Appendix). Shallow probing of the fen indicates that it is unfrozen to a depth of at least 4 feet. Thin patches of peat and open water on the fen surface make it unlikely that permafrost occurs in the larger fen areas except near the periphery of the bogs.

Figure 16. Gully formed in the road ditch along the upper slope of the ridge at Site 3. Note the boulder and pilings placed across the gully to control the rate of erosion. (GSC 163346)

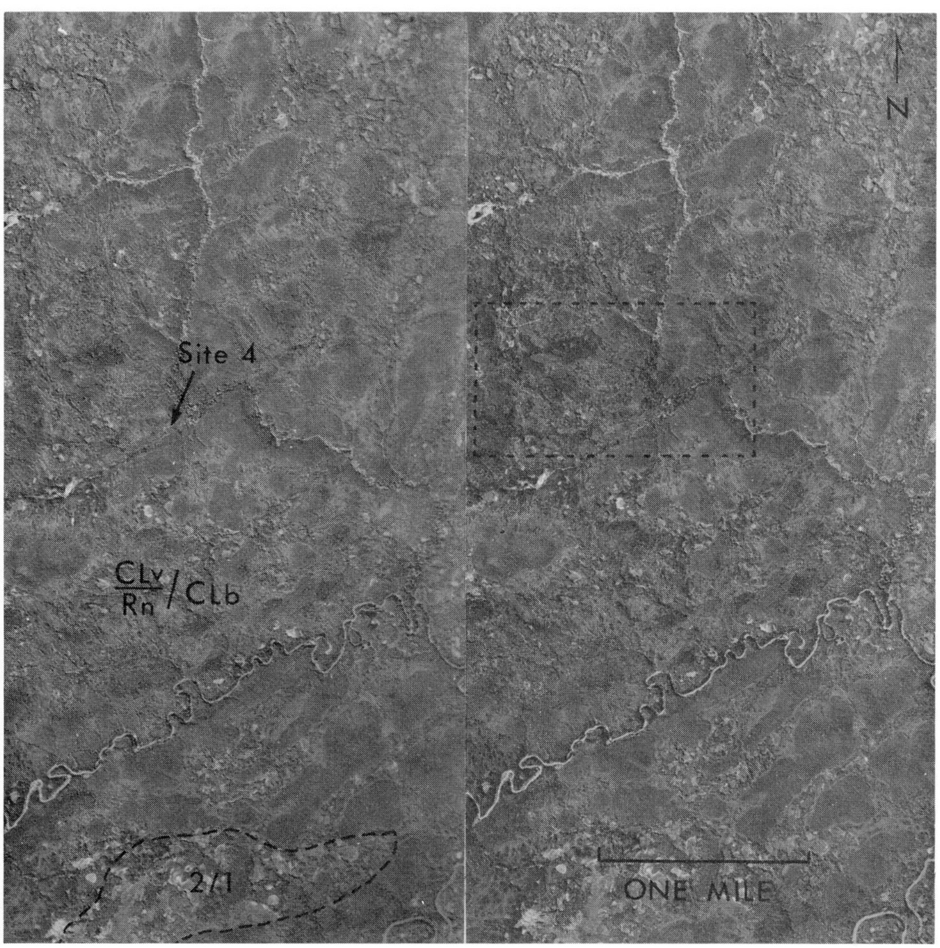

Figure 17.

Stereopair airphotos (A15021-52, 53) showing the location of Site 4. The terrain consists of clay-veneered bedrock knolls, clay-mantled bedrock knolls, and clay basins. Low-lying areas are covered with bog (1) and fen (2). The rectangular area enclosed by the dotted line is shown in Figure 18.

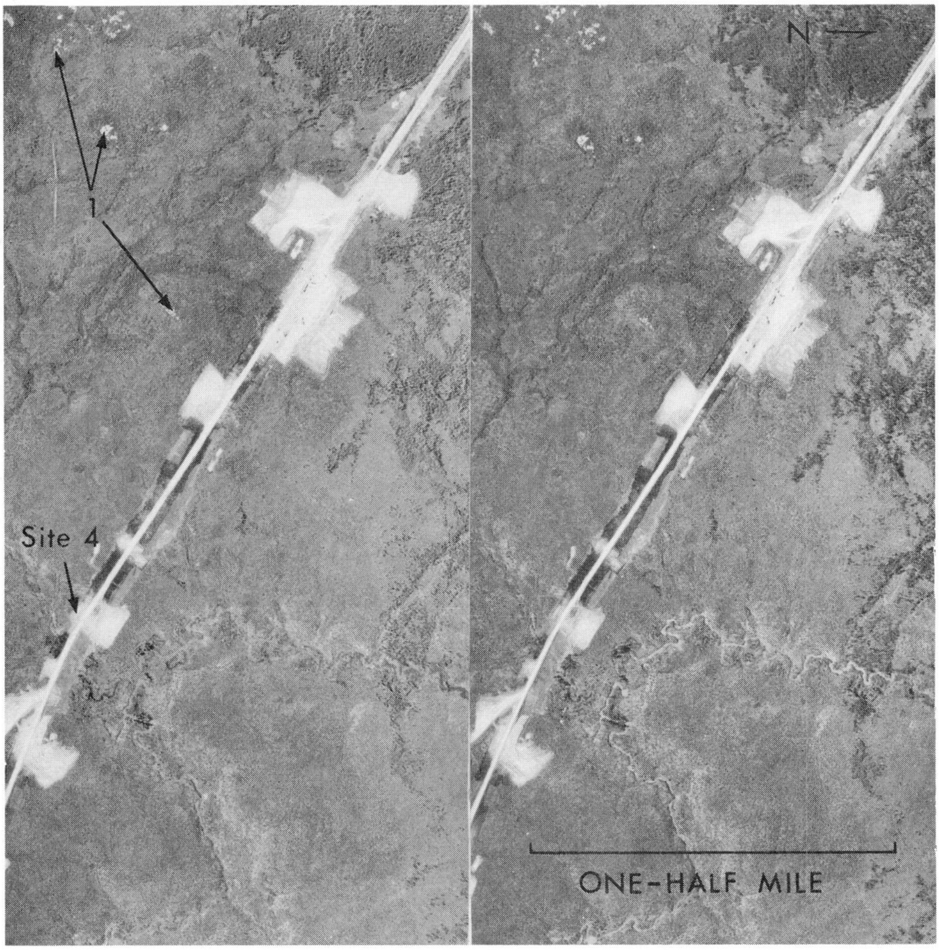

Figure 18.

Stereopair airphotos (A21947-85, 86) of the area outlined in Figure 17. This area was burned over after the smaller scale photos shown in Figure 17 were taken. Bedrock outcrops (1), not visible on the earlier photos, appear as white patches on the later, postburn photos. The light-toned clearings adjacent the road are borrow pits in clay.

Figure 19. Oblique aerial view of Site 4 (left foreground). An example of gullying in clays where they are exposed in drainage ditches along roadsides. (GSC 163396)

Figure 20. A gully about 10 feet (3 m) wide and 8 feet (2.4 m) deep in clay at Site 4 (*see* Fig. 19). (GSC 163345)

Terrain Performance. The roadbed at this site is mainly across open fen although a part is along the edge of a bog (Fig. 12). Across the fen its surface has minor irregularities that apparently result from drainage of excess water and compaction of organic material beneath the roadbed subsequent to road building.

Site 3

Location. This site is about 4.3 miles (6.8 km) north of Thompson in the SW ¼ sec. 32, tp. 78, rge. 3 (lat. 55°48', long. 97°54').

Map-unit and Landform. Site 3 is within a complex-composite map-unit (Fig. 2) that consists of broad, clay-veneered bedrock knolls and clay-mantled bedrock knolls and basins. Local relief between the knolls and intervening basins ranges from about 20 to 50 feet (6 to 15 m). The site is on the crest of a clay-mantled bedrock ridge about 2000 feet (610 m) wide and 20 to 30 feet (6 to 9 m) above the Site 2 locality (Fig. 9).

Nature of Material. Varved clay more than 30 feet (9 m) thick (*see* Testhole 3B, Appendix) is partly exposed in a large borrow pit 4 feet (1 m) deep at this site (Fig. 13). The upper one foot (.3 m) zone is typically brown and massive and is mainly disturbed varved

Figure 21. Clayey alluvium, deposited by the run-off that cut the gully in the channel wall beyond the culvert and another gully on the opposite side, covers the bottom of the channel at Site 4. (GSC 163344)

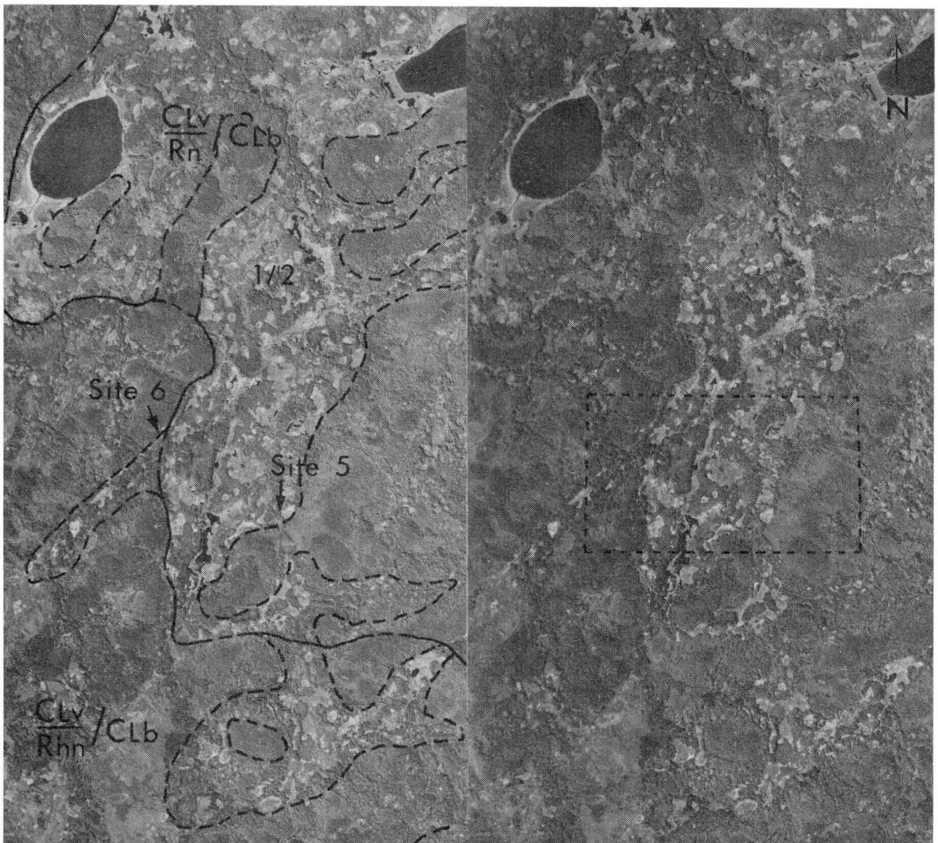

Figure 22.

Stereopair airphotos (A15021-52, 53) showing the location of Sites 5 and 6. The terrain consists of clay-veneered bedrock hills and clay-mantled bedrock knolls and basins. Bog (1) and fen (2) occur in low-lying, flat areas. The rectangular area enclosed by the dotted line is shown in Figure 23.

clay. Distinct varves consist of dark brown clay beds up to 2 inches (5 cm) thick alternating with light grey silt beds up to 6 inches (15 cm) thick (*see* Testholes 3A and 3B, Appendix).

Vegetation, Drainage, and Permafrost. A closed stand of mature spruce, jack pine, and poplar covers the surface beyond the area cleared for the roadway (Figs. 14 and 15). Organic litter several inches thick covers the well drained forest floor. Permafrost is absent from this site although patches of frozen ground persist until late summer. Frozen ground was encountered at a depth of 1 to 2 feet (.3 to .6 m) in shallow auger holes at similar sites in this area in late August, yet by mid-October shallow auger holes and borings to depths of 30 feet (9 m) (*see* Testholes 3A and 3B, Appendix) did not penetrate frozen ground.

Terrain Performance. The road surface is smooth and even across the ridge. The road is built of clay, surfaced with gravel. Where the ditch crosses the steepest part of the ridge slope (5 per cent*) a gully about 12 feet (3.5 m) wide and 8 feet (2.4 m) deep has been cut by run-off (Fig. 16).

Site 4

Location. The site is about 7 miles (11 km) northwest of Thompson in the SW ¼ sec. 11, tp. 79, rge. 4 (lat. 55°50', long. 97°57').

Map-unit and Landform. Site 4 is within the same map-unit as Site 3 and includes the bottom and side of a small drainage channel about 800 feet (244 m) wide and 20 feet (6 m) deep (Figs. 17, 18, and 19). The relief in this area is somewhat greater than that to the west as it is in a belt transitional to an area where bald bedrock hills are more common and the local relief in places exceeds 100 feet (30 m) (Fig. 1).

Nature of the Material. Lacustrine clay more than 8 feet (2.4 m) thick occurs at this site. The gully along the side of the channel (Fig. 20) exposes 2 to 4 feet (.6 to 1.2 m) of massive clay or clay with contorted varves overlying varved clay. Bands of charcoal occur in places within the contorted zone suggesting this zone resulted from earthflow (solifluction?) subsequent to a burn.

Vegetation, Drainage, and Permafrost. The vegetation at this site consists of clusters of immature poplar and low shrubs among the scattered trunks of upright, fire-killed spruce trees (Figs. 20 and 21). It is typical of a pioneer type of vegetation found in areas recently burned over. A semi-closed to open spruce forest formerly covered the fairly well drained, clay-mantled, gentle slopes of broad ridges that are characteristic of the local terrain (Fig. 17). Patches of peat about one foot (.3 m) thick are common on the slopes of low-lying areas. Permafrost does not occur at this site.

Terrain Performance. The road surface across this site is smooth and even and should remain so for a number of years. Gullying along parts of the road ditch (Fig. 20) and the development of alluvial fans in the channel bottom (Fig. 21) in time will affect the stability of the road by undercutting and culvert blockage.

Site 5

Location. The site is about 9 miles (14.4 km) northeast of Thompson in the SW ¼ sec. 15, tp. 79, rge. 4 (lat. 55°51', long. 98°01').

Map-unit and Landform. Site 5 is within an area of shallow fen and bog on a broad flat between a clay-mantled bedrock ridge to the east and a clay-veneered bedrock ridge to the west (Fig. 22). The bog at this site is a palsa mound about 5 feet (1.5 m) high and 20 feet (6 m) wide. Shallow fen occurs around the northwest end of the palsa along the road right-of-way; deeper and wetter fen occurs towards the eastern edge of the flat (Figs. 23 and 24).

Nature of the Material. The roadbed and ditches are underlain by thinly varved lacustrine clay overlain by peat, a foot or less thick, and shallow water (Fig. 26). The upper foot or so of the clay appears massive but below this it is fairly uniformly varved and at least 22 feet (6.7 m) thick (*see* Testhole 5B, Appendix). The upper zone [about 3 feet (.9 m) thick] of the clay below the water and peat is very soft and flows readily. The palsa consists of fairly well drained peat about one foot (.3 m) thick overlying ice with clay stringers totalling at least 30 feet (9 m) in thickness (*see* Testhole 5A, Appendix).

Vegetation, Drainage, and Permafrost. Low shrubs and scattered clusters of immature poplar grow on the fen and palsa adjacent the road along with a few immature black spruce trees (Figs. 25 and 27). The drainage at this site is poor. Permafrost with much ground ice occurs at a depth of about 12 feet (3.7 m) in the ditch nearest the palsa and probably underlies the roadbed and opposite ditch at about the same depth (Fig. 26). Beneath the palsa surface, ground ice and clay stringers occur below the peat cover and continue to at least the 30 foot (9 m) depth (*see* Testholes 5A and 5B, Appendix). Whether the occurrence of permafrost beneath the shallow fen at this site represents a common condition in terrain of this type has not been demonstrated. The occurrence here may be simply a wedge of frozen ground around the periphery of the palsa associated with a collapsed part of it. Certainly the bottoms of fen with deeper water are unfrozen to a greater depth and permafrost may or may not occur.

Terrain Performance. The roadbed between Sites 5 and 6 is built of clay, some 3 to 5 feet (.9 to 1.5 m)

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*Slopes were measured by Abney level.

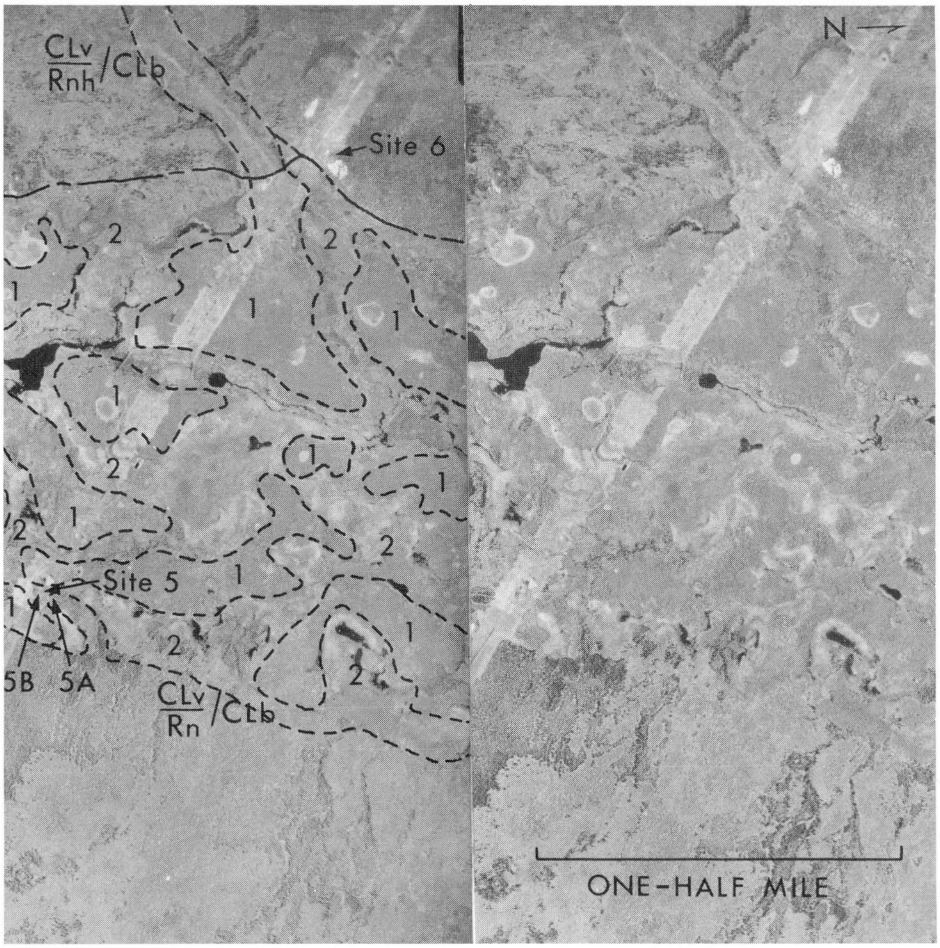

Figure 23. Stereopair airphotos (A21947-39, 40) of the area outlined in Figure 22 showing the locations of Sites 5 and 6 and of Testholes 5A and 5B. Bogs (1) and fen (2) are outlined by a dashed line.

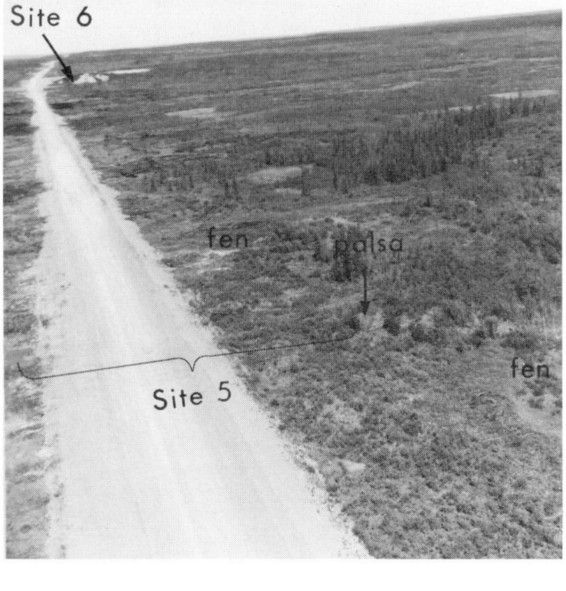

Figure 24.

Oblique aerial view towards the west of Sites 5 and 6. Roadbed of clay is built across shallow fen and bog. (GSC 163397)

Figure 25.

Shallow fen (1) at Site 5 marked by low shrubs and clusters of young poplar and scattered mature black spruce. Bog surface (2) has dense cover of black spruce along with scattered poplar. (GSC 163337)

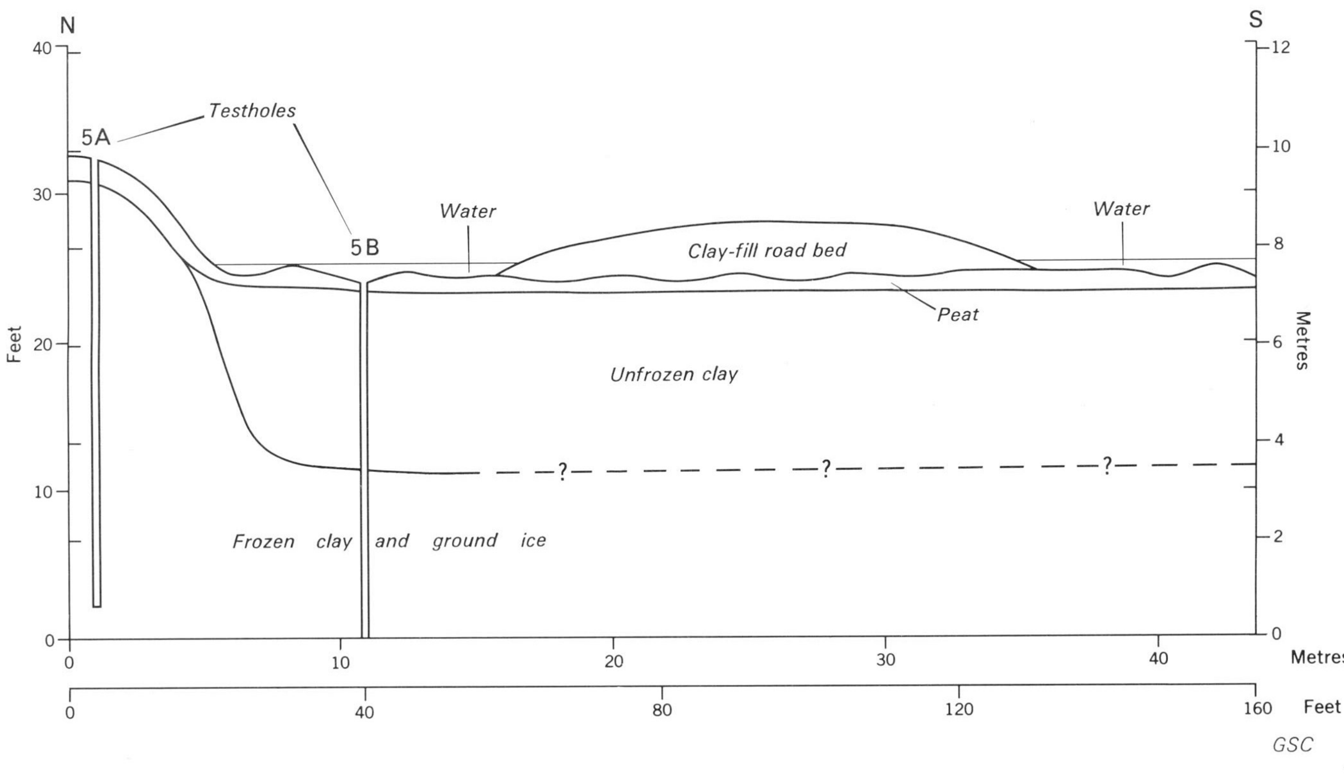

Figure 26. Cross-section of Site 5 based on surface and testhole data.

Figure 27. Shrubs and young poplar trees on shallow fen and palsa mound (1) at Site 5. Dense cover of mature black spruce beyond is along the margin of a clay-mantled rise to the northeast. (GSC 163334)

Figure 29. Drift on the lee slope of a bedrock knoll at Site 6. The stony strip is very hard bouldery till with some fines removed by water erosion. Lacustrine clay overlies the till. (GSC 163342)

thick, over fen and bog with peat from less than one foot (.3 m) to some 8 feet (2.4 m) thick. At Site 5 slight irregularities to about the one foot (.3 m) depth occur across the road surface and are most pronounced along the edge of the roadbed. They appear to result from the same conditions (water displacement and compaction) evident at Site 2. Beyond Site 5 the most

Figure 28. Road built across the lee (down-ice) slope of a bedrock knoll veneered with drift at Site 6. (GSC 163341)

Figure 30. Varved clay from 2 to 5 feet (.6 to 1.5 m) thick overlying a glacially grooved and polished bedrock surface (1) at Site 6. Pockets of bouldery till (2) occur in places beneath the clay. (GSC 163343)

pronounced irregularities are along the boundary of peat and fen. These apparently result from the combined effects of water displacement and compaction on the fen, and compaction of the bog due to limited melting of permafrost.

Site 6

Location. This site is about 10 miles (16 km) northwest of Thompson in the NW ¼ sec. 16, tp. 79, rge. 4 (lat. 55°51', long. 98°02').

Map-unit and Landform. Site 6 is within an area of clay-veneered bedrock knolls and hills and clay-mantled bedrock knolls and basins. It is mapped as a complex-composite map-unit with local relief somewhat greater than at Sites 3 and 4 (Figs. 22 and 23).

The site locality is on the lee slope of a bedrock knoll about 1500 feet (458 m) long, 1000 feet (305 m) wide, and about 30 to 50 feet (9 to 15 m) above the level of the adjacent bog (Fig. 28).

Nature of the Material. Bouldery till 1 to 2 feet (.3 to .6 m) thick covers the lee (down-ice) slope of the granitic bedrock surface. The till is overlain by about the same thickness of varved clay (Fig. 29). On the stoss (up-ice) slope of the knoll the polished and grooved bedrock surface is covered with varved clay less than one foot (.3 m) thick on the crest and about 5 feet (1.5 m) thick farther downslope (Fig. 30). Pockets of bouldery till occur in places between the clay and bedrock.

Vegetation, Drainage, and Permafrost. The vegetation at this site is a pioneer type vegetation established subsequent to a fairly recent (10 to 20 years?) burn across this area. The sides of the knoll are covered with immature poplar and jack pine (Fig. 31). Airphotos taken in the early 1950's (Fig. 22) suggest the

Figure 31. Pioneer tree growth (foreground) of poplar and jack pine on the side of the bedrock knoll at Site 6. View is eastward across organic terrain and Site 5. (GSC 163338)

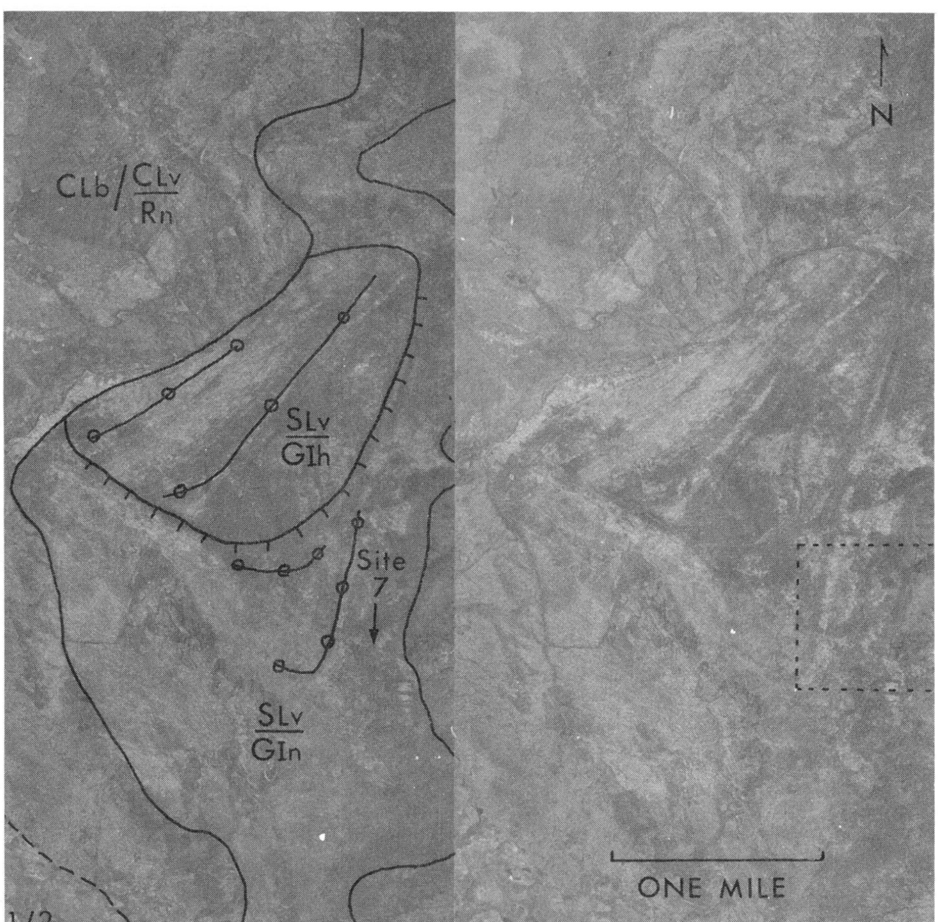

Figure 32.

Stereopair airphotos (A14984-116, 117) showing the location of Site 7 on a broad ridge of ice-contact sand and gravel, reworked by lakewater. Strandlines and wave-cut scarps are distinctive minor landforms. The rectangular area outlined by dotted lines is shown in Figure 33.

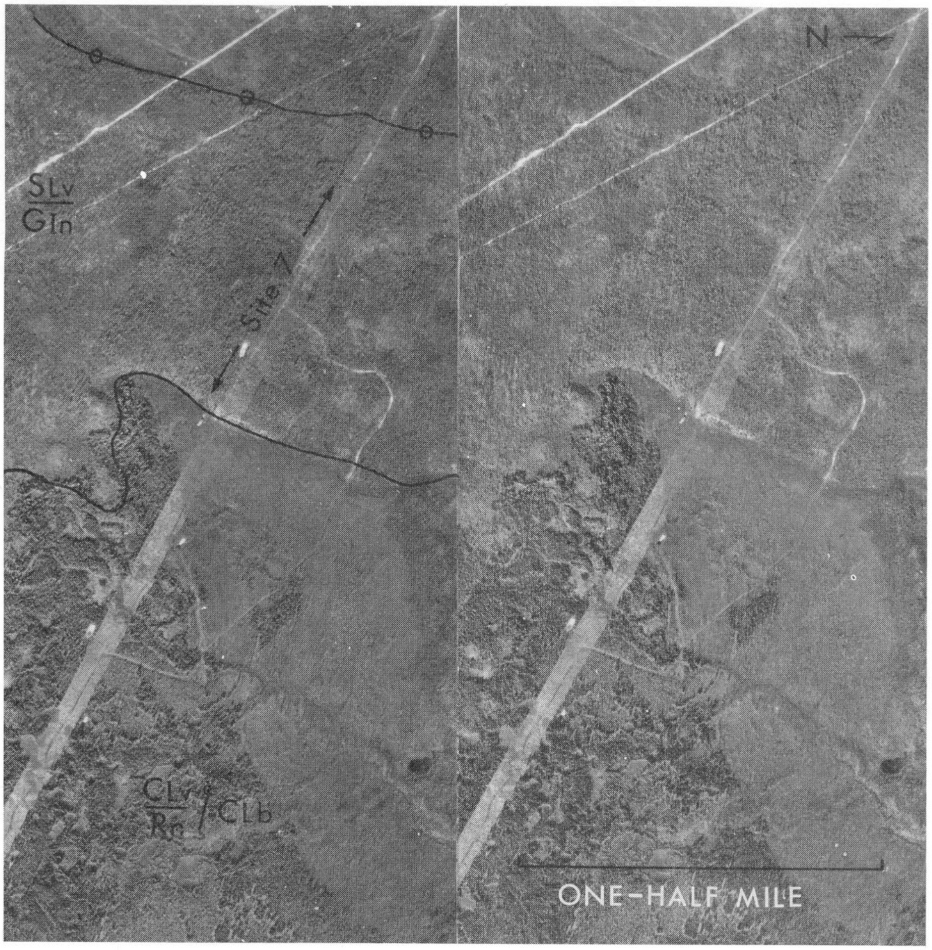

Figure 33.

Stereopair airphotos (A21842-7, 8) of the area outlined in Figure 32. The location of Site 7 on a wave-reworked ice-contact deposit is shown.

Figure 34. Roadbed on a clay basin surface (foreground) crosses an abrupt rise of lacustrine sand (1) onto a wave-reworked ice-contact hill (2). Site 7 is on a platform-like rise marked by the broad road-cut. (GSC 163360)

Figure 35. Bouldery surface of a wave-reworked slope of an ice-contact deposit of sand and gravel at Site 7. The road-cut is in a sandy beach. (GSC 163363)

pre-burn vegetation on this site was a closed stand of black spruce. Permafrost is absent, as would be expected beneath a well drained surface with extensive exposures of bedrock and sparse tree cover.

Terrain Performance. The road surface across the knoll is smooth and even (Fig. 28). Erosion or other processes that could affect the stability of the roadbed to date have produced no significant changes.

Site 7

Location. The site is about 19 miles (30 km) northeast of Thompson in the SW ¼ sec. 1, tp. 80, rge. 6 (lat. 55°54', long. 98°16').

Map-unit and Landform. Site 7 is on a gentle slope flanking a kame that was inundated by glacial Lake Agassiz (Fig. 32). It is part of a complex of hills, knolls and ridges (Fig. 1) that forms one of the prominent kame moraine systems unique to the Shield region of northeastern Manitoba. A nearly flat, sandy slope occurs just below a prominent beach ridge (Fig. 33). The slope begins as an abrupt rise some 30 feet (9 m) above the level of the adjacent clay basin (Fig. 34). Beyond the beach ridge a bouldery, flat surface slopes

Figure 36. Sand exposed in a road-cut at Site 7 (*see* Fig. 34). It is along the outer edge of a slope that probably formed as an offshore deposit adjacent to a lake-inundated kame. (GSC 163361)

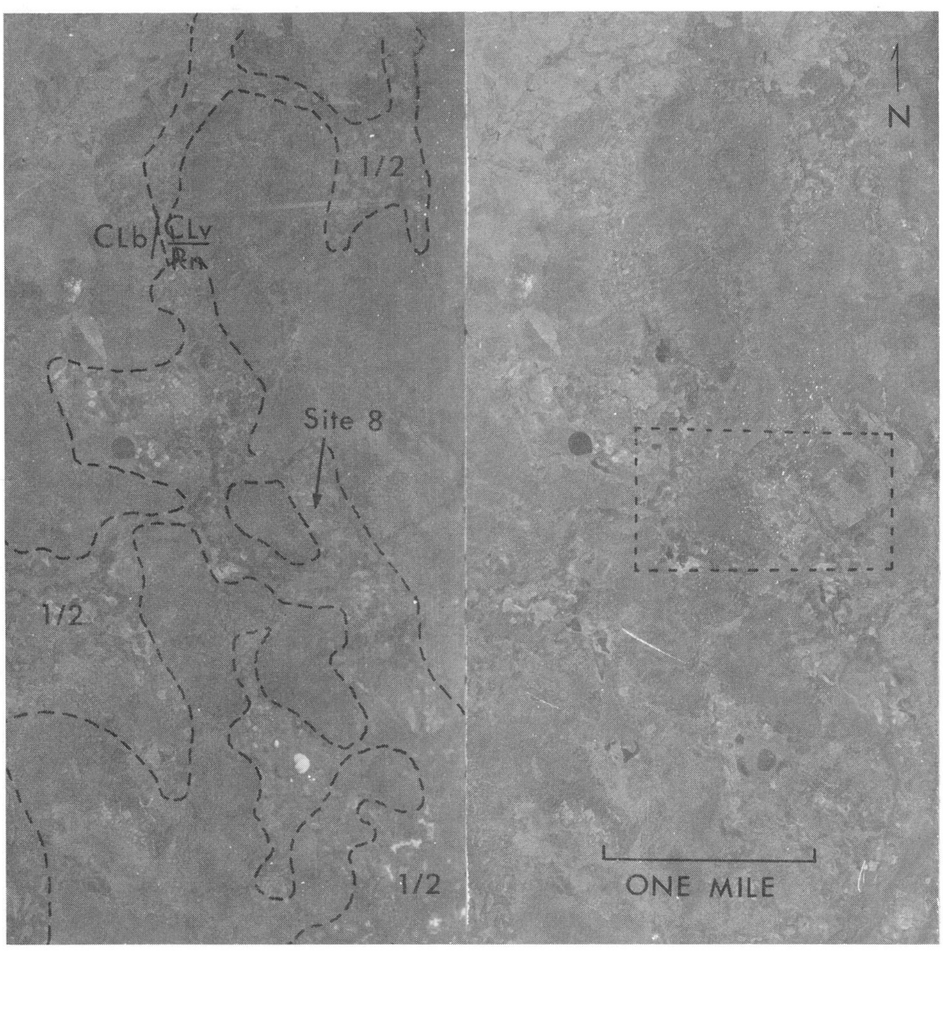

Figure 37.

Stereopair airphotos (A14984-117, 118) showing the location of Site 8 on organic terrain. The rectangular area enclosed by the dotted line is shown in Figure 38. Bog (1) and fen (2) occur in low-lying, flat areas.

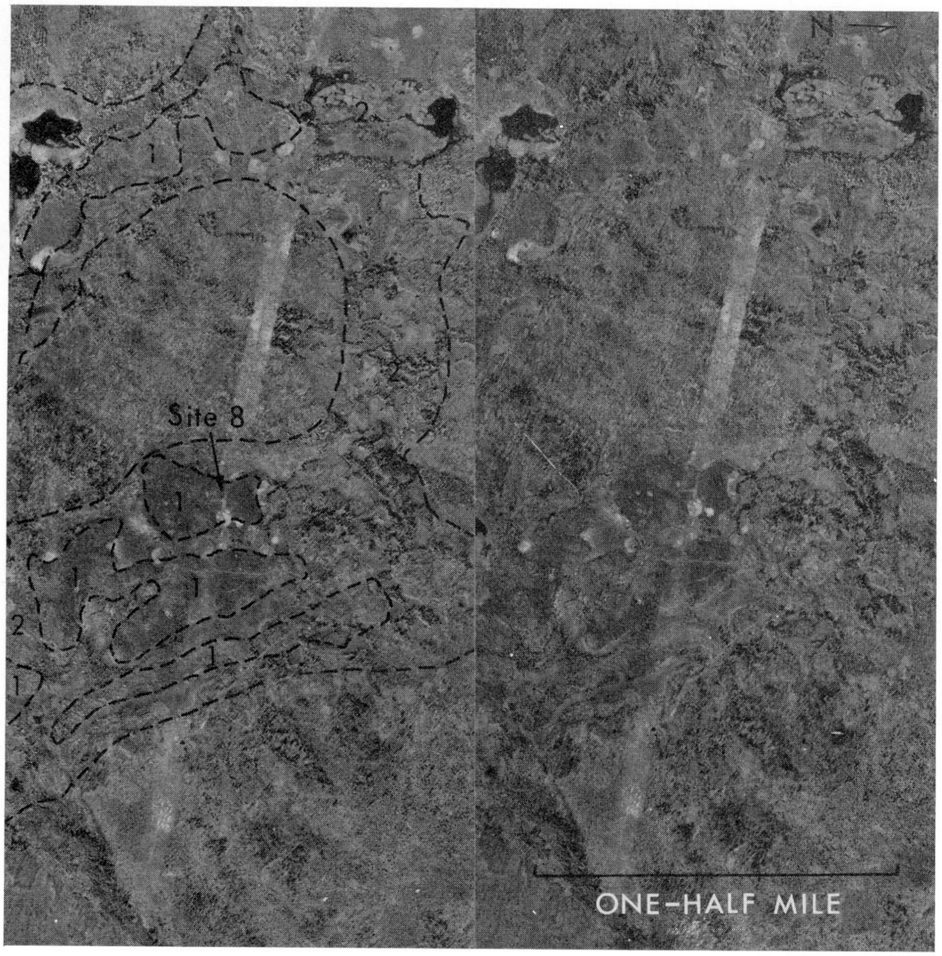

Figure 38.

Stereopair airphotos (A2842-155, 156) of the area outlined in Figure 37. The peat plateau of Site 8 (*see* Fig. 39) is shown along with other patches of bog (1) and fen (2).

Figure 39. A raised bog (peat plateau) of Site 8 forms an abrupt rise just beyond the watery fen in the foreground. (GSC 163368)

Figure 40. Oblique aerial view to the west of Site 8 looking across a bog (foreground), narrow fen (center), and towards a low, clayey rise beyond. (GSC 163398)

Figure 41. Thawing of permafrost in peat at Site 8 formed a shallow depression in the road ditch (left), apparently as a result of the temporary ponding of water and the deposition of clay over the peat. (GSC 163369)

Figure 42. Peat consisting of a fibrous and woody organic mat is exposed in a trench through the frozen bog at Site 8. (GSC 163366)

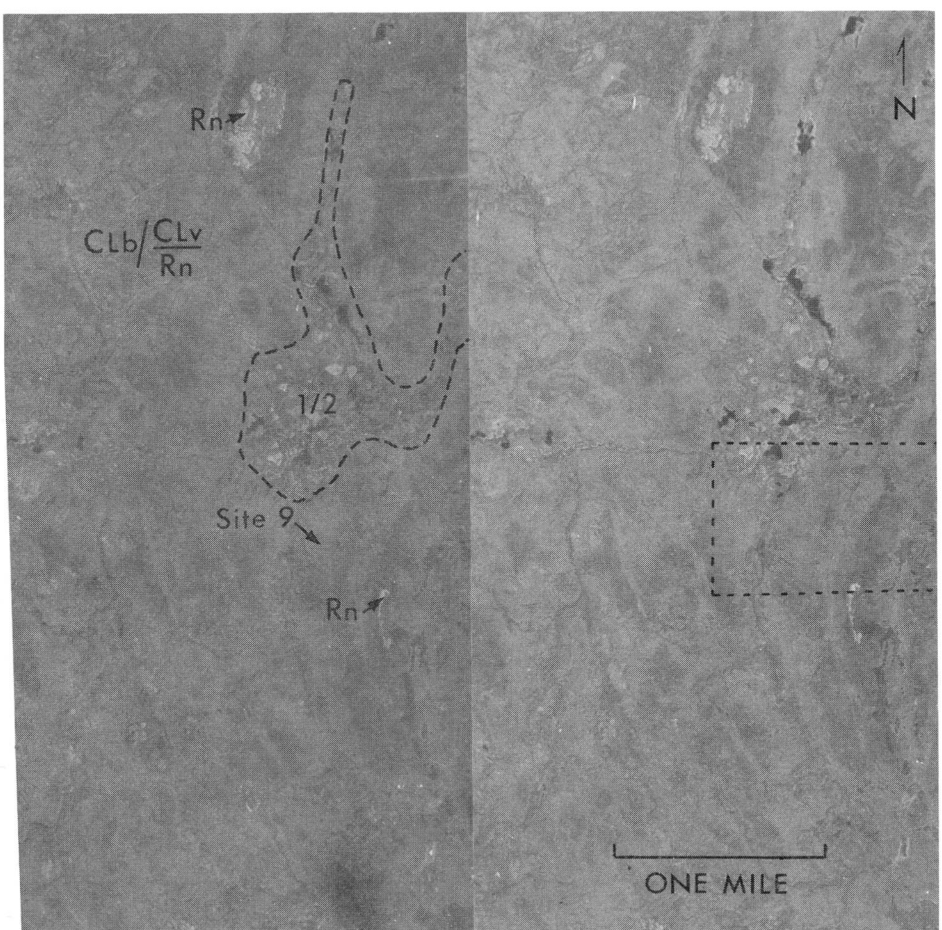

Figure 43.

Stereopair airphotos (A14984-119, 120) showing the location of Site 9 on the side of a clay-mantled bedrock ridge. Rectangular area outlined by dots is shown in Figure 44. Bog (1) and fen (2) occur in low-lying, flat areas.

gently upwards to the base of the scarp below the main body of the kame (Fig. 35).

Nature of the Material. The lower slopes of this landform are underlain by well sorted sand (Fig. 36). The sand was winnowed from ice-contact sands and gravels farther upslope where it left a bouldery surface underlain by ice-contact sand and gravel (Fig. 35).

Vegetation, Drainage, and Permafrost. Open stands of mainly jack pine with some poplar formerly covered much of the surface at Site 7. Presently, only patches of these remain and the surface is covered by low shrubs and dead fall resulting from a recent burn (Fig. 35). Permafrost does not occur beneath the well drained surface of this landform.

Terrain Performance. The road surface is smooth and even and reflects the stability of the coarse sand used for the roadbed. In places beyond this site where the silt content of the roadbed is higher, the surface is marked by a series of sharp, shallow irregularities resulting from displacement of the silt.

Site 8

Location. The site is about 21 miles (34 km) northwest of Thompson in the SW ¼ sec. 3, tp. 80, rge. 6 (lat. 55° 54', long. 98°19').

Map-unit and Landform. Site 8 is on the bog part of an organic complex on low-relief terrain characterized by clay-mantled bedrock basins and knolls, and clay-veneered knolls (Fig. 37). The bog is a distinctive, irregularly shaped rise about 6 to 8 feet (1.8 to 2.4 m) above the surrounding fen (Fig. 38) and similar to bog types Tarnocai (1970) referred to as peat plateaus. The surface is broadly concave with numerous shallow depressions and is terminated by a steep, peaty bank where it meets the adjacent fen (Fig. 39).

Nature of the Material. The surface of the bog is underlain by moist, spongy peat about one foot (.3 m) thick. Frozen peat about 7 feet (2.1 m) thick, composed of a mixture of fibrous and woody peat with minute ice lenses, underlies the unfrozen surface peat and overlies a grey, massive clay that is high in ground-ice content.

Vegetation, Drainage, and Permafrost. The upright trunks of dead spruce and patches of grass occur here and there on the bog surface (Fig. 39), although clusters of black spruce grow on some of the adjacent bogs (Fig. 40). The surface is poorly drained and permafrost occurs at the 1 to 2 foot (.3 to .6 m) depth beneath the bog and continues to at least the 8 foot (2.4 m) depth. Permafrost was not detected in shallow probing (8 ft. or 2.4 m) in adjacent fen.

Terrain Performance. The road surface on the bog and fen has minor irregularities that are most pronounced along the bog and fen margin. The roadbed is of clay that is thickest (4 to 5 ft. or 1.2 to 1.5 m) over the fen. Only minor settling of the bog surface due to melting of permafrost and compaction below the roadbed has occurred. Settling of about one foot (.3 m) has occurred in the ditches on the bog surface where water was temporarily ponded and a thin layer of clay covers the peat (Fig. 41). Although the water content of the frozen peat is high [about 80 per cent by volume (Zoltai and Tarnocai, 1970, p. 124) or from 500 to 1500 per cent by weight], the volume change upon melting of frozen peat is not as great as the ice content of frozen peat would suggest. This is evident where formerly frozen peat is exposed along the side of a trench through the bog (Fig. 42). Much of the water remains trapped in the peat voids preventing major volume reduction unless subjected to considerable compaction.

Site 9

Location. The site is located about 28 miles (45 km) northwest of Thompson in the SW ¼ sec. 9, tp. 80, rge. 7 (lat. 55°55', long. 98°31').

Map-unit and Landform. Site 9 is on the side of a clay-mantled bedrock ridge within an area of clay basins, and clay-mantled and clay-veneered bedrock knolls and ridges (Figs. 43 and 44). Local relief is mostly from 25 to 75 feet (7.6 to 22.9 m) although in places it exceeds 100 feet (30 m).

Nature of Material. Massive brown clay, several feet thick, overlies brown and grey varved clay at least 17 feet (5.2 m) thick (*see* Testholes 9A and 9B, Appendix). The varves are less than 1 inch (3 cm) thick and appear somewhat disturbed in places.

Vegetation, Drainage, and Permafrost. Mostly mature spruce and poplar form a closed tree cover over the well drained ridge surface (Fig. 45). Permafrost occurs beneath the heavily treed slope beyond the ditch at a depth of 5 feet (1.5 m) and continues to a depth of 18 feet (5.5 m). It is absent beneath the area cleared for the road (Fig. 46). The distribution of permafrost on the slope is uncertain as the subsurface data is limited (*see* Testholes 9A and 9B, Appendix). Its absence in the cleared area is largely the result of the removal of the tree cover, whereas its apparent absence below the 18 foot (5.5 m) level in the undisturbed part may reflect the closeness of the underlying bedrock.

Terrain Performance. Failure of the clay exposed in the road ditch appears to have resulted from the combined effects of an oversteepened slope, gullying, and the melting of permafrost. The geologic conditions and steepness of the natural slope (5 per cent) are similar to those at Sites 3 and 4 where only minor gullying has occurred. The ditches at Sites 3 and 4 are shallower and permafrost is absent. Excavation of the upslope part of the road ditch at Site 9 has resulted in an unusually wide and steep (15 per cent) slope (Fig. 47) that has failed by earthflow. The disturbed zone

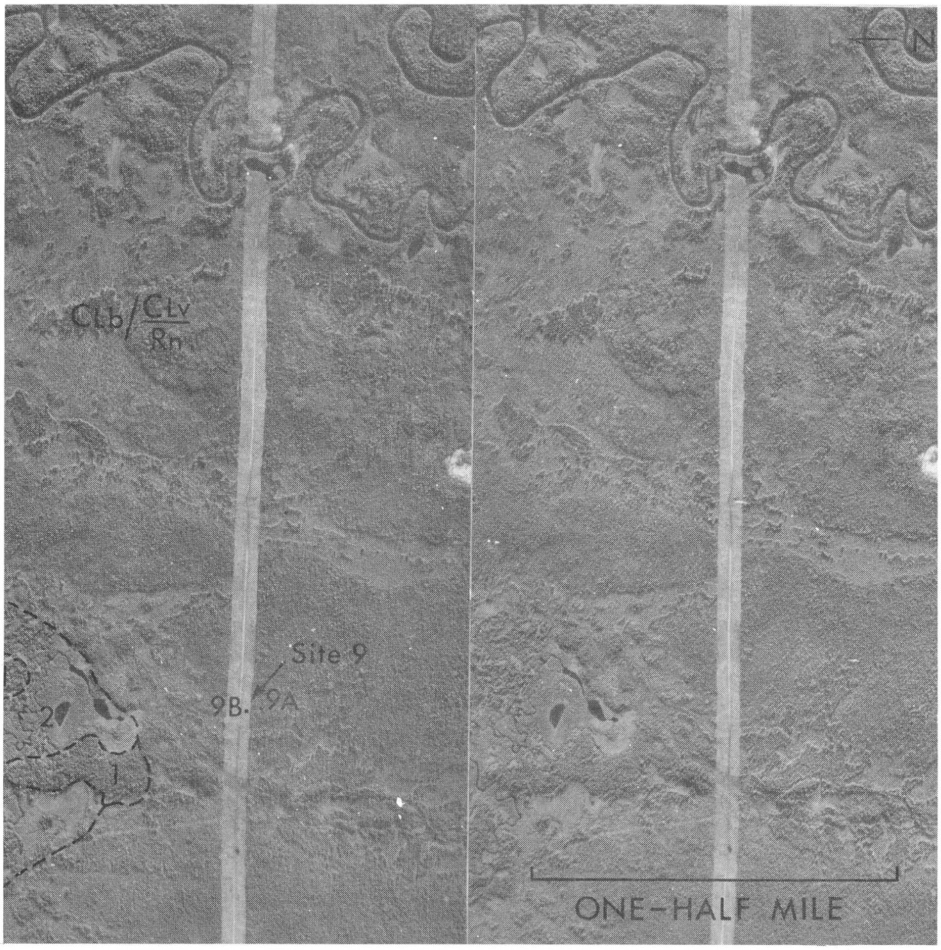

Figure 44. Stereopair airphotos (A21841-33, 34) showing the area outlined in Figure 43. The locations of Site 9 and Testholes 9A and 9B are shown.

Figure 45.

Oblique aerial view of Site 9 to the southeast. The earthflow is marked by the 'wrinkled' appearance of the surface in the road ditch (1). The locations of Testholes 9A and 9B are shown. (GSC 163399)

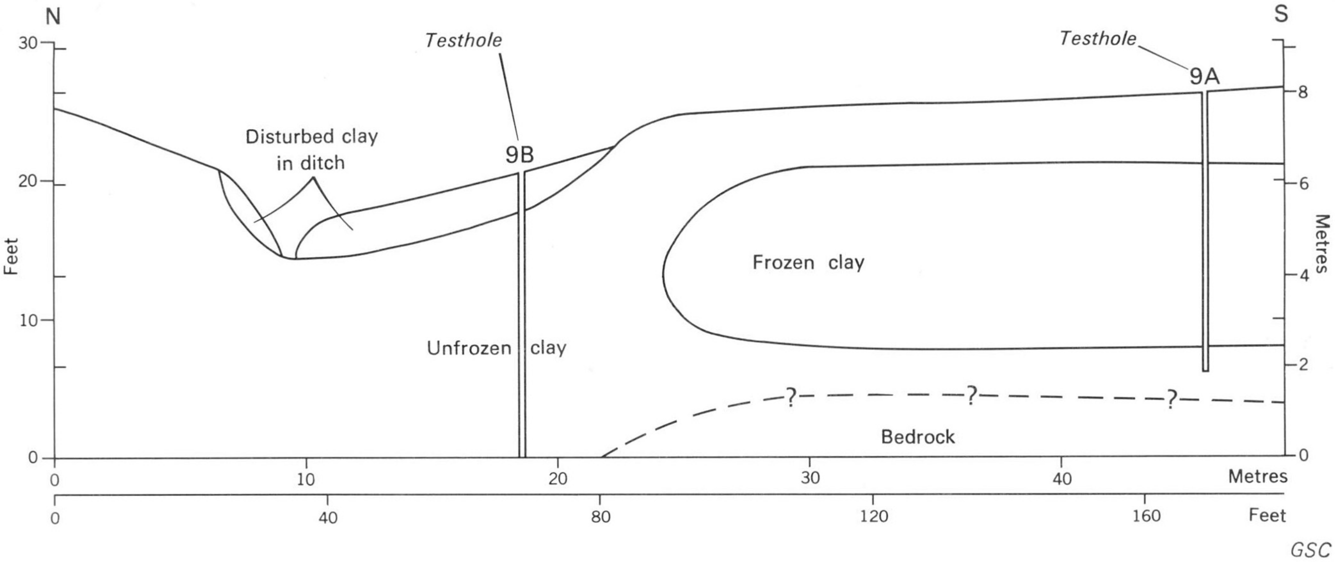

Figure 46. Cross-section of Site 9 based on surface and testhole data. Position of bedrock clay contact is assumed.

Figure 47.

Disturbed surface of the earthflow along the road ditch at Site 9. (GSC 163371)

Figure 48. Gully at the toe of the earthflow at Site 9. The earthflow apparently was triggered by downcutting of the gully. (GSC 163370)

Figure 49. Downslope view of the gully and earthflow at Site 9. (GSC 163372)

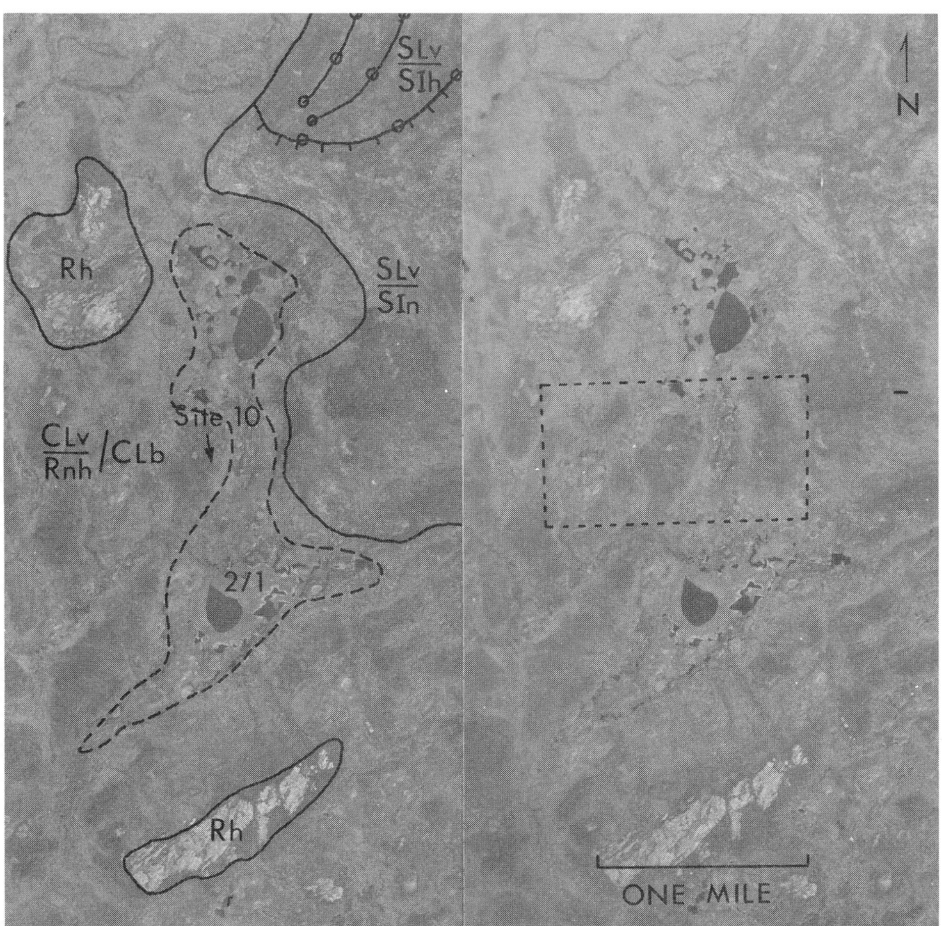

Figure 50.

Stereopair airphotos (A14984-120, 121) showing the location of Site 10 on the side of a drift-veneered bedrock hill. The rectangular area shown in Figure 51 is enclosed by dotted lines. Bog (1) and fen (2) occur in low-lying, flat areas.

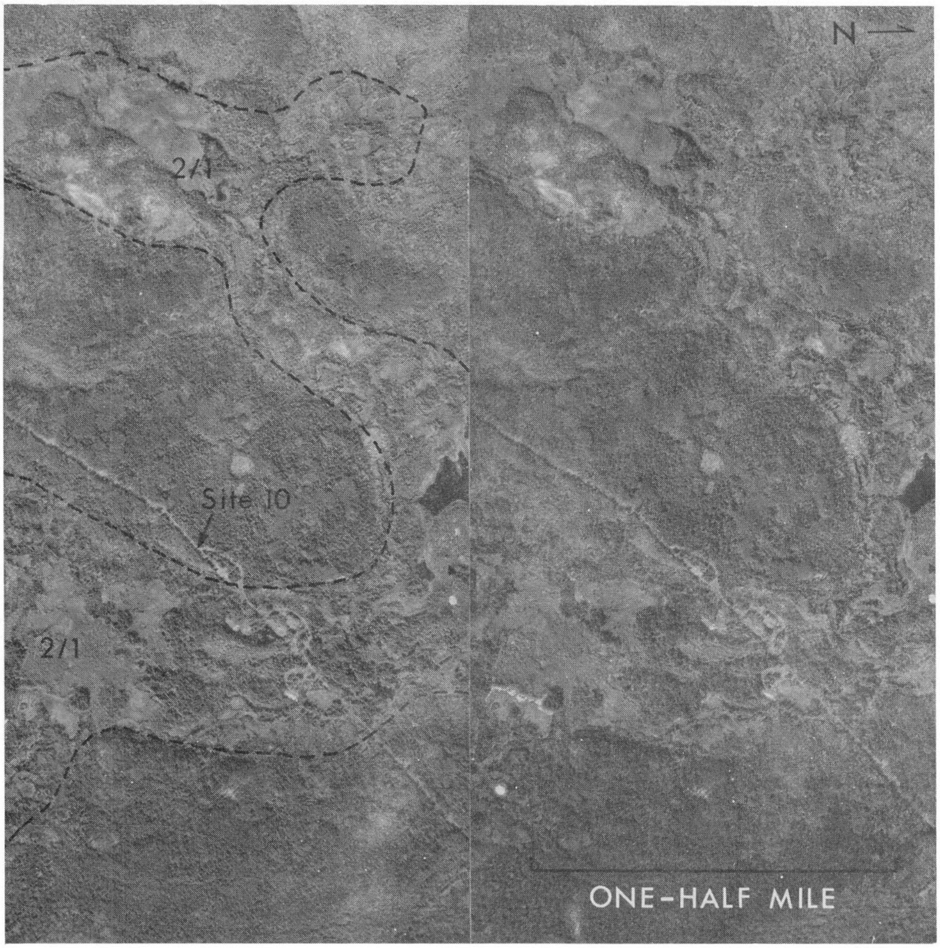

Figure 51.

Stereopair airphotos (A21874-180, 181) of the area outlined in Figure 50.

Figure 52. Oblique aerial view of Site 10, looking towards the northwest. Boulders in the ditch (bottom right) overlie bedrock. Thin clay overlies bouldery till farther upslope. (GSC 163400)

Figure 53. Bouldery till (foreground) and shattered bedrock (centre) in the road ditch along the hillside at Site 10. The cut in the lowest area beyond is in clay. (GSC 163375)

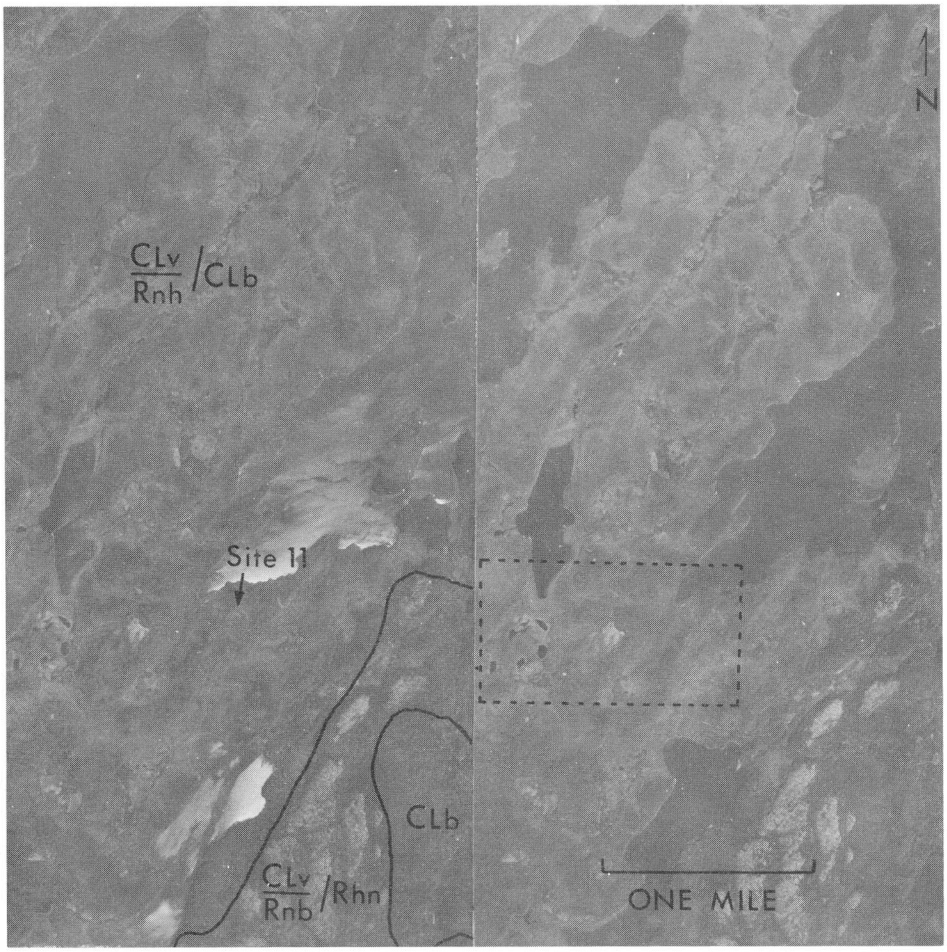

Figure 54.

Stereopair airphotos (A14984-123, 124) showing the location of Site 11 within a clay basin between bedrock hills. The dotted lines enclose the area covered by Figure 55.

consists of a series of closely spaced (about 2 ft. or .6 m) arcuate breaks in the clay with 1 to 2 feet of displacement (Fig. 47) and isolated small blocks of clay at the toe of the flow (Fig. 48). The depth of the disturbed zone was not determined, although the gully depth indicates it is less than 5 feet and probably about 3 to 4 feet (.9 to 1.2 m). Some disturbance is also evident along the outer edge of the roadbed (Fig. 49). Continued deepening of the gully by water run-off may reactivate the earthflow, although the present slope appears to have a greater stability than the initial slope. Undercutting of the roadbed will result regardless of earthflow if the present rate of gullying continues.

Site 10

Location. The site is about 11 miles (18 km) northeast of Nelson House in the NE ¼ sec. 4, tp. 80, rge. 8 (lat. 55°55', long. 98°39').

Map-unit and Landform. Site 10 is in an area of clay-veneered bedrock hills and intervening clay basins (Figs. 50 and 51) with local relief from 50 feet (15 m) to more than 100 feet (30 m). It is on the southeast slope of a bedrock hill about 3000 feet (915 m) long and 1500 feet (458 m) wide (Fig. 52).

Nature of the Material. The bedrock at this site is naturally exposed along the side of the ridge or overlain by a veneer of bouldery till (Fig. 53). Massive and varved clay several feet thick overlies thin bouldery till on the ridge crest.

Vegetation, Drainage, and Permafrost. Mature spruce mixed with some poplar, jack pine and birch forms a closed tree cover on this well drained site. Permafrost is not present at this site.

Terrain Performance. The road surface across the slope (5 per cent) is smooth and stable. Problems encountered were initial and entailed smoothing the somewhat irregular and steep bedrock slopes. Maintenance at this site will be minimal.

Site 11

Location. The site is about 6 miles (9.6 km) north of Nelson House in the SW ¼ sec. 31, tp. 79, rge. 10 (lat. 55°53', long. 98°51').

Map-unit and Landform. Site 11 is within terrain similar to that around Site 12, consisting of clay basins and clay-veneered bedrock hills (Fig. 54). The site

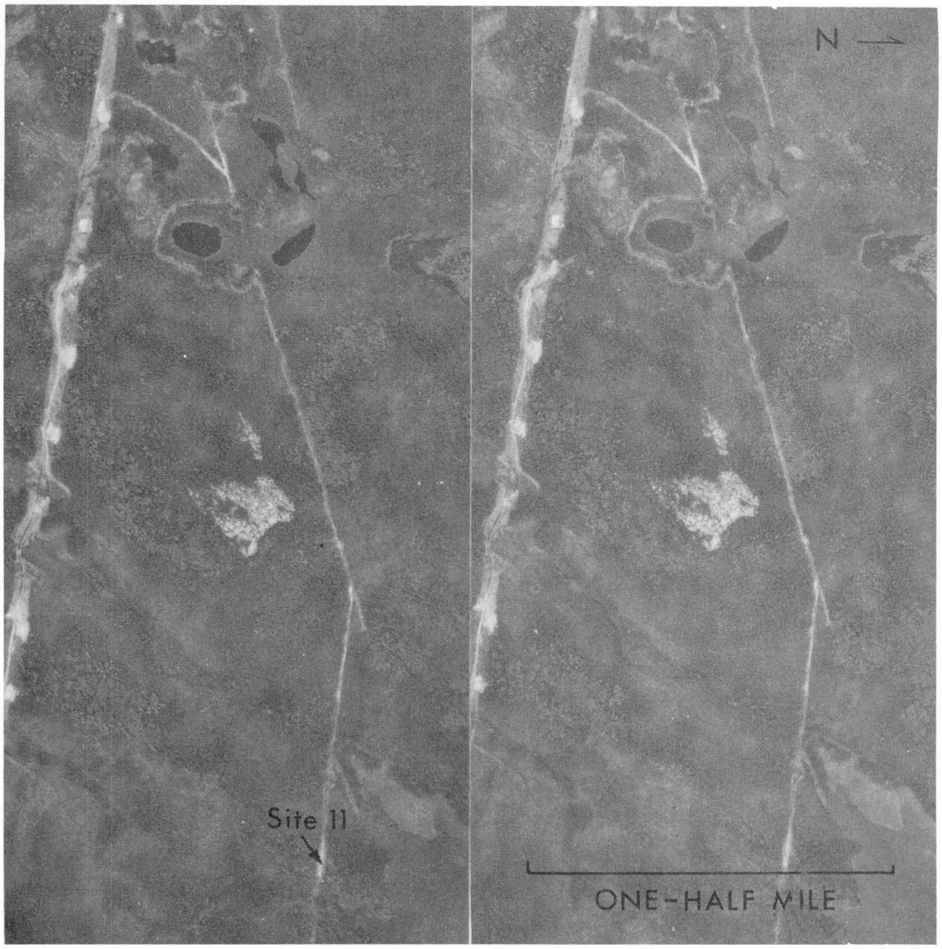

Figure 55.

Stereopair airphotos (A21128-207, 208) of the area outlined in Figure 54. Light grey patches on the ridges are mainly poplar and dark grey patches are mainly black spruce.

Figure 56. Varved clay and silt overlying glacially polished and grooved bedrock at Site 11. Bouldery line above the clay is the gravelled road surface. (GSC 163380)

Figure 57. A broad gully formed in the road ditch at Site 11 as a result of the removal of some 5 feet of clay over the bedrock. Lateral erosion in time will undercut the roadbed. (GSC 163379)

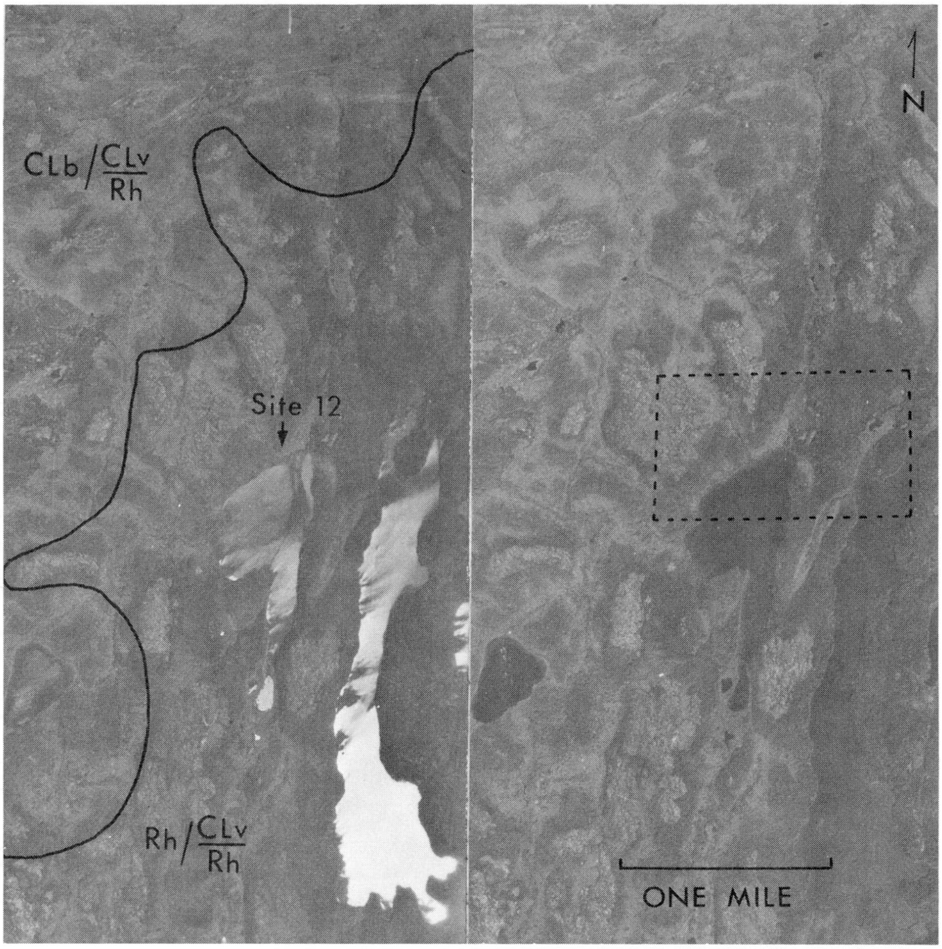

Figure 58.

Stereopair airphotos (A14984-125, 126) of Site 12 on the lee (down-ice) slope of a bedrock ridge. Rectangular area outlined by dotted lines is shown in Figure 59.

is on a low bedrock ridge within a clay basin between bedrock hills (Fig. 55).

Nature of the Material. Varved clay and silt, some 5 to 15 feet (1.5 to 4.6 m) thick, overlie a glacially polished, striated and grooved bedrock surface (Fig. 56). The silty layers are buff coloured and about double the thickness of the clayey, dark brown layers [less than 1 inch (2.5 cm) thick].

Vegetation, Drainage, and Permafrost. Prior to clearing, the well drained ridge crest was covered by a closed stand of predominantly poplar trees and the sides by spruce trees. There is no evidence of permafrost at this site.

Terrain Performance. The roadbed of clay, surfaced by gravel, has a smooth, even surface. Water erosion along the ditch has removed a considerable amount of the clay overlying the bedrock in about one year since the cuts were made (Fig. 57). Continued lateral erosion of the clay over a period of years undoubtedly will affect the stability of the roadbed.

Site 12

Location. The site is about 9 miles (14 km) northwest of Nelson House in the SW $\frac{1}{4}$ sec. 4, tp. 80, rge. 10 (lat. 55°54', long. 99°00').

Map-unit and Landform. Site 12 is within an area of closely spaced bedrock hills in part veneered with clay (Fig. 58). Clay basins occur between the hills but are more restricted than in the area to the west, and local relief commonly approaches 100 feet (30 m) or more. The ridge is about 3000 feet (915 m) long and 800 feet (244 m) wide (Figs. 59 and 60).

Nature of the Material. Gneissic rock with distinctive dark bands and 'augen' is exposed in the up-ridge road-cut (Fig. 61). The opposite cut is in bouldery till composed of large, angular boulders (Fig. 62). A silty sand matrix occurs between the angular rock detritus (Fig. 63). Patches of clay a foot or so thick overlie the bedrock and till.

Vegetation, Drainage, and Permafrost. A closed tree cover of mixed poplar and spruce along with some jack pine and birch occurs on most of the ridge. Patches of bedrock with scattered trees are present between

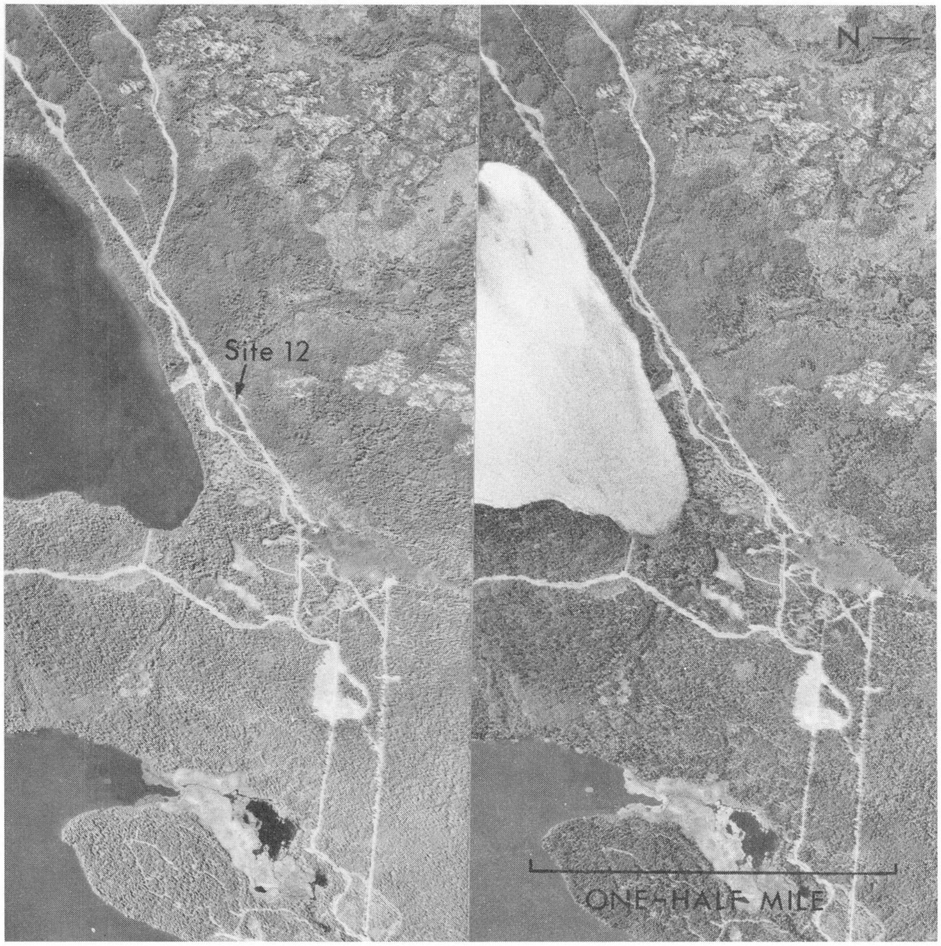

Figure 59.

Stereopair airphotos (A21122-31, 32) of the area outlined in Figure 58.

Figure 60. Road-cut through the lee slope of a bedrock ridge at Site 12. Undisturbed gneissic bedrock forms the cut on the left, whereas the opposite cut about 40 feet (12 m) farther downslope is in bouldery till. (GSC 163385)

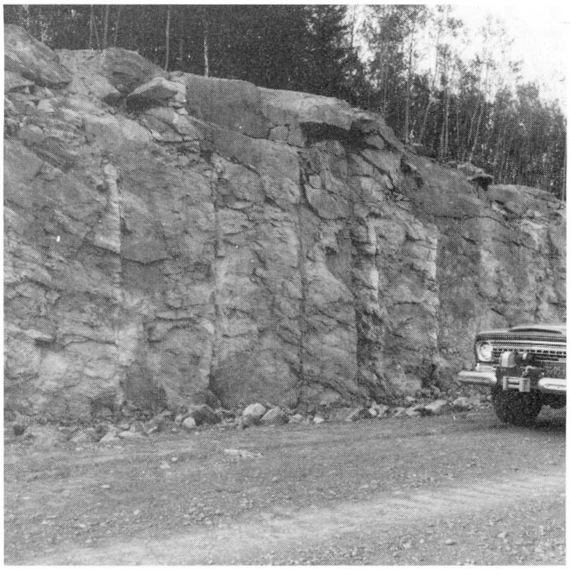

Figure 61. Road-cut in gneissic bedrock thinly venered in places with till patches and clay at Site 12. (GSC 163384)

Figure 62. Bouldery till exposed in the road-cut farthest downslope at Site 12. (GSC 163383)

the closed cover on the ridge crest. Permafrost does not occur on this ridge.

Terrain Performance. The initial high cost of construction across a ridge of this type in part is compensated for by permanent stability and low maintenance of the roadbed.

CONCLUSIONS

1. Airphoto interpretation and some ground checking permit identification of landforms and most surficial deposits of the Precambrian Shield terrain in north-central Manitoba. Airphotos (black and white) on a scale of about 1: 60 000 are adequate for reconnaissance mapping; airphotos on a scale of about 1: 16 000 are needed for more detailed mapping, particularly in areas of organic terrain.

2. Permafrost occurrence in certain types of organic terrain can be predicted by means of airphotos as can its absence from well drained, sparsely wooded landforms of mineral sediments. Its occurrence in certain fairly well drained, heavily wooded, north-facing slopes cannot be predicted by airphoto interpretation.

3. A roadbed of clay built across undisturbed frozen bog and unfrozen fen will develop some post-construction settling in one or two years. Settling results in broad dips and sharp breaks about one foot deep in the road surface. The sharp breaks commonly occur along the bog-fen boundary. Maintenance consists mainly of infilling the most severe breaks with sand and gravel.

4. Clay exposed in road ditches on the sides of clay-mantled hills, knolls and ridges with 3 to 5 per cent slopes (measured by Abney level) is rapidly eroded by spring run-off and rain storms. Narrow, steep-sided gullies up to 10 feet deep have formed in one or two years. The roadbed in places will be undercut and clay blockage of culverts will result if erosion is allowed to continue unchecked. Boulder facing of parts of the road ditch prior to gully development should control much of this type of erosion.

5. Ditches in clay slopes harbouring permafrost are less stable than the unfrozen slopes and may fail by earthflow triggered by gullying.

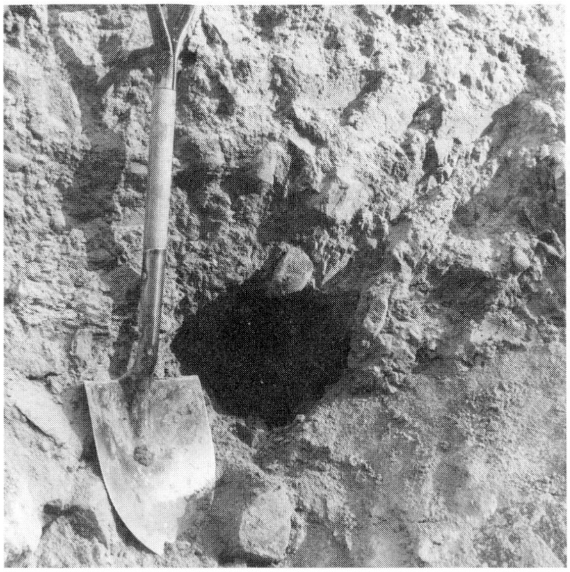

Figure 63. Close-up view of the bouldery till at Site 12. The cavity next to the shovel is probably the result of blasting during excavation of the cut. (GSC 163386)

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APPENDIX

Testhole Data and Soil Index Properties

Jean Veillette

Introduction

A total of ten holes were drilled and cored to a maximum depth of 29.5 feet (9 m) at Sites 2, 3, 5, and 9 (*see* Fig. 1, Text). Massive and varved clays, with and without permafrost, were penetrated in all of the holes. Coring logs for eight of these holes, together with results of water content, Atterberg limits, and grain-size analyses, are presented (Figs. A1 to A8).

Coring equipment consisted of split-barrel samplers of 1 3/8 inch I.D. (inside diameter) and 3 inch I.D., and a motorized cathead hoist clamped to a lightweight aluminum derrick. Casing was used in areas of wet, unfrozen material. A Haynes drill, equipped with a 1½ inch I.D. modified barrel and operated by a 5 hp. motor or by hand, was used for some holes in permafrost. Both pieces of equipment can be installed in locations inaccessible to heavier equipment.

Sampling Procedure

Cores were examined in the field for the occurrence of ground ice, then labelled and bagged in plastic sleeves for future detailed description. Core examination and selection of samples was done in a trailer kept at a temperature slightly below freezing in order to prevent thawing and allow a detailed description of ground-ice structure. Representative samples were selected for analysis of grain size and Atterberg limits. Samples taken for water content determinations consisted of long channel samples obtained by splitting the cores lengthwise. This procedure was adopted in order to minimize the variations in water content between adjacent dark and light layers in varved clays, and to provide a reliable water content value for a given length of core. All samples were then canned in air-tight tin cans using a hand-operated canner.

Soil Moisture

Water-content Profiles

On the basis of field observation of cores and study of water-content profiles, cores from boreholes 3A (Fig. A3), 9A (Fig. A7), and 9B (Fig. A8), appear to represent three different soil conditions: unfrozen stable conditions (3A), recent permafrost (9B), and low ice-content permafrost conditions (9A). The textural composition of soils at these three sites is very similar, and they occupy well drained elevated positions. Site 3A presents the lowest and most regular water-content profile (average 29.3 per cent - Fig. A9). Marked deflections (average 33.5 per cent) towards the wet side are present on the 9B profile, and 9A presents the highest water content (average 35.0 per cent). Although ground ice was observed in the cores of 9A, the water content is only slightly higher than 9B where unstable moisture conditions probably exist. Three liquid limits yielded values of 38.3 per cent, 38.1 per cent, and 36.6 per cent, and the water content at the 10.5 foot (3.2 m) deflection of the profile gave a value of 39.2 per cent. Testhole 9B is located on a bare slope (*see* Fig. 46, Text) on which the vegetation cover has been removed for about 3 to 5 years. The data analyzed here suggest that similar permafrost conditions, as those observed at 9A, may have existed at 9B prior to the stripping of the vegetation cover. The unfrozen material observed at the bottom of Testhole 9A and the gradual decrease in water content below 14.8 feet (4.5 m) suggest that the borehole may have penetrated below the permafrost body.

Testholes 9A and 9B exhibit contorted and deformed varve layers whereas unfrozen clays sampled elsewhere (Testhole 3A) have undisturbed varves. Though deformed varves commonly are associated with the geological history of the sediments, they may also be related to the presence, or recent presence, of segregated ice.

In the southern fringe of the discontinuous permafrost zone, the permanently frozen ground may be gradually thawing and in a state of "retrogression". Hardy (1965) stresses the importance of a close examination of water-content profiles to detect areas of recently thawed permafrost. Bulges towards the wet side in the natural water-content profiles (Fig. A9), particularly if the water content in the "bulge" exceeds the liquid limit for the soil, indicate that permafrost has recently existed at that site, and that the soil has not yet reached equilibrium following the thawing of the ice.

Water Content of Dark and Light Layers

Johnston *et al.* (1963) illustrated the difference in water content between adjacent dark and light layers in varved sediments. Water content results for eight samples including dark and light layers are shown in Table 1.

Table 1

Water Content for Adjacent Dark and Light Layers

Sample No.	Dark Layers	Light Layers
2A13	53.37%	31.79%
3A4	33.40	25.39
3A11	39.56	33.15
3B2	25.72	18.25
5B10	41.87	33.66
9A2	41.89	29.68
9A3	40.41	31.69
Unspecified	46.87	30.88
Average	40.38%	29.31%

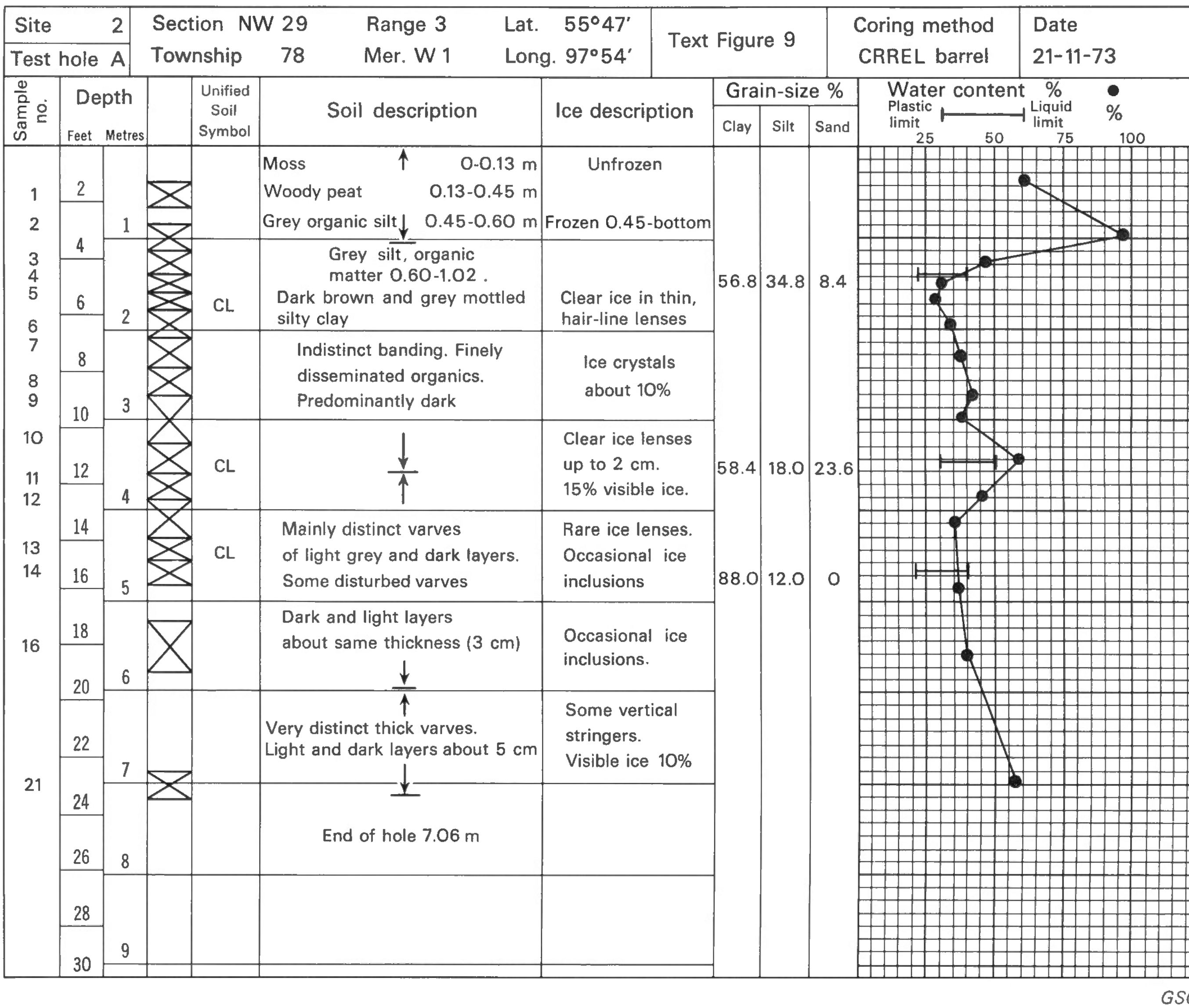

Figure A1. Field and laboratory data from Testhole 2A.

Site 2	Section NW 29	Range 3	Lat. 55° 47′	Text Figure 9	Coring method	Date
Test hole B	Township 78	Mer. W 1	Long. 97° 54′		CRREL barrel	22-11-73

Sample no.	Depth Feet	Depth Metres		Unified soil symbol	Soil description	Ice description	Grain-size % Clay	Silt	Sand
1	2				Moss 0-0.12 m Peat 0.12 -0.26 m	Frozen 0.50 m to 1.95 m			
2	4	1							
3	6			CL	Dark brown massive silty clay; wood fragments at 0.88 m. Compact	Clear ice crystals; lenses up to 2 cm. Visible ice 25%	70.0	27.6	2.4
4		2							
5	8				End of hole 2.18 m	Unfrozen below 1.95 m			
	10	3							
	12	4							
	14								
	16	5							
	18								
	20	6							
	22	7							
	24								
	26	8							
	28								
	30	9							

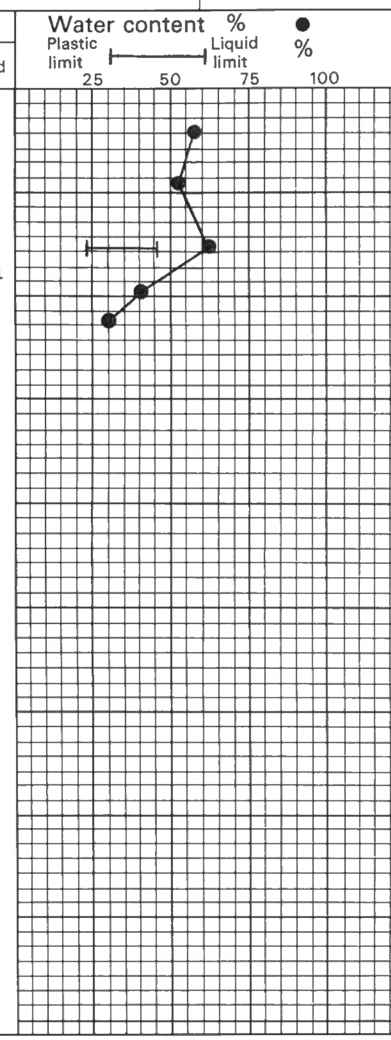

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Figure A2. Field and laboratory data from Testhole 2B.

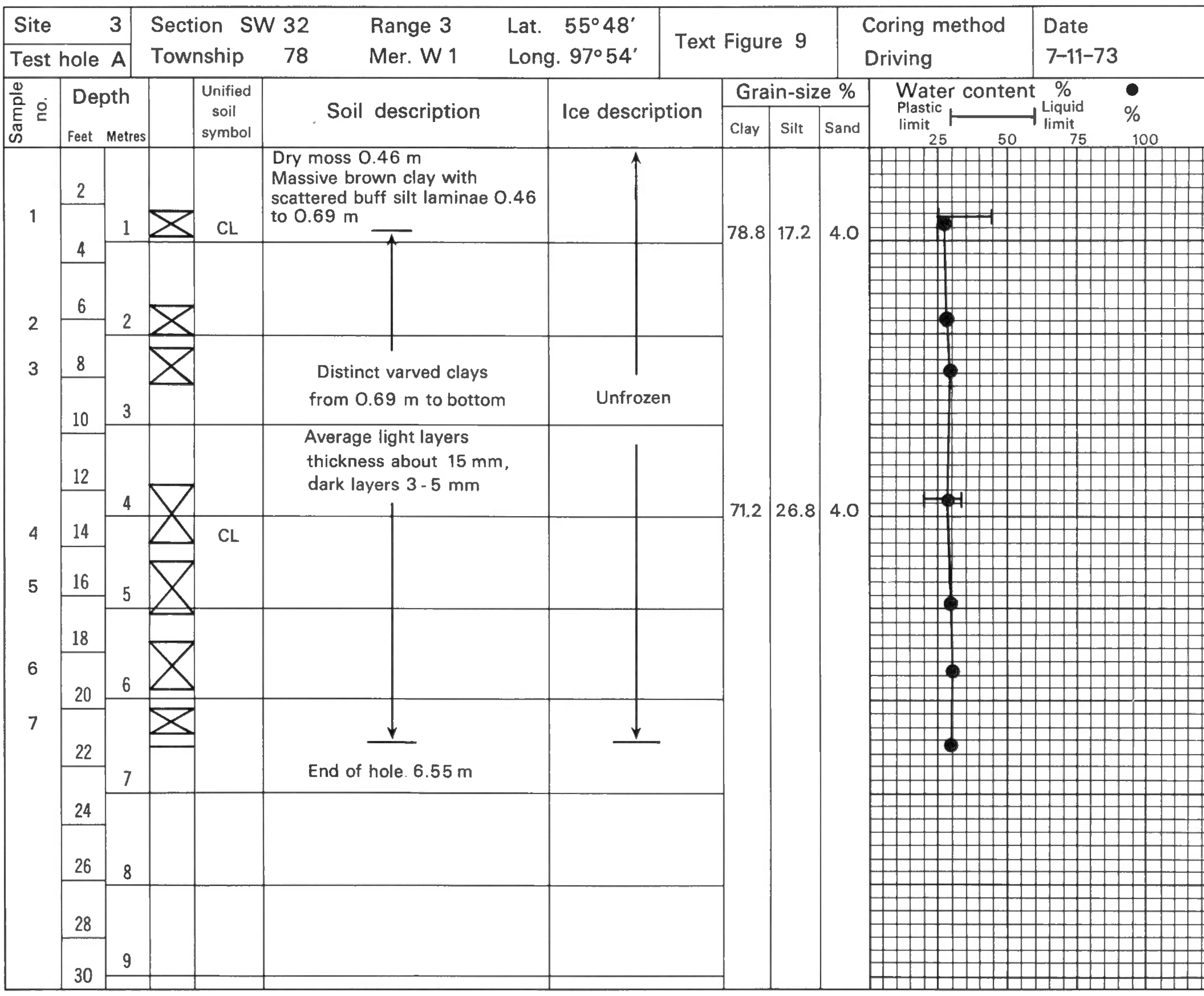

Figure A3. Field and laboratory data from Testhole 3A.

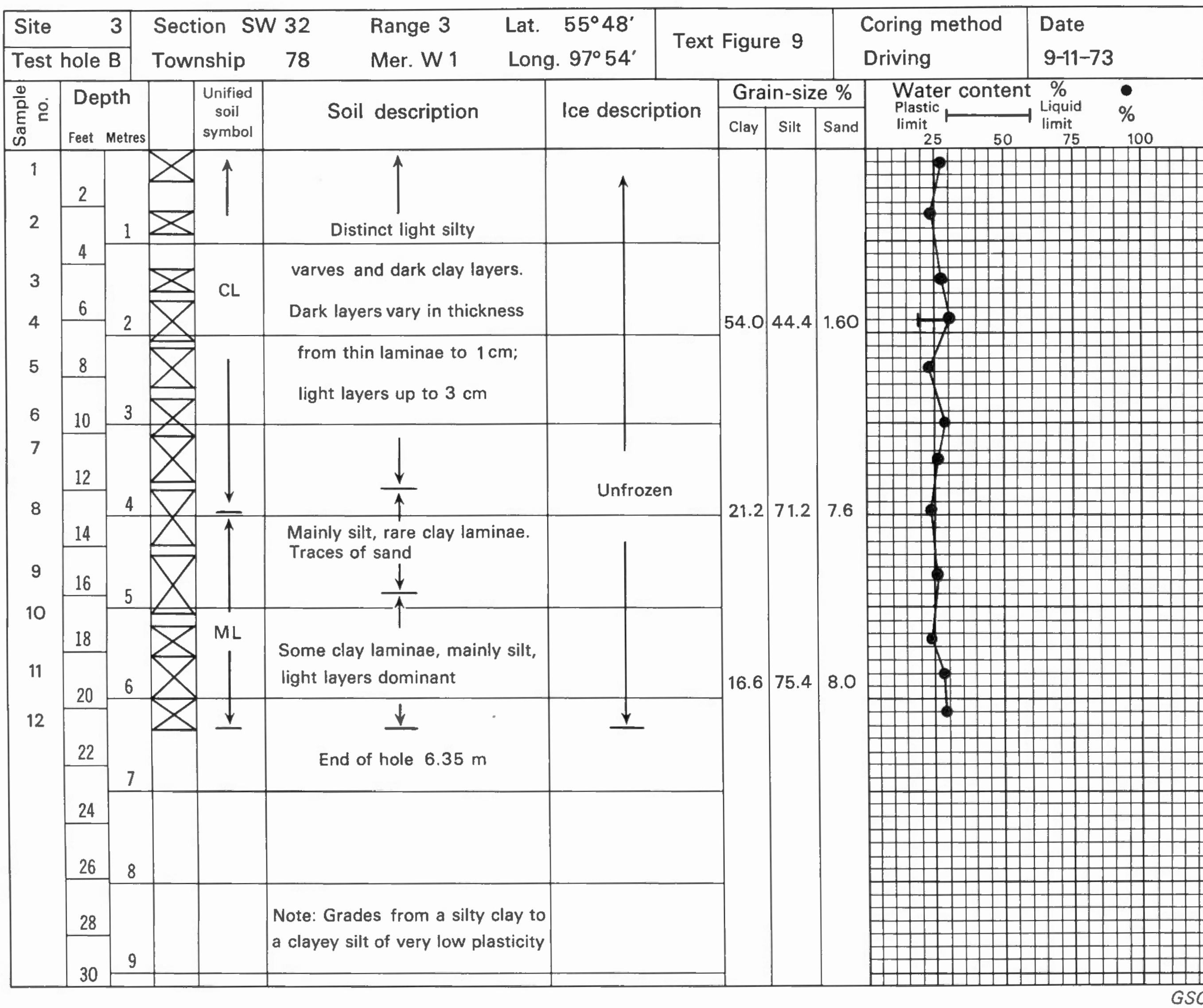

Figure A4. Field and laboratory data from Testhole 3B.

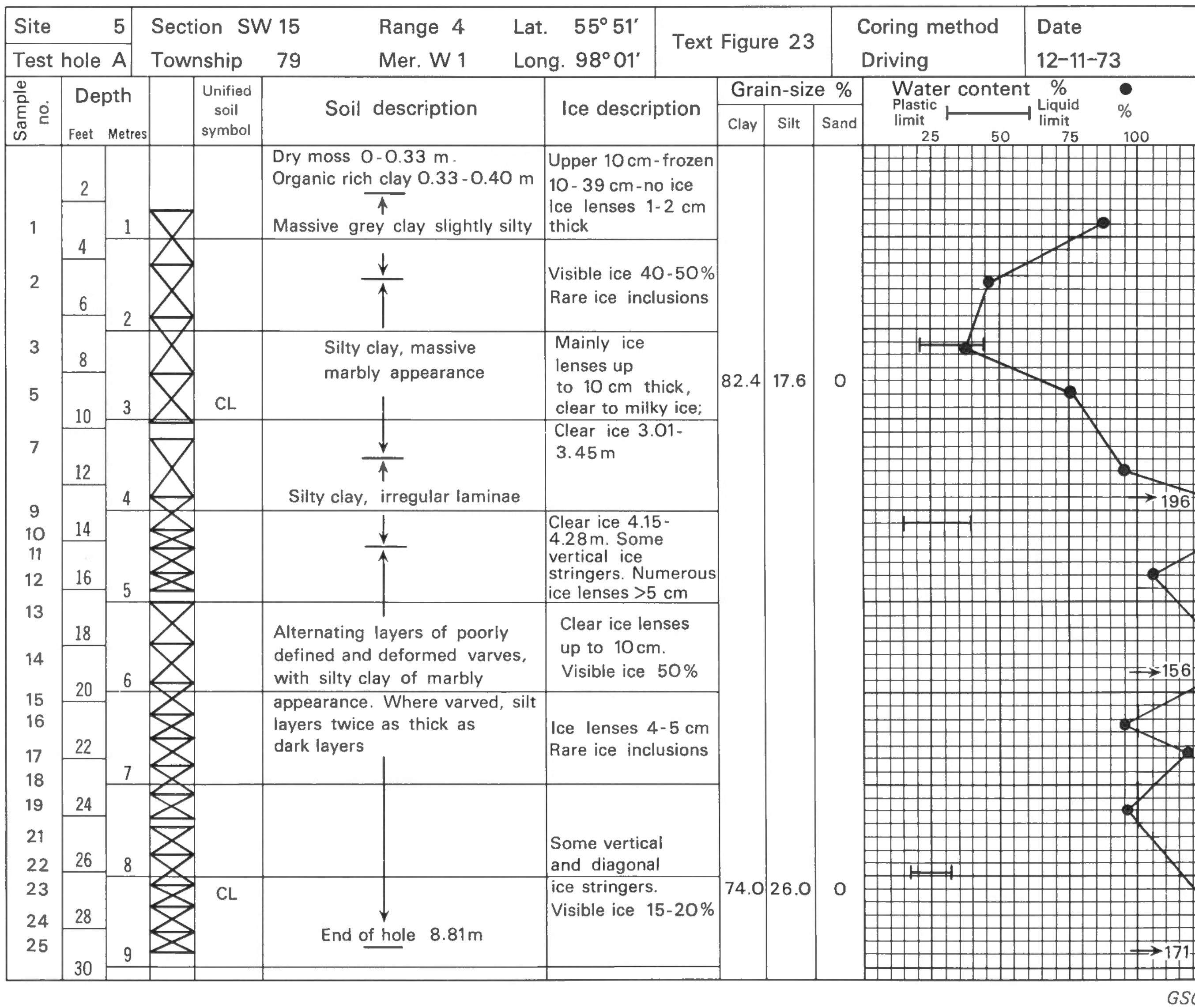

Figure A5. Field and laboratory data from Testhole 5A.

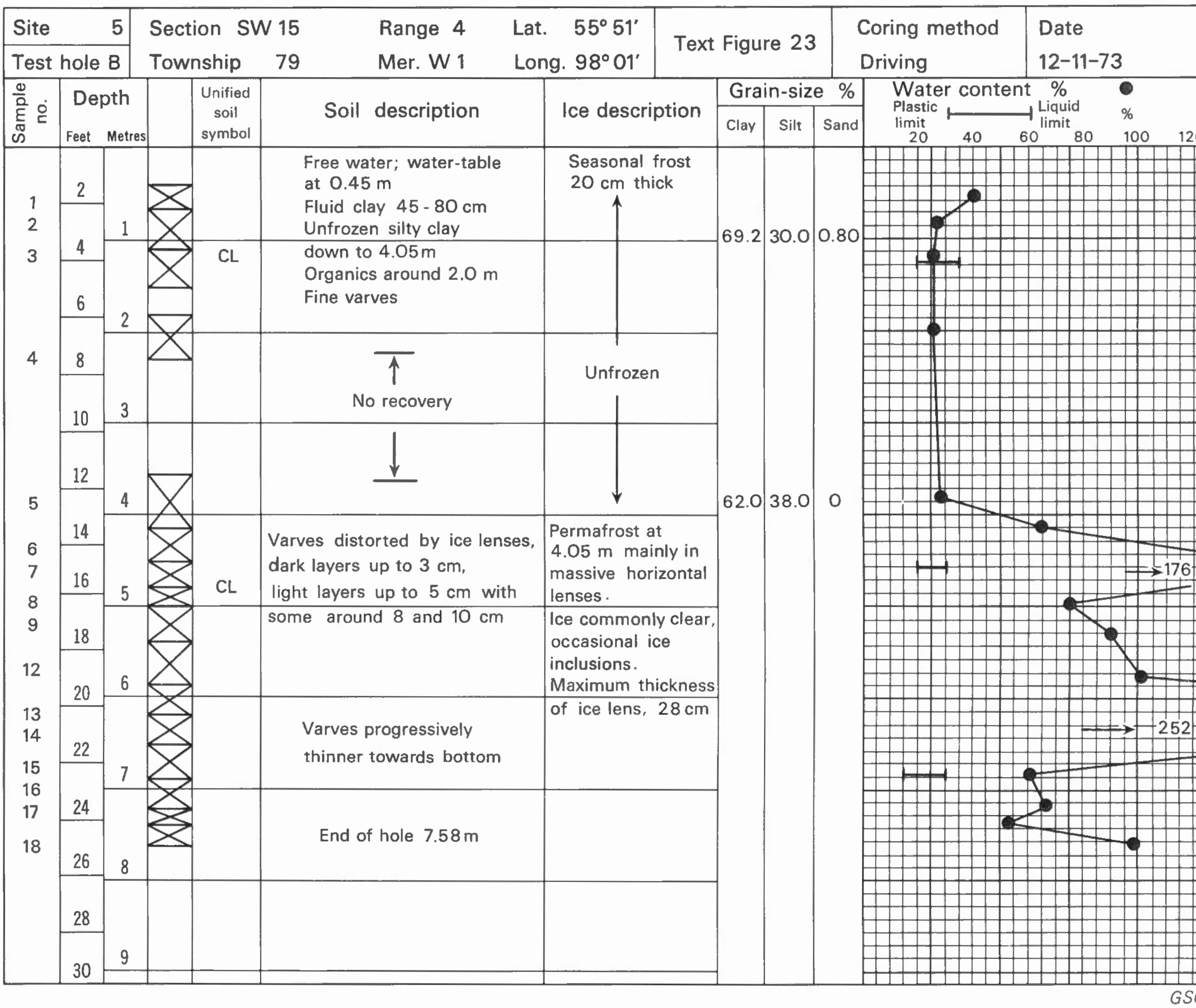

Figure A6. Field and laboratory data from Testhole 5B.

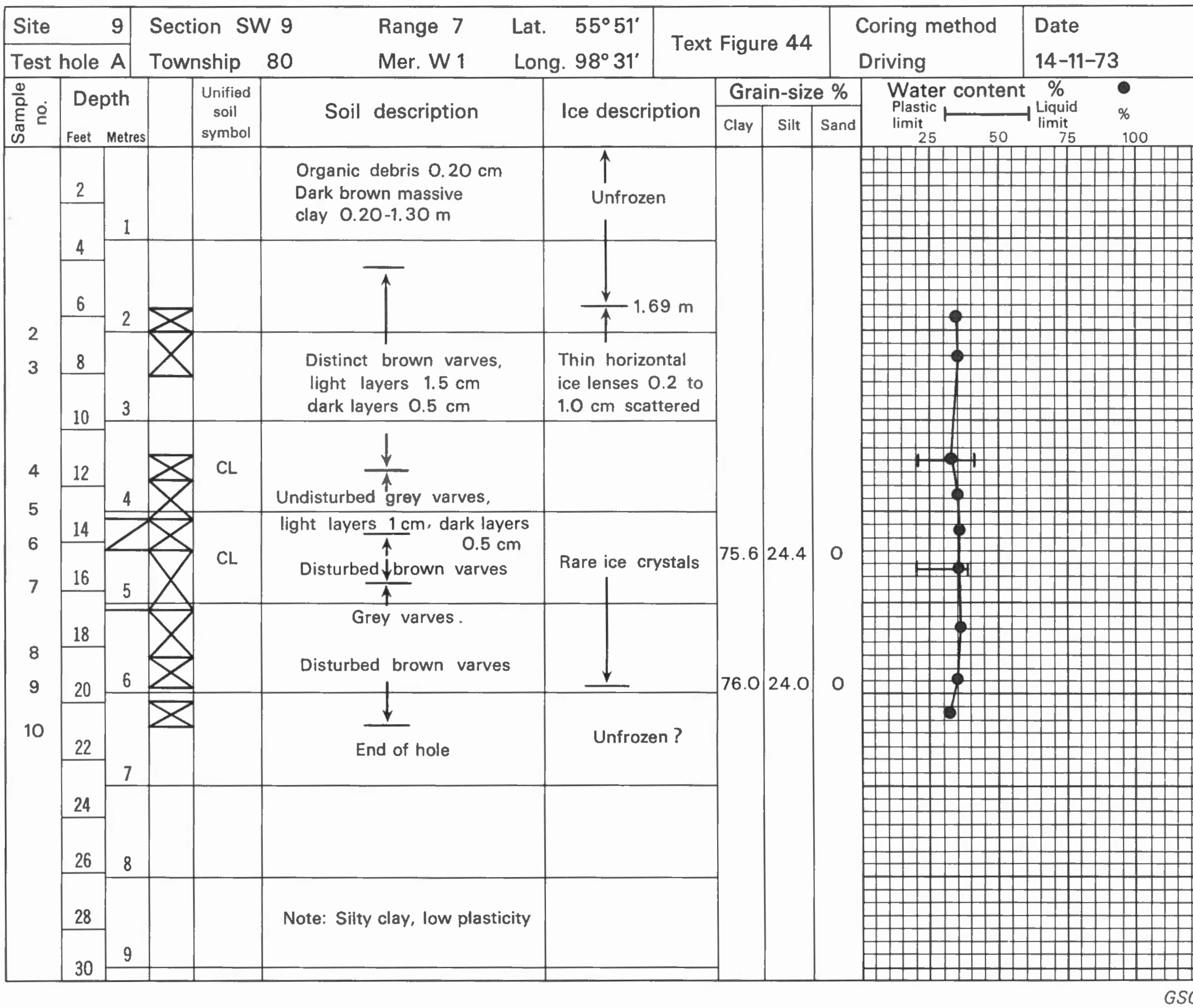

Figure A7. Field and laboratory data from Testhole 9A.

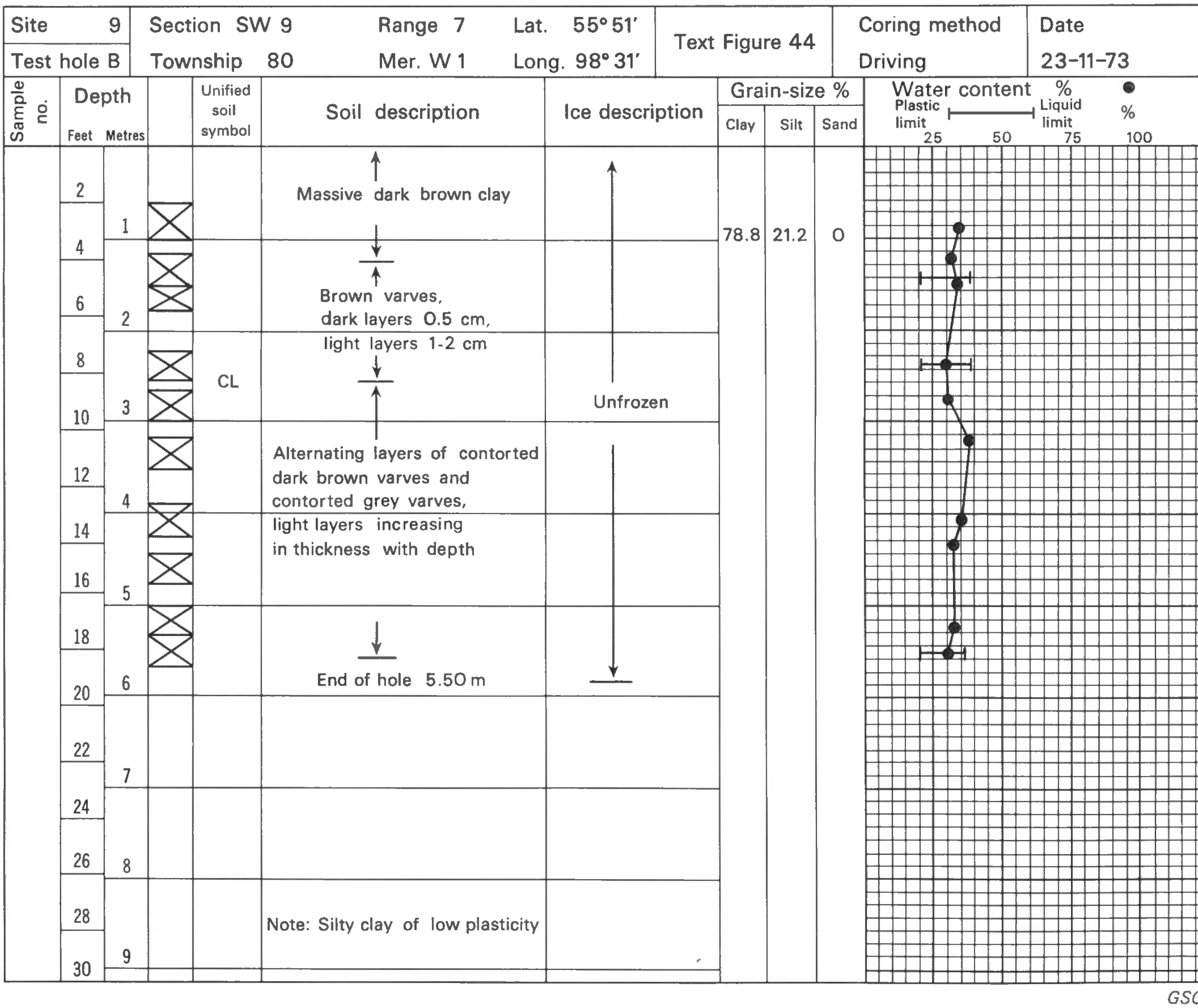

Figure A8. Field and laboratory data from Testhole 9B.

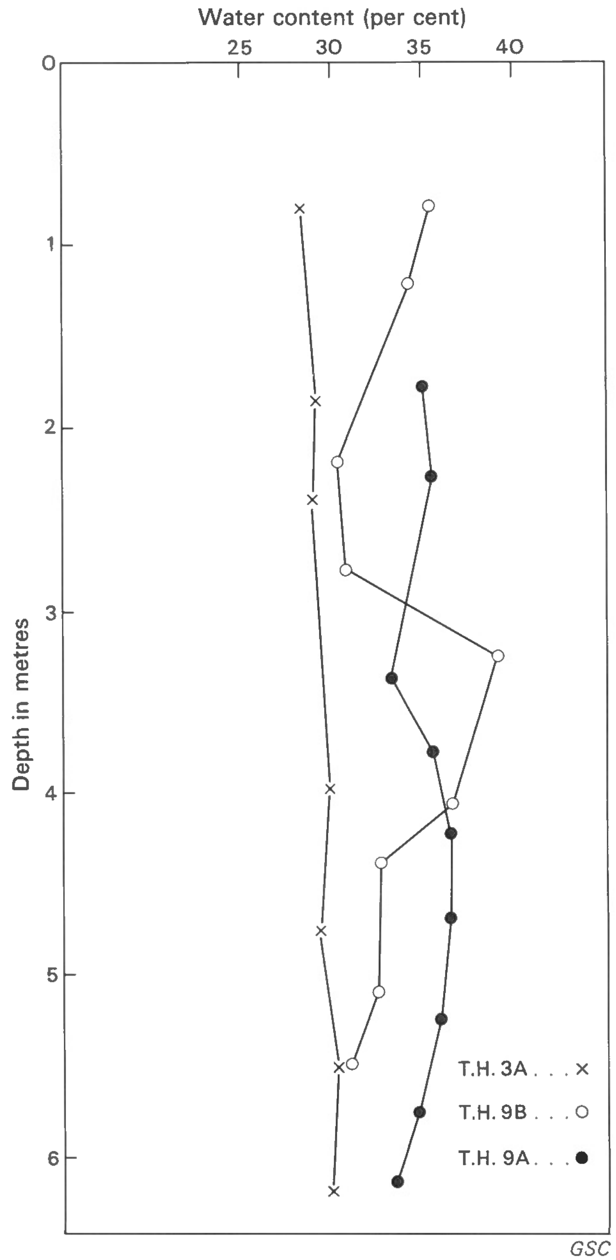

Figure A9. Water-content profiles for Testholes 3A, 9A and 9B.

Deflections in a water-content profile towards the wet side should not necessarily be interpreted as indicating retrogressing permafrost in varved sediments, because samples containing mostly dark layers will indicate higher water content than those containing mostly light layers. Where comparisons are made between boreholes, textures must be similar, as well as the ratios of dark material to light material. The sampling technique of securing channel samples up to 2.3 feet (0.7 m) long along the cores adopted for this project, appears to minimize this effect, as evidenced by the water profiles of Testholes 3A and 5B (uppermost thawed portion) where relatively straight plots are obtained.

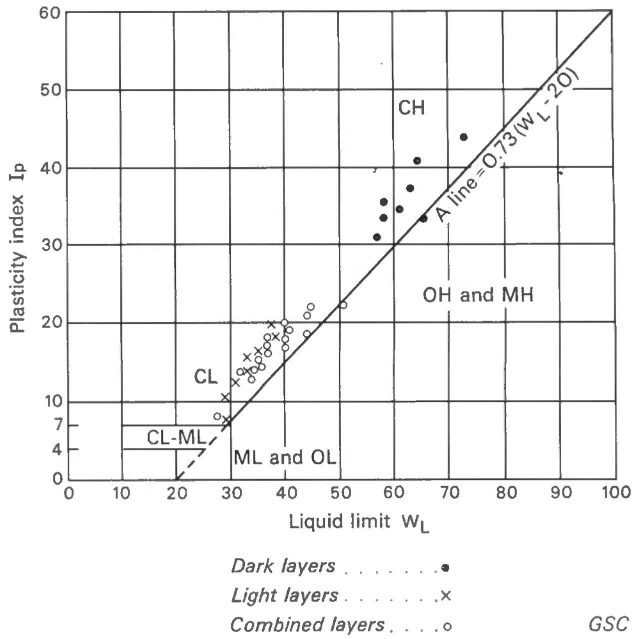

Figure A10. Plasticity chart of varved clays.

Grain Size

Grain-size analyses were performed on eighteen combined channel samples of dark and light layers. The method used was the 3-point hydrometer method for sand, silt and clay. Results of these analyses appear on the testhole logs (Figs. A1 to A8). Two separate grain-size analyses were performed on dark and light layers: 9B-3 (dark) with 90 per cent clay, 10 per cent silt and 9B-3 (light) with 62.4 per cent clay, 37.6 per cent silt. Grain-size analyses on combined samples indicate the predominance of the clay fraction over the silt fraction in most samples. The only exception to this general situation is at Testhole 3B (Fig. A4), where the bottom half of the hole consists mainly of light, silty layers. The highest sand fraction is also from this section (sample 3B-11, Fig. A4). The highest clay fractions were found at Testholes 5A (sample 5A-5, Fig. A5) and Testhole 2A (sample 2A-14, Fig. A1). Varves at Testhole 2A showed equal thicknesses of dark and light layers.

Atterberg Limits and Plasticity

Liquid and plastic limits obtained from eighteen channel samples are plotted on the testhole logs (Figs. A1 to A8). These results along with the liquid and plastic limits obtained from sixteen individual dark and light layer samples are plotted on a plasticity chart (Fig. A10). Dark and light layers used for the analyses were obtained from adjacent layers of Testholes 2A, 3A, 3B, and 9A, and at depths ranging from 3 feet (.09 m) to 22.8 feet (6.9 m).

The plasticity chart (Fig. A10) illustrates the marked difference in plastic properties between light and dark layers. The dark layers are made up of inorganic clays of high plasticity. Combined samples of light and dark layers would be expected to occupy an intermediate position along the A-line (Fig. A10). The combined samples considered here, however, indicate only very slight increases in liquid limits and plastic properties compared to the light-layer samples. This behaviour probably reflects the preponderance of silty material over clayey material for a given length of core, and is consistent with individual layer thicknesses as observed in the cores.

Activity

Varved clays at the Thompson townsite have been found inactive from previous investigations (Johnston *et al.*, 1963). The plotting of plasticity index versus clay fraction on Skempton's chart produced similar results. In fact, the assumption of a 100 per cent clay fraction for the dark layers would result in an inactive clay rating.

Permafrost

Ground ice was present in the shallow bog at Site 2 (Figs. A1 and A2) in the palsa and adjacent fen at Site 5 (Figs. A5 and A6) and in a clay-mantled bedrock ridge at Site 9 (Fig. A7). The water-content profiles of 5A (Fig. A5) and 5B (lowermost part) (Fig. A6), indicate a higher ice content when compared with Site 2 (Testhole 2A, Fig. A1). Testholes 5A and 5B present permafrost conditions associated with a palsa ridge. The presence of ice-rich permafrost at 13 feet (4 m) below the surface at 5B appears unusual; free water exists at the surface, and permafrost bodies in the discontinuous zone commonly are not found below the water-table. A tentative explanation for this situation could be that 5B is located on a former palsa ridge which has thawed and collapsed, allowing water from the nearby pond to invade the present site.

Results from Testholes 9A and 9B (Figs. A7 and A8) are believed to be associated with a permafrost body in a state of regression. This situation is discussed in the text.

Ground temperature measuring cables to depths of 20 feet (6 m) were installed at Testholes 2A and 5B and will be monitored.

References

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