GEOLOGICAL SURVEY OF CANADA
Miscellaneous Report 53

FIELD GUIDE TO THE

CHURCHILL REGION MANITOBA

Canada

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Glaciations, sea level changes, permafrost landforms, and archeology of the Churchill and Gillam areas

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FIELD GUIDE TO THE CHURCHILL REGION, MANITOBA

GLACIATIONS, SEA LEVEL CHANGES, PERMAFROST LANDFORMS, AND ARCHEOLOGY OF THE CHURCHILL AND GILLAM AREAS

Abstract

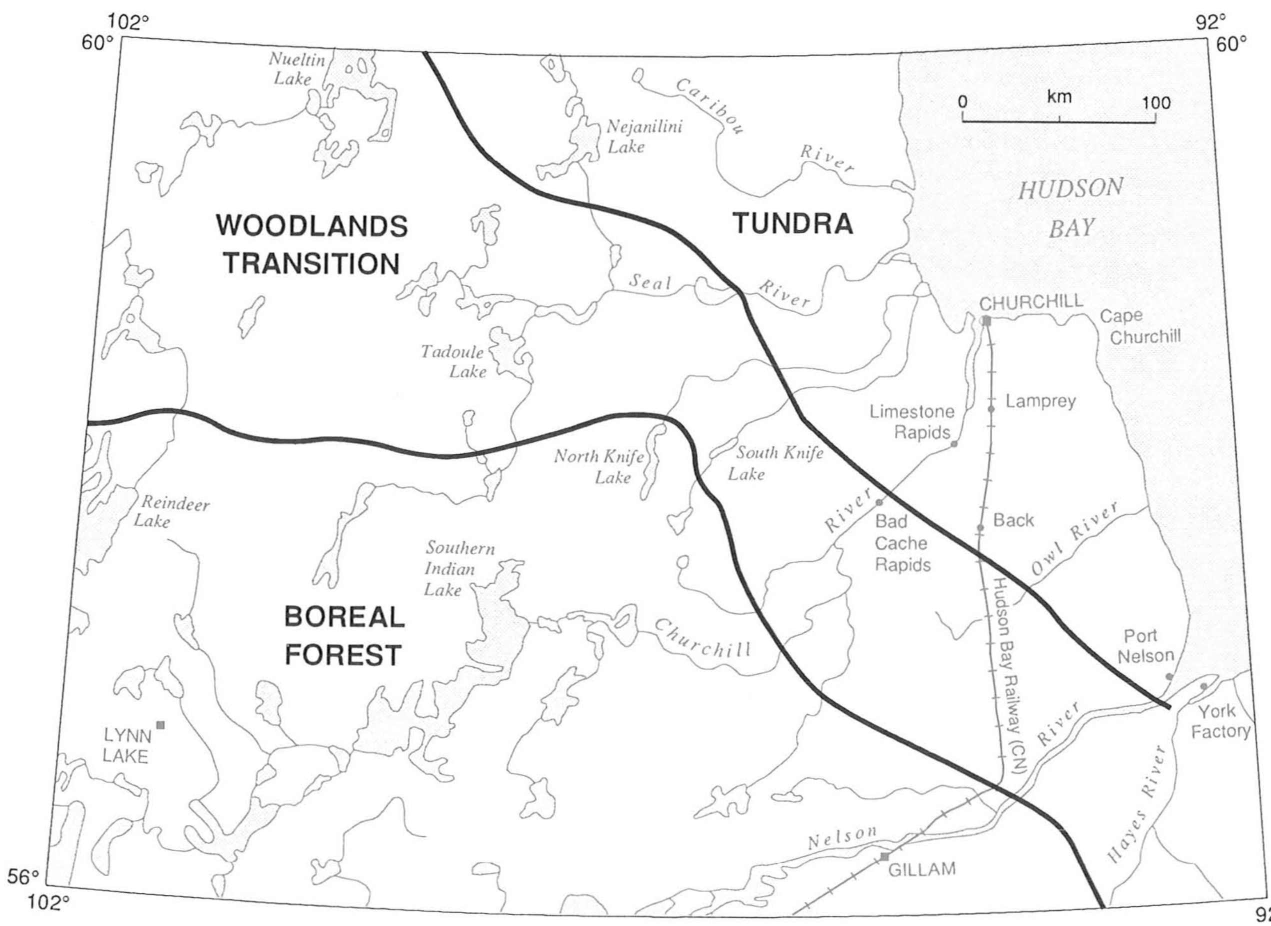
This guidebook presents the geological evolution, glacial history, sea level record, periglacial geomorphology and archeology of the Churchill region, and emphasizes some of the problems encountered with permafrost engineering. The first part of the guide presents a summary of the natural environment, explains how the land evolved, and how it is changing now. The second part gives site by site descriptions of specific features along several excursion routes in tundra and peatland environments at Churchill, across the Hudson Bay Lowlands along the Hudson Bay Railway, and into the boreal forest at Gillam. The cultural history of the area is described at the archeological sites on the west side of the Churchill estuary.

Résumé

Ce guide présente l'évolution géologique, l'histoire glaciaire, les changements du niveau de la mer, la géomorphologie périglaciaire et l'archéologie de la région de Churchill en mettant l'accent sur certains problèmes géotechniques liés à la présence de pergélisol. La première partie du guide donne une description sommaire de l'environnement naturel, expliquant l'évolution, passée et actuelle, du relief. La deuxième partie donne une description des éléments caractéristiques de chacun des sites situés le long de plusieurs itinéraires traversant une zone de toundra et des tourbières (à Churchill), les basses terres de la baie d'Hudson le long de la voie ferrée du Hudson Bay Railway et la forêt boréale (à Gillam). L'histoire culturelle de cette région est décrite au site archéologique situé sur la rive ouest de l'estuaire de la rivière Churchill.

Churchill is situated on the west coast of Hudson Bay at latitude 59°N (Fig. 1). This locale is especially good for examining the northern Canadian landscape because most of the permafrost forms associated with subarctic conditions are not only found here but can be reached by the existing road network. The first part of the guide summarizes the geography and geology of northern Manitoba. The second part describes specific features along several excursion routes around Churchill. From Churchill we head southward by rail across tundra barrens and boreal forest to Gillam, where the guide describes the main features between the townsite and Long Spruce Dam. The finest record of the ice ages in the Hudson Bay Lowlands are revealed in the cliffs along Nelson River downstream from the dam. A summary of that record is included in the guide, but most of the high cliff exposures are not described in detail because they are steep and dangerous.

Figure 1. Northern Manitoba: locations and vegetation zones.



Landscape Summary

Geological evolution of the landscape in northern Manitoba

Much of the terrain in northern Manitoba is a gently sloping plain that rises gradually inland from the coast at a rate of about 1.5 m/km, although the country is hillier in the northwest near the Saskatchewan border (Fig. 2A,B). The monotony of the tundra barrens in the north, the peatlands in the east, and boreal forest covered plains in the southwest is broken by rock knobs, small glacial ridges and hills, and relict gravelly strands formed by postglacial lakes and seas. Permafrost features such as palsas, ice wedges, and hummocks and hollows caused by the growth or decay of ground ice, provide most of the microrelief in the area. Some of the rivers in the region, such as Caribou River, flow in shallow, poorly defined channels. Others, such as Seal River and lower Churchill River flow in broad valleys. In a few places, such as Bad Cache Rapids, Churchill River has incised a deep gorge into bedrock and glacial deposits. The landscape reflects both its ancient and recent geologic history, with numerous cycles of rock formation, upheaval and tilting, and erosion.

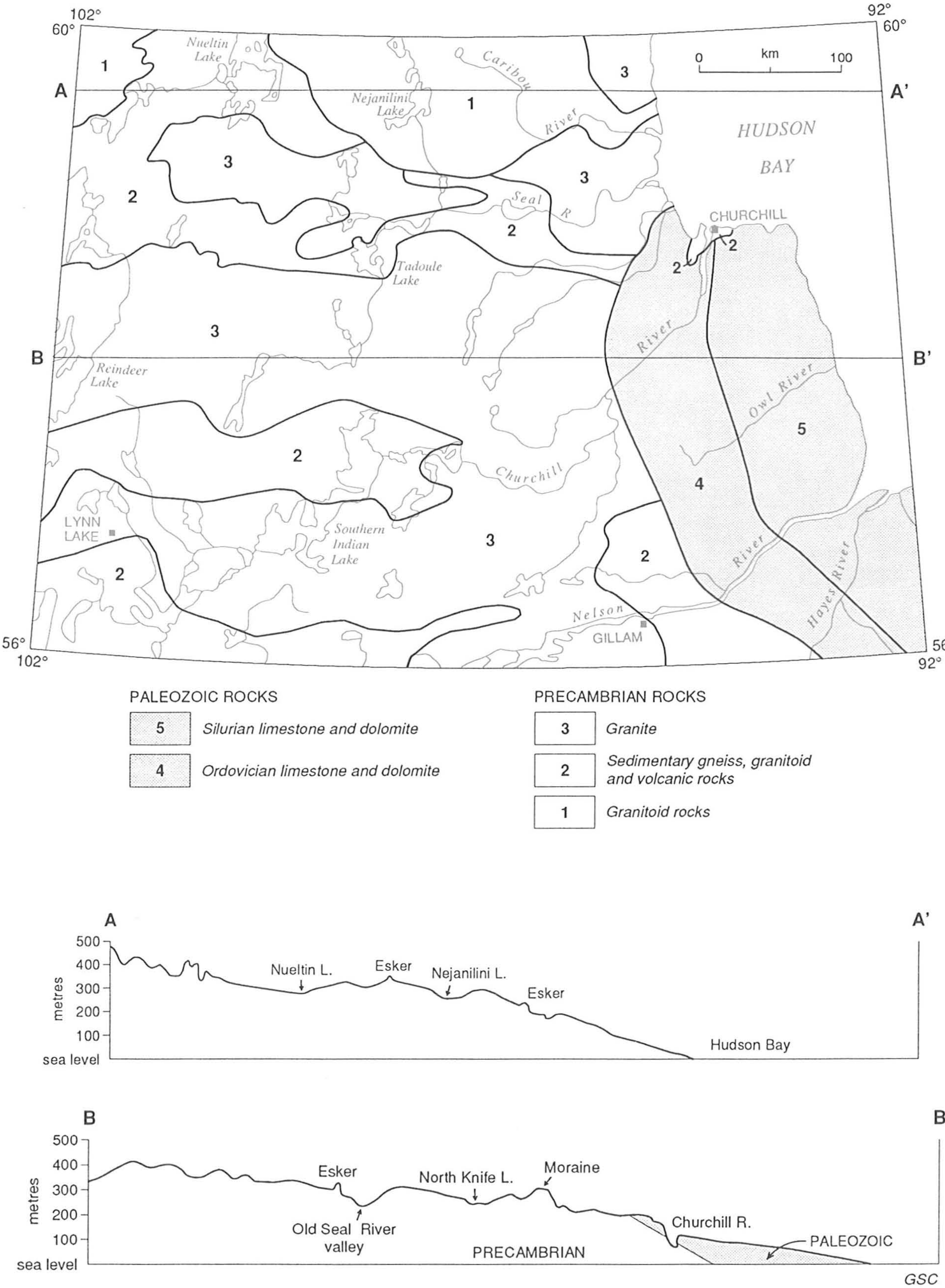
Precambrian geology and development of the Canadian Shield

In northern Manitoba, the Canadian Shield consists of several ancient remnants of the earth's original crust, flanked by belts of complexly deformed younger rocks. The oldest continental remnants are the Archean granitoid bodies near Nejanilini Lake (Fig. 2A, unit 1; Schledewitz, 1986). They formed during early crust-making events more than 2.5 billion years ago (Fig. 3). Younger rocks of Proterozoic age occupy the rest of the region, and are the roots of an extensive mountain belt. During various mountain building cycles, old crust was folded and faulted, new crust was created by vulcanism and intrusion of magma, and sediments were deposited. These events variously produced the Wollaston fold belt in the hilly northwestern part of the province, the Seal River volcanic belt (Fig. 2A, unit 2), and the granites in the Chipewyan batholith (unit 3). Among the youngest units are quartzites preserved near Churchill. They consist of now modified and strained sediments derived from the Proterozoic mountain belts whose roots form the present landscape. Much of the subdued topography west of Churchill River developed in Late Precambrian time. This old land surface can be traced beneath younger rocks and seen in cross section beneath Paleozoic rocks north of Isabelle Lake. The quartzites at Churchill, which were more resistant than the surrounding rocks, have been worn down less, and today stand out as ridges along the coast.

Paleozoic geology: creation of the sedimentary rocks of the Hudson Platform

Rocks of Paleozoic age were laid down as sediments in seas that transgressed and regressed over extensive parts of the Canadian Shield (Nelson and Johnson, 1966; Norris and Sanford, 1968). The sedimentary rocks in northern Manitoba were deposited into a basin centred east of the coast; hence, the sediment layers slope gently eastwards. During transgressions, areas that once were land gradually were covered by deepening bodies of water; during regressions, the deep water basins gradually became first shallow water environments, and then terrestrial areas. The sequence of sediments records these events. The basal units in a transgressive cycle are sandstone and conglomerate; these rocks formed where rivers transported sand

Figure 2A. Bedrock geology. Horizontal markers show the location of transects.
B. Topographic transects across northern Manitoba.



and gravel and dumped these sediments as deltas along the coast. Fine grained silty or clayey sediments and the calcareous remains of marine organisms were deposited in deep water open marine environments, and now form the limestones that make up much of the sedimentary strata and overlie the sandstones. Calcium-magnesium carbonates developed during regressions in shallow, lagoonal areas where conditions were highly saline; these sediments make up the dolomite seen today at the top of the sequences.

In the Churchill area four main groups of rocks record major marine cycles. The first two, called the Bad Cache Rapids Group, and the Churchill River Group, are found westwards of the airport, are Ordovician in age (Fig. 2,3), and were deposited between 440 and 500 million years ago. Those between the airport and Cape Churchill, belonging to the Severn River and Ekwan River Formations, are of Silurian age and were deposited between 440 and 395 million years ago. The main fossils found in the sedimentary rocks, are corals, brachiopods, cephalopods, gastropods and trilobites. Rocks younger than Silurian were probably deposited in northern Manitoba, but no record of them exists today.

The Paleozoic rocks were once far more extensive than they are today, as evidenced by the isolated remnants of limestone scattered across much of the Canadian Shield; all the younger rocks and much of the Paleozoic cover have been completely eroded away, exhuming the old Precambrian erosion surface west of the Paleozoic/Precambrian contact shown in Figure 2. Parts of Nelson and Churchill River valleys formed during these erosion intervals.

The ice ages: Quaternary glaciations and intervening warm periods

The youngest major geological events preserved in the Churchill area are the products of glacial epochs and warmer ice-free periods between them, called interglaciations. The ice ages began about 2 million years ago, and the last continental ice sheet - the Laurentide Ice Sheet - disappeared from the Churchill area about 8000 years ago. The glaciers scoured and eroded the exposed soil and bedrock, and in places, carved deeply into the bedrock. As they advanced, they transported the eroded debris for considerable distances and deposited it where

millions of years ago	ERA	PERIOD
present – 1.6 – 65	Cenozoic	Quaternary Tertiary
65 – 250	Mesozoic	Cretaceous Jurassic Triassic
250 – 570	Paleozoic	Permian Carboniferous Devonian Silurian Ordovician Cambrian
570 – 2500 – 4000+	Precambrian	Proterozoic Archaean

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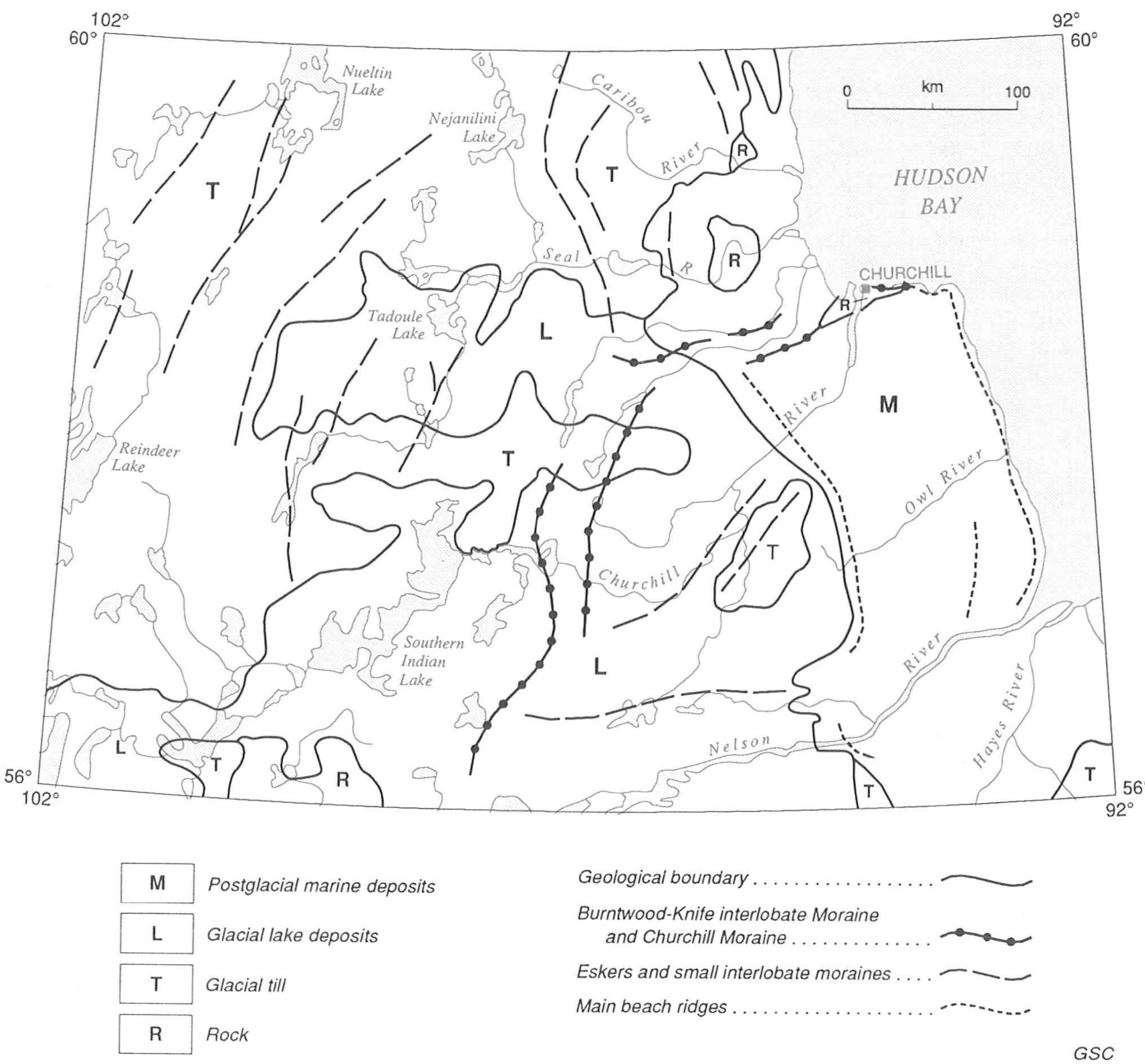
Figure 3.
Geological time scale, with ages in millions of years.

melting was occurring beneath, or at the front of, the glaciers. Glacial and postglacial deposits now cover most of the region (Fig. 4). Glacial deposits are fairly thin (5-20 m) at Churchill, but increase in thickness to 10-30 m farther south. The thickest deposits lie within Nelson River valley (75 m).

The ice sheet that covered most of Canada had several centres of outflow or accumulation areas: western Keewatin, central Quebec, the Maritimes, the Rockies, and at times northern Ontario and Hudson Bay basin (Fig. 5). During the ice ages, northern Manitoba lay near the zone of convergence of ice flowing southwards from the Keewatin ice centre, and ice flowing westwards from Quebec and Hudson Bay basin. Thus, at various times, the ice covering the Churchill area flowed in a different direction from that covering Gillam, so the glacial history at Churchill differs

Figure 4. Glacial geology.



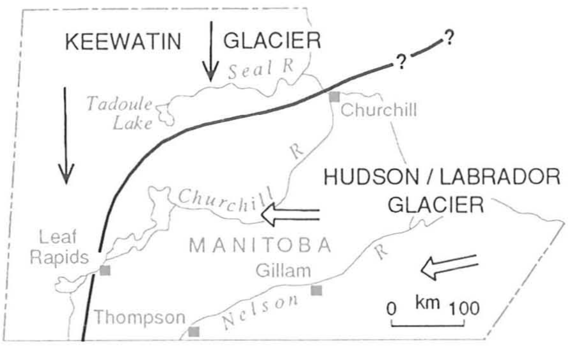
somewhat from that at Gillam. The history of the ice ages can be reconstructed from the different layers of glacial deposits because the various glaciers crossed different rock types. Ice flowing southwards from the Keewatin ice centre crossed and eroded Canadian Shield terrain and produced sandy granitic glacial debris (called till), whereas ice flowing westwards out of Quebec and Hudson Bay crossed limestone terrain and produced silty calcareous till. The nature of nonglacial periods between glaciations is determined by interpreting the sediments, pollen, vegetal remains including peat and wood, insects, bones, and shells lying between the layers of glacial debris. A detailed record of the last three glaciations and the intervening warmer periods is beautifully preserved in the sediments forming the cliffs along Nelson River east of Gillam, and along parts of Churchill and North Knife rivers. At Churchill, most evidence of former ice flow is preserved as erosional marks on bedrock.

Figure 5. Extent of the Laurentide Ice Sheet during the last glaciation, and major ice flow centres.

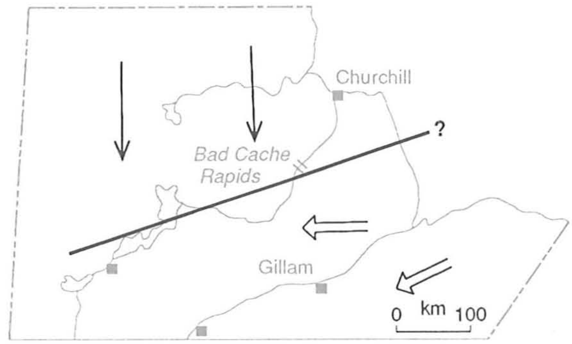
The first glaciation for which we have a record was a strong flow out of the Keewatin ice centre (Fig. 6, unit c); Keewatin ice covered the whole region. There followed a cool nonglacial period during which the ice melted. The area was then first covered by a large lake or sea, which left thick clayey deposits. As the land rose (rebounding from its reduced load of ice) and the water body receded, tundra-type vegetation covered the entire area. This interval lasted long enough for a deep soil to develop, the remains of which are seen in the cliffs at Sundance (Nelson River) (Fig. 6, unit D). During the next glaciation, the region was affected by both southward and westward flowing ice sheets. Ice flowing westwards from the Quebec centre reached as far west as Lynn Lake and probably as far north as Seal River (unit E). The rest of the region was covered by an ice sheet whose flow was influenced by the Keewatin ice centre. The following interglacial warm period, from about 125 000 years ago to 75 000 years ago, contained many features common to our present landscape (Dredge et al., 1990). As the ice sheets melted, the land was covered by a cold sea. As the land rose, the region became vegetated in a pattern similar to that of today; the northern edge of the boreal spruce forest lay in the Gillam area, while sites near Churchill and Port Nelson supported tundra moss, grass, shrub-sedge, and birch communities. Peat bogs were common, rivers flowed in Nelson and Knife River valleys although their courses differed slightly from today's and the banks of the Nelson were probably very low. Woolly mammoths, beavers, small mammals, beetles, and weevils roamed the area; snails and ostracods lived in freshwater ponds, and molluscs and foraminifera lived in the sea. Hudson Bay was an open marine environment, cold for much of the time, but one foraminifer species suggests that during part of the interglaciation water temperatures may have been as warm as those in the Carolinas today. At the beginning of the interglaciation the sea was as much as 160 m higher than present but gradually regressed to a datum below present sea level. Parts of Hudson Bay became dry land. The interglacial period was characterized by an initial cool period followed by a period warmer than present, a period when conditions were similar to those of today, and a return to a long, cool period that merged into the next glaciation.

Figure 6.
Cliff exposure on Nelson River near Sundance: (**A**) Precambrian bedrock at rapids; (**B**) Paleozoic limestone; (**C**) and (**E**) glacial till; (**D**) fossil soil horizon; (**F**) postglacial marine deposits of the Tyrrell Sea. (Photo E. Nielsen, Manitoba Dept. of Mines)

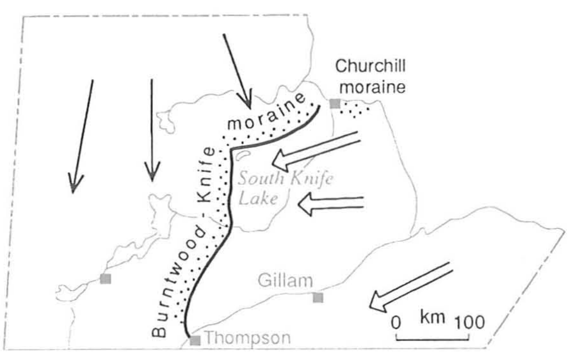
Figure 7. The ice ages: changing ice flow directions.



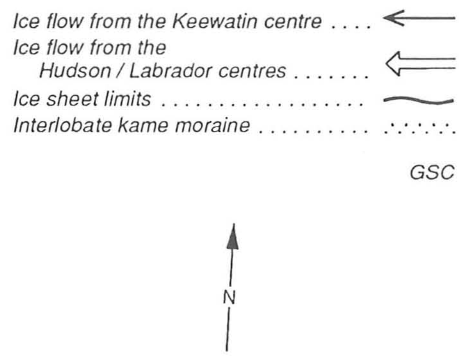
Stage 1. Extent of Keewatin and Hudson / Labrador ice early in the last glaciation



Stage 2. Intermediate



Stage 3. Keewatin and Hudson ice at the time of deglaciation



The last major glaciation to affect the area began as a vigourous westward ice flow across the Hudson Bay Lowlands that brought fossiliferous limestone debris as far west as Tadoule Lake (Fig. 7, stage 1). The Gillam area was covered by this westward flowing part of the ice sheet throughout the last glaciation. In the north, however, when the Keewatin ice centre became more vigourous, ice flowing southwards invaded the northern limb of the westward moving glacier. This southward flow reached as far south as Bad Cache Rapids, about 70 km south of Churchill (Fig. 7, stage 2). Development of a late ice centre in the Hudson Bay area reactivated westward flow, and pushed back the Keewatin ice almost to Churchill. The position of the confluence between the Keewatin and the Hudsonian parts of the ice sheet is marked by a large ridge of sandy gravel and glacial debris, called the Burntwood-Knife Moraine, which runs northwards from Thompson to South Knife Lake, and then arcs eastwards in segments towards Churchill (Fig. 4 and Fig. 7, stage 3). This ridge developed progressively as the ice front retreated; the southern part of the ridge is about 1000 years older than its northern part. The final position of convergence between the two ice masses is marked by a string of boulders forming the Churchill Moraine.

After the ice ages: glacial lakes and postglacial seas

Because drainage into Hudson Bay was still blocked by the ice sheet in that basin, and because the earth's crust had been depressed by the weight of ice, a glacial lake developed in front of the melting ice. This gigantic lake, called Glacial Lake Agassiz, covered much of the mid-continent (Fig. 8). The lake extended over the Gillam area

Figure 8. Parts of Manitoba and adjacent provinces covered by Glacial Lake Agassiz.

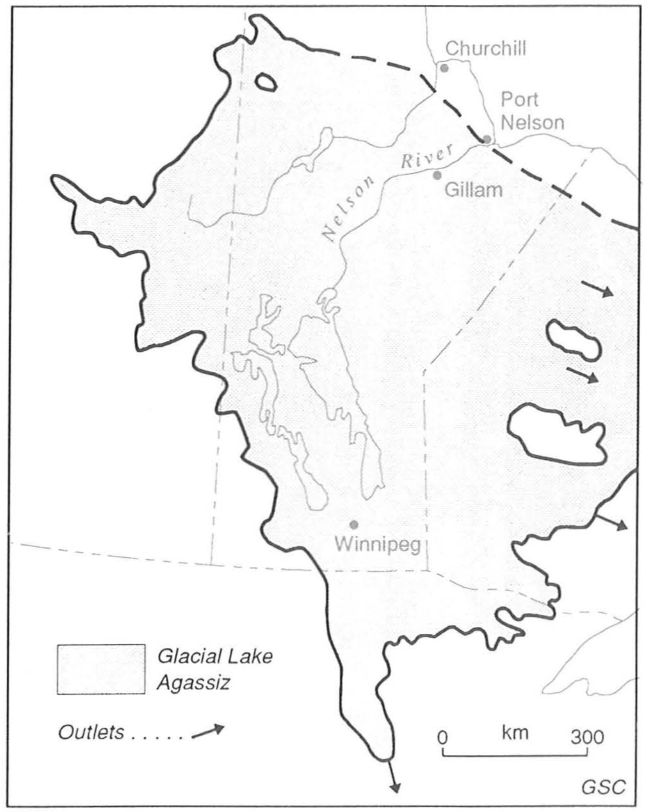
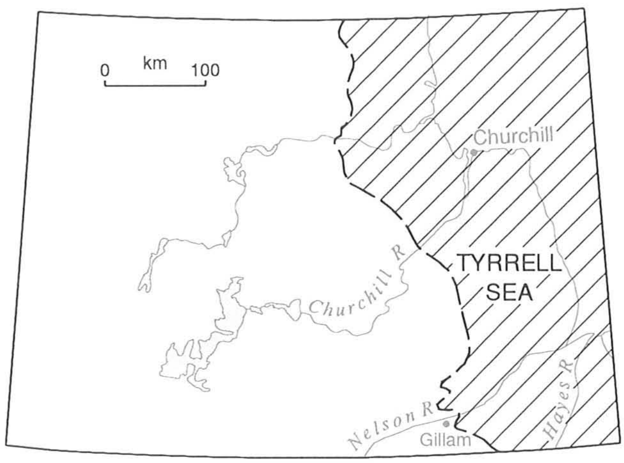
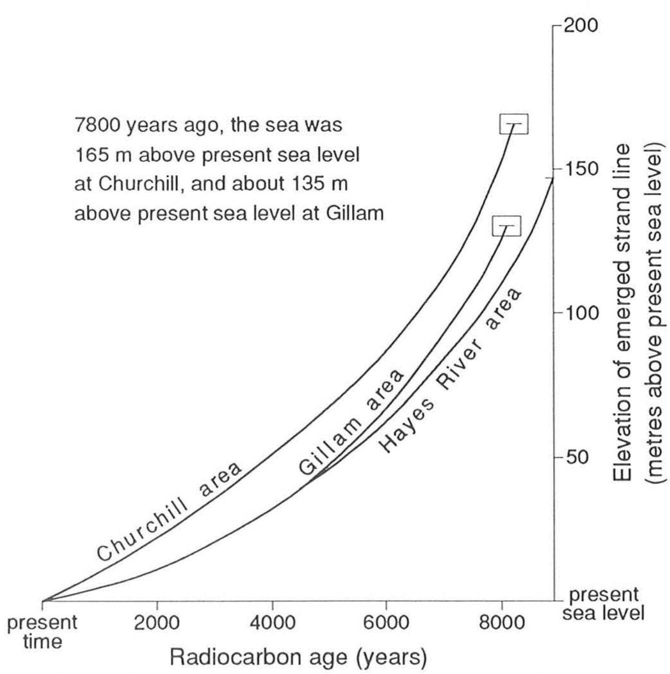


Figure 9. Raised beaches formed during the regression of the postglacial Tyrrell Sea and emergence of the land. Photo taken near the mouth of Whale River, looking north. (GSC 204860-B)

Figure 10. Sea level changes: 8000 years of emergence. Shaded pattern shows area inundated by the Tyrrell Sea.





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as far east as Port Nelson. It reached as far north as North Knife River but probably did not reach Churchill (Dredge and Nixon, 1990). Underwater moraines, deltas and layered clay deposits (varved clays) were deposited into the lake: they blanketed the glacial deposits, filled in irregularities in the topography, and made extensive areas almost flat. Icebergs breaking off from the ice front into the water drifted across the lake, grooving the lake bed where their keels scraped the bottom. These crisscrossing linear grooves can still be seen from the air near Winnipeg and between Gillam and Churchill. The shape of Glacial Lake Agassiz constantly changed in response to the opening and closing of outlets as the ice margin melted back. The lake ended suddenly about 7800 to 8000 years ago when the ice mass blocking drainage into Hudson Bay disintegrated.

Tyrrell Sea is the name given to the marine water body that flooded the Hudson Bay Lowlands following deglaciation while the land was still depressed by the weight of the glaciers. The sea was deepest immediately following deglaciation and extended about 100 km inland from the present coast (Fig. 4). As the land rebounded in response to removal of the ice load, the sea regressed to its present level of Hudson Bay. The highest beach formed by this sea lies at about 122 m above present sea level (a.s.l.) near Gillam and about 165 m a.s.l. northwest of Churchill. The two beaches formed at the same time, about 8000 years ago: the differences in elevation are caused by different styles of crustal rebound and warping caused by the different ice loads in the two areas.

As the sea regressed from its inland position to the present coast it left muddy deepwater marine sediments capped by a series of relict, sandy, gravelly beach ridges marking former strandlines (Fig. 9). Fossil marine shells from these deposits have been radiocarbon dated to determine the rate at which the crust rebounded and the land emerged. Figure 10 shows how sea level has changed. It indicates that the sea flooded the region between 7700 and 8000 years ago and that initially the sea was more than 100 m higher than present (actually that the land was 100 m lower), and that the crust was depressed more in the Churchill area than in the Nelson River valley. The land emerged (rebounded from its ice load) rapidly immediately after the ice melted, and the rate of emergence has been slowing down since then. The land around Hudson Bay is still slowly rising, and between Cape Churchill and Port Nelson, where tidal flats extend seawards for about 6 km, the coastline is moving out into the bay at a rate of about 40 m per century.

The rate of present uplift based on radiocarbon dates is similar to the rate calculated by other methods. The historic record of the tide gauge near the grain elevator also gives an average rate of vertical uplift of 40 cm per century.

Although rock, glacial deposits (till), and marine deposits are exposed at the surface at Churchill, the entire area to the south is mantled by icy peat deposits. Peat began to accumulate when the glacial lakes drained and the postglacial sea receded. The peat is thickest (about 4 m) in areas that drained more than 6000 years ago and thinnest in recently emerged areas near the coast.

Rivers

The present course of Churchill River between Limestone Rapids and Bad Cache Rapids (Fig. 11) probably developed after the ice ages, although channels carved into the bedrock beneath Hudson Bay suggest that a preglacial major river system occupied the present Churchill estuary and flowed across the floor of the Bay during Tertiary times (about 2 to 65 million years ago) when sea level was much lower than present. The main branch of the earlier Churchill River, however, flowed from Southern Indian Lake northward through the valley now occupied by the lower reaches of the modern Seal River and into Hudson Bay about 50 km northwest of Churchill. The other major river in the area, the Nelson, has re-occupied a major river valley which may have developed in Precambrian times (the shape of the valley can be seen below Paleozoic cover rocks). The course of Limestone River, near Gillam, occupies a valley eroded by subglacial meltwaters. The other rivers developed entirely in postglacial times. Drainage over much of the region is exceptionally poor, because of the extremely gentle regional slope of the land, low local relief, and general impermeability of the fine grained, ice bonded substrate. Many streams flow in either shallow or poorly defined channels. Standing water covers more than 50% of the land surface between Churchill and Gillam in summer.

Climate, vegetation, and permafrost

Climate and climatic change

Churchill now experiences a marine subarctic climate and is highly influenced by air masses in Hudson Bay. Gillam lies on the border between maritime and boreal air masses; summer weather there varies greatly from day to day. Mean annual air temperatures are -7.3°C at Churchill and -4.8°C at Gillam. Daily means at Churchill range between 12°C for July and -28°C for January; at Gillam they range from 15° to -26°C. Precipitation averages 400 mm annually at Churchill airport and 280 mm at Gillam. At both sites, about half the precipitation falls as snow. Prevailing winds are from the northwest, in both winter and summer.

Pollen studies from cored bogs, and relict stands of aspen and white spruce in northern Manitoba and Keewatin, indicate substantial migrations in the tree line since the ice sheets melted about 8000 years ago. Warm climate prevailed until about

Figure 11.
Churchill River near Bad Cache Rapids, showing Precambrian rocks at river level, gorge walls of Paleozoic limestone, and tree covered glacial deposits on the slope above.
(GSC 200841-B)

7000 years ago, followed by a cooler period during which peat began to accumulate (Fig. 12). Nichol's (1967) climatic reconstructions show that the forest tundra margin was once 300 km farther north and that summer temperatures between 6000 and 3500 years ago were about 3°C warmer than at present. A cooling period occurred between 3500 and 1500 years ago, followed by a warming trend (the Medieval Warm Period), which lasted with minor fluctuations until 600 years ago. Cooler conditions have prevailed since that time. Whether we have begun a climatic cooling and are part way into the next glacial epoch, or whether the cooling trends are short term fluctuations remains to be seen.

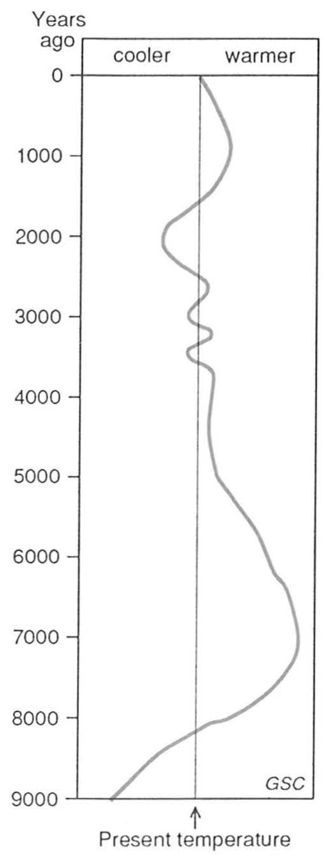

Figure 12.
Temperature changes in northern Manitoba as reflected in changing vegetation patterns (after Nichols, 1967).

Figure 13. Ground temperatures in permafrost terrain at Churchill (after Brown, 1978).

	BEDROCK (°C)			CLAYEY SOIL (°C)			DRY PEAT (°C)			WET PEAT (FEN) (°C)		
	Average	Summer	Winter	Average	Summer	Winter	Average	Summer	Winter	Average	Summer	Winter
Surface	-2.3	+12	-15	-4	+1	-12	-2.5	+2	-10	0	+7	-2
5 m depth	-2.3	+3	-10	-3	-2.5	-3.5	-2	+1	-2.5	0	+1.5	-1.5
10 m depth	-3.2	+1	-5	-3	-2.5	-3.5	-1.5	+0.5	-2	0	+0.5	-1

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Vegetation

The vegetation of the Churchill area is discussed in detail in other handbooks. Northern Manitoba spans three vegetation zones (Fig. 1). A tundra zone characterized by subarctic shrub heath and stunted, scattered spruce covers the northeastern part of the region. Sphagnum and sedge peatlands supporting heath-lichen vegetation are widespread in coastal lowlands. Treeline runs diagonally across the region, from northwest to southeast. Within treeline, the northern part is open spruce-lichen woodland; the southern part lies within the closed boreal forest. Spruce is the dominant tree type, although pine, birch, tamarack, and alder are also common. In many places the spruce forest grows on thick peat deposits.

Permafrost and ground ice

Most of northeastern Manitoba lies in the region of continuous permafrost (perennially frozen ground), although at several drillsites near Churchill, in wet fen, permafrost was not encountered. Permafrost is about 80 m thick at Churchill (it thickens inland and disappears offshore) and about 25 m thick at Gillam, which lies at the southern limit of continuous permafrost. No permafrost is encountered south of Thompson.

Soil temperatures depend on air temperature, the inherent physical properties of the various soil materials, and their moisture contents. At Churchill the average surface temperature of both rock and mineral soil is -2° to -4°C (Fig. 13; Brown, 1978). At 5 m depth, soil temperatures fluctuate between -3° and +1°C, whereas bedrock fluctuates between -10° and +5°C. The maximum ground temperature in the heathland peat is -4°C. Depth of seasonal surface thawing (active layer depth) depends on water content. The active layer increases from about 50 cm in the relatively dry heath peatland, to 60 cm in moist peat, and to about 15 m in fens. The active layer is about 1 m thick in exposed mineral soil.

At Gillam there is commonly no permafrost in exposed gravelly beach deposits and kames, but permafrost conditions persist in forested, peat mantled areas.

Information on the distribution and type of ground ice comes from features visible on airphotos (frost polygons, palsas, and thaw-flow slides), from smaller features seen on the ground, and from subsurface drilling investigations using power augers. Both the forested bog and polygonal peat are ice rich. Peat displaying polygonal surface cracks contains huge amounts of segregated ground ice in the form of ice wedges. In addition, the average ice content of the peat between wedges is 22% by volume. This ice occurs as coatings around organic fibres, small crystals, thin laminae, and layers of ice up to 10 cm thick. Commonly an icy layer lies at the contact between peat and the mineral soil beneath. Cores taken through forested peat and palsa bog show similar ice types, contents, and distributions. Ice contents of the mineral soils underlying peat are highly variable. Silty and clayey till and emerged, fine grained marine deposits contain high ice contents in their upper 3 m but become less icy with depth. Where glaciolacustrine deposits are composed of very fine clay, some capillary moisture remains in an unfrozen state despite subzero soil temperatures.

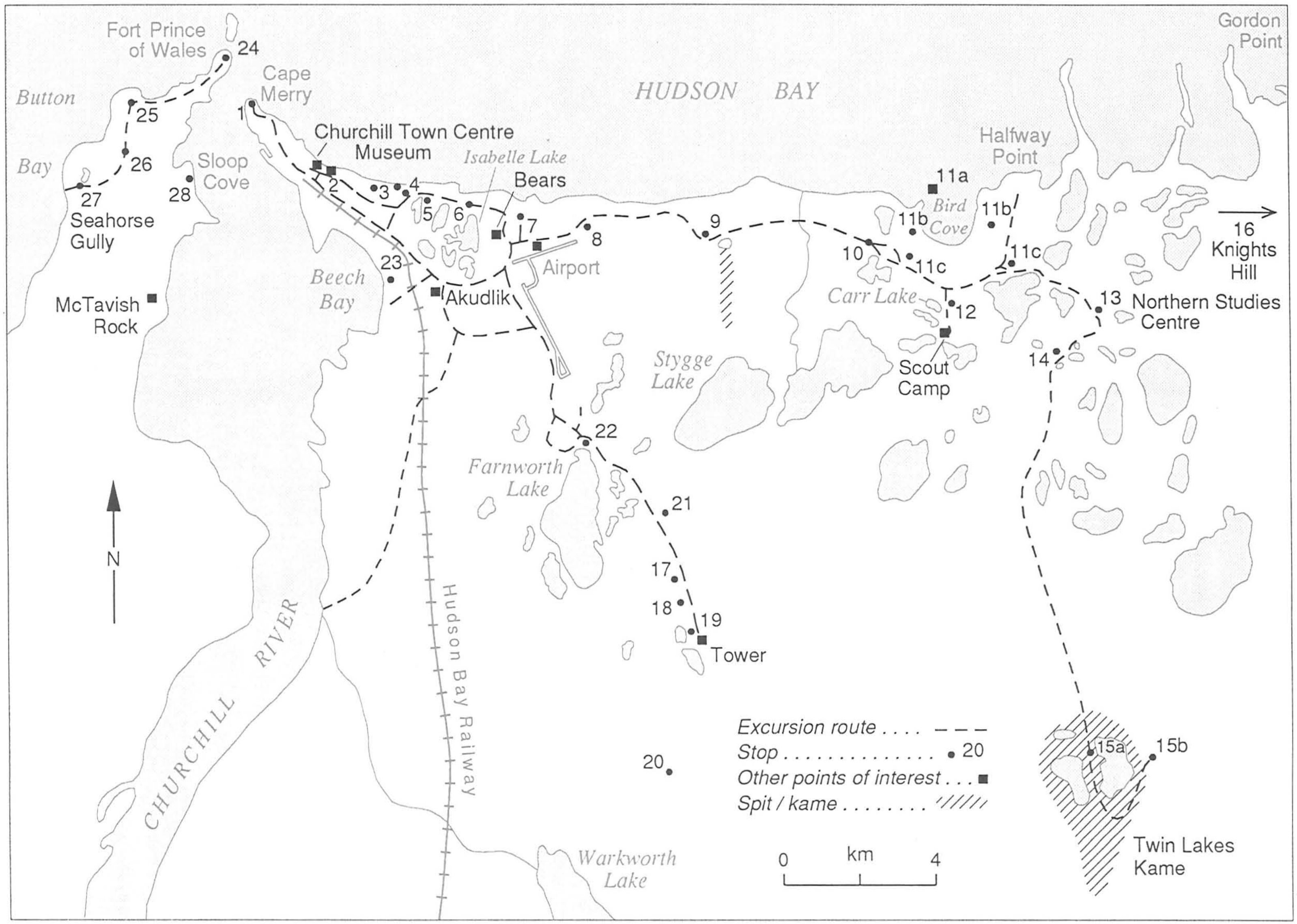

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Figure 14. Excursion routes and stops, Churchill area.

EXCURSION ROUTES AND GUIDE TO SITES (FIG. 14)

Cape Merry to the Town of Churchill

Follow the gravel road from the grain elevators to the Parks Canada booth at Cape Merry. This headland was named after John Merry, deputy-governor of the Hudson's Bay Company from 1712 to 1728.

Stop 1 Cape Merry

Cape Merry provides an interesting starting point for the excursion because all elements of the natural and historic heritage of the Churchill area are represented. The rocks are Precambrian quartzites and greywackes whose original sedimentary structures (mainly crossbeds) are still visible in some places. The east-west cracks are rock joints. Younger Paleozoic rocks lie directly offshore. The rocks at Cape Merry have been polished and trimmed by glaciers, mainly from the Keewatin ice centre, which flowed southwards across this area, creating a sequence of striae (scratches), grooves, and crescentic fractures (e.g., Fig. 15) trending southwards at a bearing of 160° to 180°. There are also faint scratches in some places that indicate an earlier flow westwards by ice from Hudson Bay. The rocks were swept clean of glacial debris by waves when sea level was higher.

Flowers and shrubs typical of the tundra barrens grow near shallow ponds among the rocks. The Cape is also an excellent vantage point for watching terns, jaegers, and shorebirds, or the pods of whales that inhabit the estuary throughout the summer. Ringed seals lie offshore on the ice in Hudson Bay, and polar bears wander across the headland in late summer and fall.

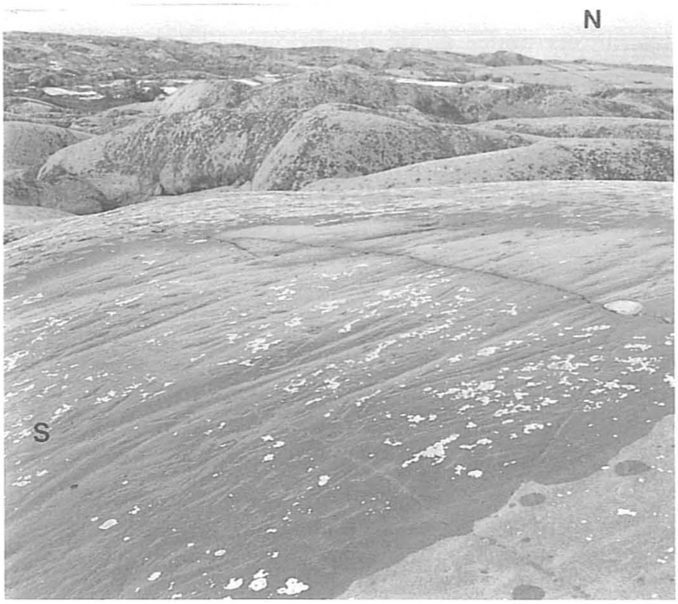


Figure 15.
Glacial scratches on the rock surfaces at Cape Merry. Ice flowed from north to south.
(GSC 205238-B)

An old powder magazine and six-cannon battery overlook Churchill River, complementing the defence system of Fort Prince of Wales, visible across the river.

Follow the gravel track back to the paved road and the grain elevators. Churchill is the terminus for the Hudson Bay Railway. Since 1931, prairie grain has been brought by rail to the docks and then shipped to Europe. The shipping season lasts from July to October.

Stop 2 Town centre and museum

Churchill's town centre was constructed in the 1970s, as one of the first town centres designed for northern living. The administrative offices, recreational facilities, library, hospital, and schools are all housed in a single complex. The Eskimo Museum, founded by the Oblate Fathers, houses various pieces collected during their mission work. The museum contains Canada's finest collection of Pre-Dorset, Dorset and Thule artifacts of ivory, stone and wood, as well as contemporary carvings and textile artworks.

Coast Road from Churchill to Airport

Stop 3 Boreal Gardens (private property)

3a Greenhouse. The greenhouses are part of an experiment to assess the potential for growing produce under northern conditions of abundant natural summer light, but low air temperatures. A variety of different greenhouse configurations have been constructed, and different arrangements of plastic and glass are being tested. The present electrically heated greenhouse maintains an inside temperature above 0°C for 6 to 7 months. It supplies vegetables and bedding plants for sale and personal use.

3b Mudboils. Along the side of the driveway above the greenhouse is a series of small, active mudboils which have developed in the veneer of gritty marine silt and stony till (glacial debris) overlying the surrounding bedrock (Fig.16). These features were first noted in 1980 and have been seasonally active since that time. Partially vegetated, inactive or intermittently active mudboils can be seen nearby where stony marine silts mantle the bedrock.

3c Windmills. Churchill is exposed to fierce winds from Hudson Bay. An experimental vertical axis wind turbine was erected in 1981 to test windmill operations under arctic conditions. The windmill was financed by National Research Council of Canada and is connected with the Manitoba Hydro power grid. It turns about 80 rpm and frequently has to be damped because the winds are too high. The windmill has been generating about 40 megawatts per year (5 kilowatts per hour), which is equivalent to 1-2% of Churchill's demand for power. Because the windmill is connected to the power grid it does not supply power directly to the greenhouse or residence.

Stop 4 Rocks between Boreal Gardens and Isabelle Lake

4a Protoquartzite. The grey rock ridge between Churchill and the airport is composed of proto-quartzite. The rocks are the lithified, metamorphosed remnants of sand and mud that were deposited in an alluvial, river mouth environment about 1800 million years ago. They consist of rounded, sand-sized quartz grains, along with finer sericite and chlorite micas. Black specular haematite, blue lazulite in quartz veins, pyrite, green malachite, and zircon are also present. In some places fine, dark layers of haematite grains trace out festoon crossbeds and ripple marks

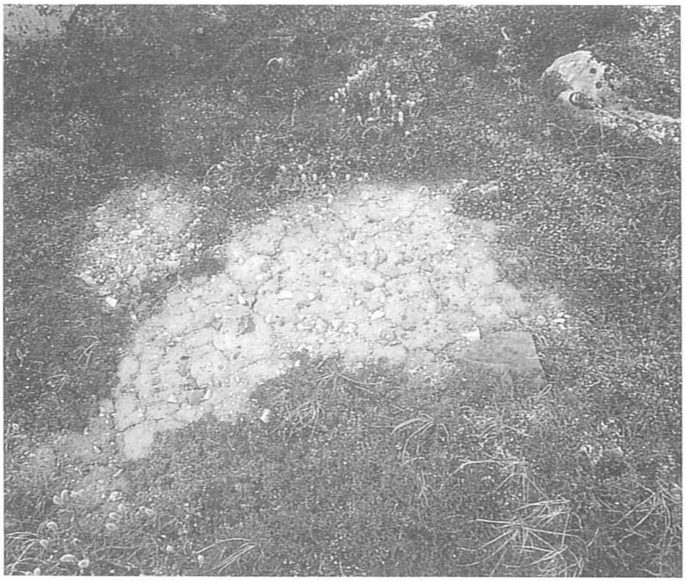


Figure 16.
Active mudboil.
(GSC 204314-D)

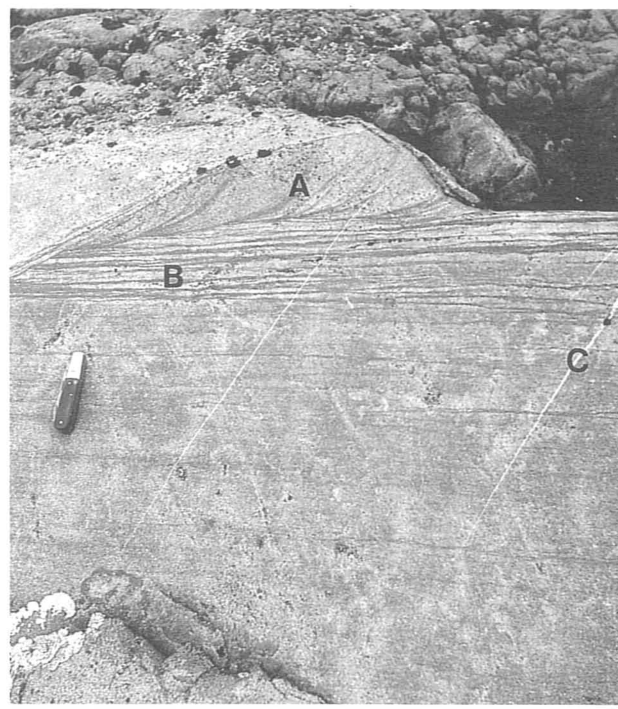


Figure 17.
Protoquartzite outcrop. Original sedimentary structures such as crossbeds (**A**) and laminae (**B**) are accentuated by dark iron grains. Quartz veins (**C**) which formed during subsequent metamorphism crosscut the strata.
(GSC 138277)

Figure 18.
Gently dipping Paleozoic strata of limestone and dolomite in foreground, with Precambrian protoquartzite forming the ridge in the background and the small dark rock knobs that protrude through the limestone strata.
(GSC 205238-D)

that are part of the original sedimentary structures (Fig. 17). These structures are best seen on clean, wet surfaces. Rounded whitish pebbles of quartz and quartzite can be seen within the rock. Many of these are zoned with weathering rinds around their edges. Some of the pebbles are elongate as a result of having been squashed during later metamorphism. White quartz veins fill fractures in the rock.

4b Limestone. *Proceed across the rocks and descend to the Hudson Bay coast.* Buff-coloured Paleozoic carbonate strata are exposed in a cove along the shore, where they dip gently into Hudson Bay (Fig. 18). These rocks are only about 420 million years old and contain Ordovician fossil corals, brachiopods, and trilobites. Fossil ripple marks, similar to modern ripple marks which form in the sand at low tide, can be seen in the limestone. The rocks exposed here are part of a marine formation. The uppermost strata, exposed at water level, contain numerous rounded cobbles of the older proto-quartzite. These clasts may have been incorporated into the old marine beds in Paleozoic times in the same way as the modern beach shingle and gravels are being incorporated into the sand and mud at the base of the rocks along the present shore. The contact between the Paleozoic and Precambrian bedrock is an ancient erosional unconformity, marking one of the periods of subaerial erosion and peneplanation of the Canadian Shield.

Stop 5 Pond west of Isabelle Lake

5a Rocks. Near the pond west of Isabelle Lake the surface of the rock has been grooved, striated (scratched), and polished by the action of glacier ice moving southwards across the region. Superposed on the main pattern of striae and grooves are a series of scratches with variant orientations. These variable scratches were probably created by sea ice during the regression of the postglacial sea.

5b Erratics. A belt of granitic and metamorphic erratic boulders is imbedded in the mud and gravel adjacent to the pond. These may be remnants of the end moraine that snakes along the coast road between the radio domes and Bird Cove (described later).

Stop 6 Isabelle Lake Icing (Aufeis)

Each winter, and for part of each summer, a large icing fills an abandoned gravel pit in the beach ridge along the road north of Isabelle Lake (Fig. 19). When the photo was taken in May 1985, the icing occupied an area of about 2000 m^2, and formed a sheet-like mass of ice with several mounds 3-4 m high, connected by an ice ridge. By June, when air temperatures rise to +6°C, the icing is greatly much reduced in area and has ablated enough to expose the road. Remnants persist throughout the summer in some years.

The icing first formed when a pit was excavated into raised beach gravels. The south wall of the pit intercepted the flow of groundwater between Isabelle Lake and the coast. A spring developed between the base of the gravels and the impermeable bedrock below. Considerable hydrostatic head is maintained by the body of water in Isabelle Lake. The main ice mass forms during the winter by groundwater seepage; hydrostatic pressures are responsible for the mounds and connecting ridges. French and Gilbert (1982) considered the icing development to be related to a talik (unfrozen layer) in the permafrost beneath the lake.

Similar icings have formed where the road crosses a flight of raised beaches at the dump 1.5 km east of the airport, and at Twin Lakes, where water seeps out of the base of the kame at the contact between the kame gravels and underlying, frozen, impermeable silty till. An artificial icing is exposed under the turf along the road to Akudlik across from the old Navy buildings. This deposit resulted from a broken water line. Its persistence is caused by the insulating effect of the soil and peat overlying the ice body.

Stop 7 Roches moutonnées and krumholz

Drive to the treed area at the edge of the rocks, near Miss Piggy, *the wrecked DC 5.* The Precambrian rocks that outcrop along the coast road between Isabelle Lake and the airport have formed roches moutonnées (Fig. 20). The north sides of these features were rounded and polished by the compressive, grinding action of glaciers flowing southward across the region. The steeper south sides of the features were created where loose joint blocks froze onto the base of the glacier, and were then plucked away from the outcrop by the moving ice.

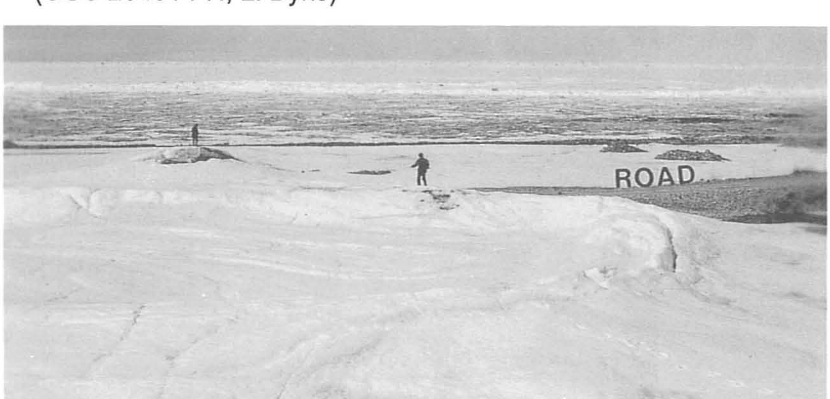
Near the coast, scattered clumps of stunted, crooked spruce (krumholz) grow in protected spots. Strong winds off Hudson Bay are responsible for their lobstick branch habit. A branchless zone along the trunk marks the extent of the protective winter snow cover and the site of maximum winter wind shear.

Airport to Northern Studies Centre

Stop 8 Airport rocks

The outcrop directly east of the airport turnoff and others in the Churchill area, form a broad, glacially smoothed ridge of Precambrian proto-quartzite, which rises about 30 m above the shore of Hudson Bay. The rocks have a rectangular pattern of joints and fractures. These lines of weakness have been etched out by glaciers and subsequently by wave action during the postglacial period of marine emergence. The glacially abraded and polished rock surfaces display a variety of glacial erosional forms, including striae (scratches), and chattermarks (lines of small, crescentic fractures) where pebbles in the base of the glacier impacted against the bedrock. Large streamlined forms resembling whalebacks (Fig. 21), grooves, and surfaces bevelled by the passage of glacier ice were also created. Churchill lies near the zone of confluence of two major ice masses within the Laurentide Ice Sheet. Crosscutting striae and bevelled surfaces show the sequence of ice flow events.

Figure 19. Icing blocking the road below Isabelle Lake. (GSC 204314-N; L. Dyke)



Scattered striae oriented northwest (300°) were produced from an early ice flow from Hudson Bay or central Quebec. This westward flow deposited the silty calcareous glacial debris which is exposed along Churchill and Nelson rivers. The subsequent and principal ice flow in the Churchill area was southwards, from a centre in Keewatin. This ice produced striae oriented between 160° and 180°, and many of the grooves and whalebacks on the rocks. The glacier creating these forms advanced to about as far south as Limestone Rapids on Churchill River and emplaced a sandy granitic glacial debris on top of the older silty material; this northern ice did not reach into the Gillam-Nelson River area. Final ice flow in the Churchill area was towards the southwest (220°). This flow produced striae that cut across older glacial forms and bevelled earlier erosional surfaces. Fine striae, sometimes curved,

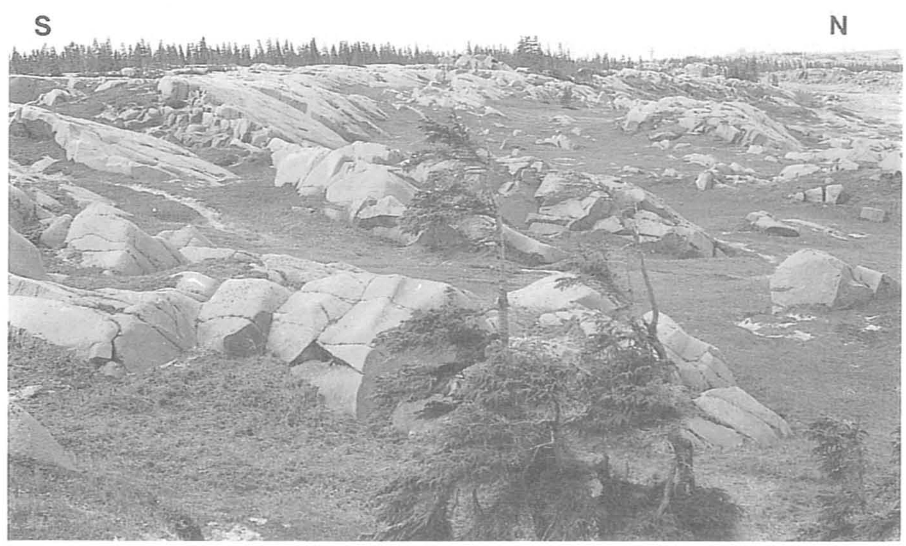


Figure 20.
Roches moutonées in quartzite: glaciers flowed from right to left. Krumholz vegetation: branch pattern indicates direction of prevailing wind. Bushy lower parts of trees are protected from harsh winter winds by snow. Branchless portion above the bushy zone is the area of maximum wind shear.
(GSC 205238-R)

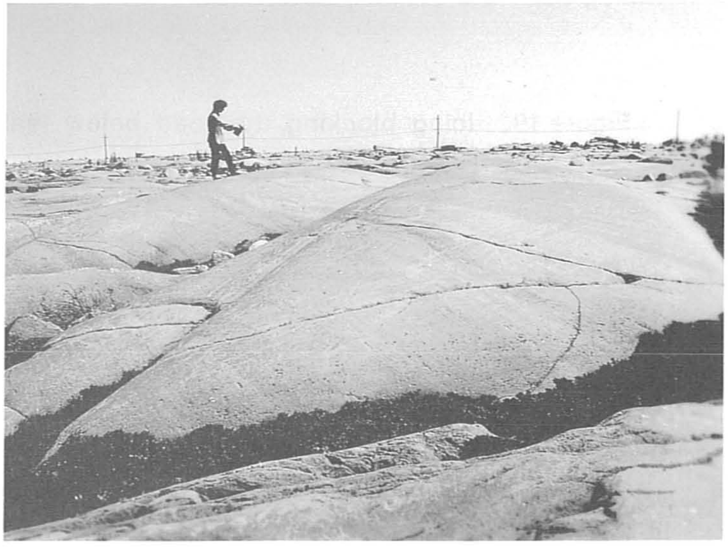


Figure 21.
Glacially shaped whaleback form, with scoured and scratched surface: glacier flowed from left to right. Cracks in the rock are joints; faint wavy lines are crossbeds.
(GSC 204314-L)

and of variable orientation crisscross the outcrop; these are thought to have been produced by shore ice in the postglacial period where sea level was higher than present.

Frost heaving of bedrock is a common periglacial process in the Churchill area, and the rocks east of the airport display some of the most spectacular examples of this process in the Arctic. The continuity of whalebacks and glacial grooves has been disrupted by frost heaving (Fig. 22, 23), and massive panels of rock have been ejected up to 3 m above the surrounding outcrop surface. These panels are bounded by the more closely spaced pairs of a family of prominent north-south trending fractures. The heaved panels are from 1 to 5 m wide and up to 20 m long. Water is visible throughout the summer in spaces vacated by heaved blocks. Vertical movements of some panels have been monitored since 1979 (Dyke, 1984). Changes

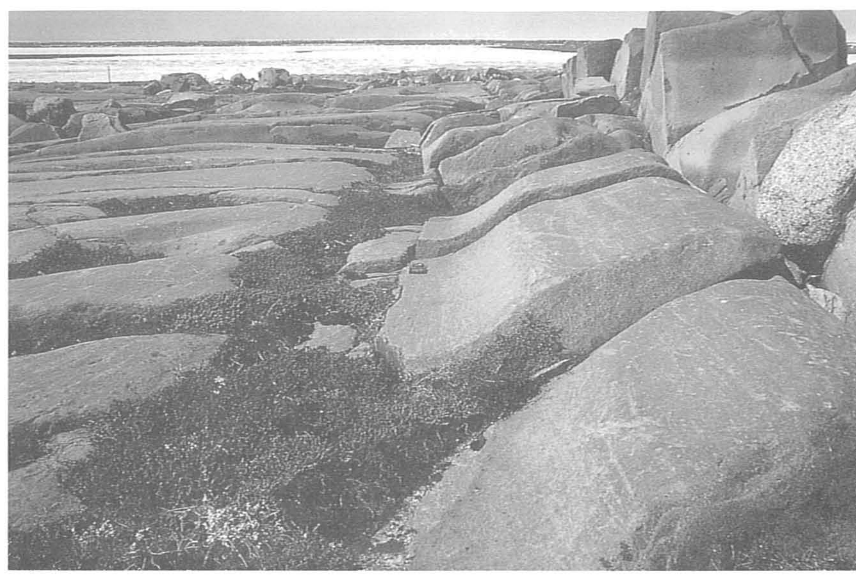


Figure 22.
Glacial groove with right side heaved up by frost action. The glacier flowed from the back of the photo towards the front.
(GSC 205238-Q)

Figure 23.
Frost heaved mass of rock, subsequently split by further frost action.
(GSC 205238-P)

in elevation between yearly surveys average 0.6 cm but have been as great as 3.9 cm. The heaving is probably produced by excess pore water pressure that develops as summer water becomes confined between permafrost and a downward advancing freezing front. Water pressure as high as 400 kPa has been measured at depths of about 2 m, more than enough pressure to balance the weight of overlying rock.

The heaved panels are roughly evenly spaced, suggesting that a mimimum area is required for the confinement of enough water to provide the force necessary for heave. Once a panel begins to heave it may become a point of weakness, ensuring that subsequent heave is concentrated there. Uplift presumably continues until the base of the block or panel is raised to the level of the water table. The yearly movements now observed are probably not cumulative; rather they are net movements representing heave followed by settlement during the summer thaw. Exceptions will occur where cobbles fall into spaces vacated by blocks, jamming the voids, or where ice fails to melt from one year to the next.

Raised Beaches. Between stops 8 and 9, about 1.5 km eastwards of the airport turnoff, we cross a set of raised beaches, which rise from sea level to about 15 m. The highest beach formed about 1500 years ago. An icing similar to that at Isabelle Lake develops seasonally between the road and the coast and lasts until mid summer. Beware, polar bears frequently visit this spot, attracted by the nearby garbage dump and incinerator.

Stop 9 SARSAT ground station

The search and rescue satellite receiving station is part of a multi-nation network that pinpoints the location of emergency radio transmissions.

South of the roadway is a good vista of the tundra barrens (Fig. 24). Small ponds and shallow lakes created by the thawing of permafrost dot the surface of this extensive plain. A long sandy spit projects from the rock outcrop into the clay flats. This feature formed about 1300 years ago as the land emerged from the postglacial Tyrrell Sea. On the shoreward side of the SARSAT rock outcrop, a flight of raised beaches extends from sea level to 22 m. Shells within the uppermost beach have

Figure 24.
Tundra barrens seen from the SARSAT station. Foreground is quartzite bedrock. Middle distance shows a shallow thermokarst (tk) lake and relict spit formed on old marine sediments.
(GSC 204314-E)

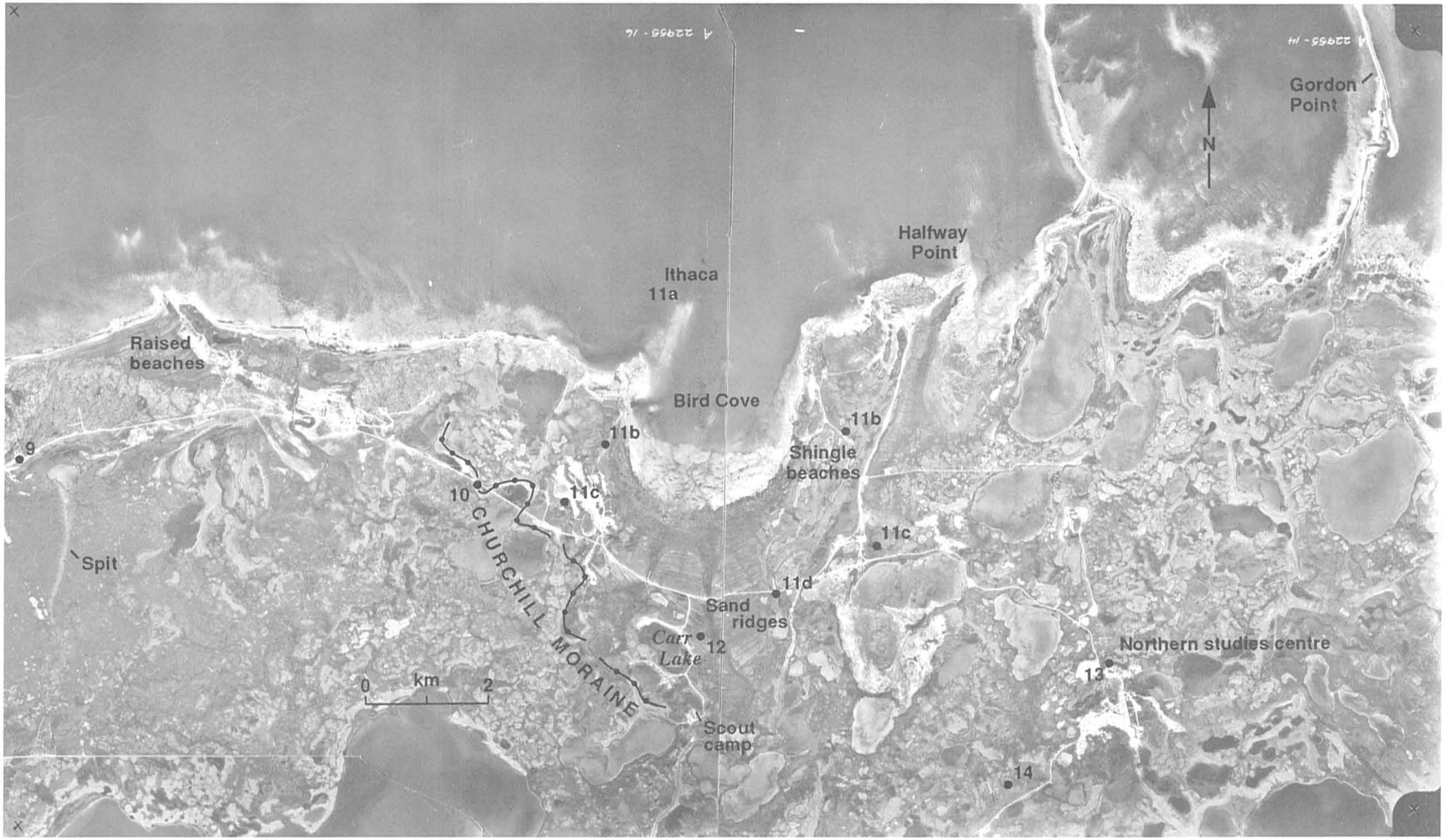


Figure 25. Aerial view of Bird Cove (A 22955-14, 16). Beaded line follows the Churchill Moraine.

been dated at 2120 ± 130 years ago (GSC-723). Huge quantities of limestone gravel have been extracted from these deposits, so that the original form of the beaches has been largely obliterated. Beware of polar bears at this stop.

Stop 10 Churchill end moraine

Proceed 8km east of the SARSAT station to where a side road arcs southward from the paved road (Fig. 25). A band of boulders winds across the paved road and loops along the side road. It is part of a broad low ridge that can be traced out between the headland to the west and the Scout Camp south of Carr Lake. The ridge (Fig. 26) is armored entirely by large Precambrian erratic boulders which are embedded into its surface; these boulders are strikingly different from the other cobbles and boulders that form the surrounding beach ridges. The ridge is thought to be a remnant of an end moraine formed by the receding Keewatin glacier. It was later heavily reworked by the Tyrrell Sea, leaving the surface lag of boulders. The line of Precambrian boulders near Isabelle Lake may be a continuation of this feature.

Stop 11 Bird Cove area

11a Ithaca. The wreck of the **Ithaca** sits on the tidal flats in Bird cove. The ship was caught in a windstorm in September 1961 while carrying supplies from Churchill to Rankin Inlet for the nickel mine.

11b Beach features at Bird Cove. The landscape around Bird Cove is composed of beach ridges of dolomitic gravel and shingle separated by water-filled depressions. The regular form of the ridge and swale topography is interrupted by irregularly-shaped thermokarst ponds. The greater height of the beach ridges at this site relative to those near Carr Lake may be a response to higher wave energy along this more exposed part of the coast. Also of interest are the large ridges that extend into Hudson Bay at right angles to the present coast (Fig. 25), and their emerged counterparts to the east of Bird Cove. The spits at Halfway and Gordon points are still forming. Their location corresponds to the position of eddies in the coastal

Figure 26. Wave-washed remnants of the Churchill Moraine; the low ridge of Precambrian boulders is traceable for several kilometres. (GSC 205238-M)

circulation system, controlled by the shape of the coast. The raised linear features, exploited for gravel, are thought to be similar spits or transverse bars created by waves and currents refracting off the rock promontories, which were once offshore. They consist of coarse dolomitic shingle and gravel, but contain numerous granitic boulders, ice rafted into the locally derived deposits.

11c Stony earth circles. A pattern of stony earth circles has developed adjacent to some of the pathways near the main road between the Carr Lake turnoff and the roadway to Halfway Point (Fig. 27). These frost features have fine-grained muddy centres, and stony or cobbly borders. They may develop by the injection of fines from the subsoil into the surface layer as a result of cryostatic pressure during autumnal freeze-back; the finer, wetter soil is the last to freeze and pressure is relieved by upwelling. The circles differentiate further by lateral thrusting and ejection of stones from fines by repeated freezing and thawing. The turf covered centres of most circles indicate that they are relict forms; however, the presence of some unvegetated centres suggests that some of the features are active.

11d Palsas. The small grassy mounds in wet terrain about 1.3km east of the Carr Lake turnoff are ice cored peat and soil hummocks, called palsas (Fig. 28). The growth and development of this type of feature is discussed later, in the introduction to the Farnworth Road sites.

Stop 12 Beach features near Carr Lake

Turn south off the main road and proceed toward the cottages at Carr Lake. The sideroad crosses a flight of raised beaches extending from sea level at Bird Cove up to an elevation of 10 m. The highest beaches formed about 1240 ± 130 (GSC-682) years ago. There is a regular progression of beach ridges from this site down to sea level, but the slope of the land is so gentle (3 m/km) and regular that the ridge and swale form is only apparent from aerial viewpoints (Fig. 25). The raised beaches near the cottages are composed of sand and gravel; those near the coast are made of dolomite shingle, and the tidal area inside Bird Cove is a sand and clay flat.

Figure 27. Stony earth circles. The finest material is found at the centre of the feature; coarser gravels delimit the perimeter. (GSC 204314-G)

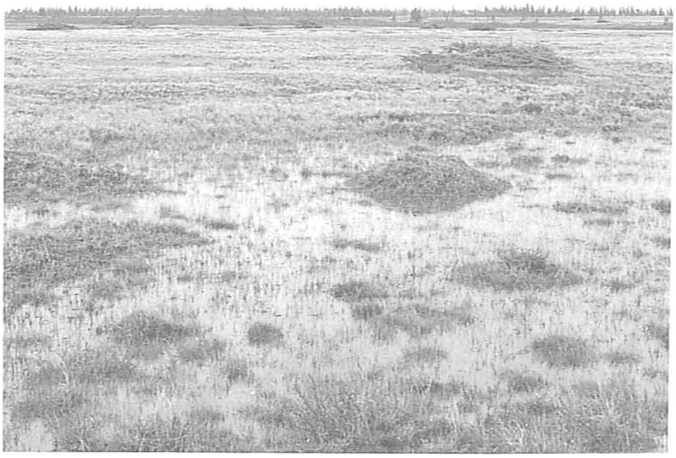


Figure 28.
Small palsa mounds in wet terrain.
(GSC 205238-L)

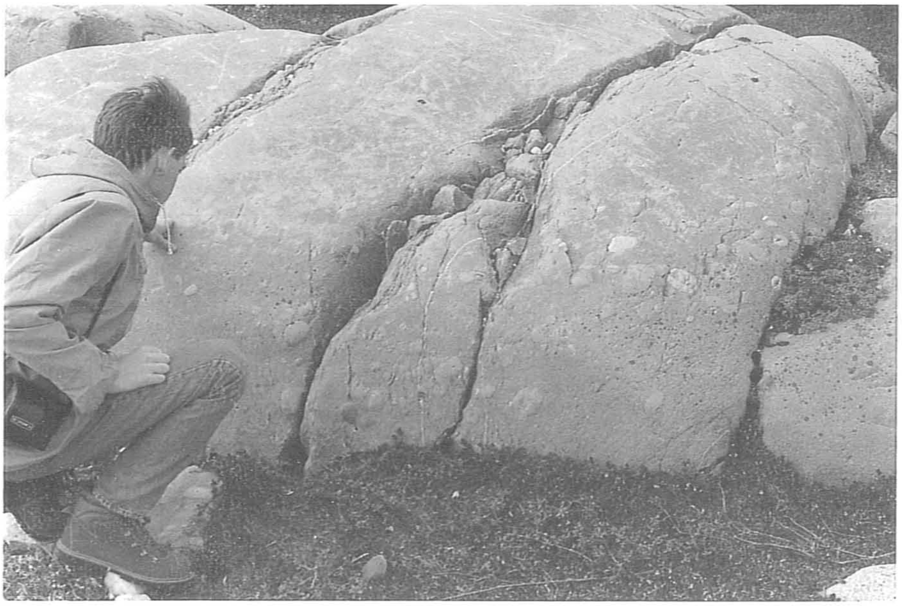


Figure 29.
Protoquartzite at the Northern Studies Centre, with crossbeds, rows of flattened quartz pebbles, and glacial scratches.
(GSC 205238-K)

Figure 30.
Peatland terrain south of the Northern Studies Centre. Ice wedges underlie the depressions which form polygonal patterns in the peat.
(GSC 205238-J)

An emergence curve has been constructed for Churchill, based on radiocarbon age determinations on marine shells collected from beaches such as these (Fig. 10). The lower part of the curve was established using the mussel *Mytilus edulis*, which grows in intertidal environments and therefore is used as an accurate indicator of successive positions of sea level.

Northern Studies Centre to Twin Lakes

Stop 13 Northern Studies Centre and rocket range

The Churchill Research Range was constructed in 1957 to support International Geophysical Year rocket firings. It was established by the United States Army Engineers, but in 1966 National Research Council of Canada assumed responsibility for the installation, which was used for upper atmospheric research. Churchill lies within the zone of maximum auroral activity and is thus particularly well situated for monitoring and investigating the northern lights (aurora borealis), which create spectacular ionospheric displays. Nike, Black Brant, and other types of rockets with instrument packages were regularly fired, primarily during winter months. The last rocket was fired in May 1985.

The main building now houses the Northern Studies Centre. The centre was established in 1976 by the people of Churchill and the government of Manitoba to facilitate northern studies. It offers educational courses on northern themes and provides accommodation for scientists working in the area.

The bedrock across from the main building contains layers of quartz pebbles (Fig. 29) and sedimentary cross beds, both of which were part of the original river deposits from which the rocks formed. The flattening of the pebbles occurred during Precambrian times when the sediment was metamorphosed and lithified. Glacial scratches cover the surface of the outcrop.

Stop 14 Ice wedge polygons

Proceed to the small lake 1.7 km south of the Studies Centre. The area of open peatland near small lakes on the rocket launch site is the only accessible place in the Churchill area where ice-wedge polygons are well displayed (Fig. 30), although open polygonized peatlands occupy hundreds of square kilometres between Churchill and Gillam (cf. Figs 46 and 47). The polygons have developed in a fibrous shrub-tundra type of peat covered with *Cladonia* lichen (reindeer moss). Vertical wedges of massive ice form the lattice of the polygons. The tops of the ice wedges lie about 60 cm below the peat surface and mark the base of the active layer. Ice is also present within the frozen peat, as interstitial crystalline ice, random inclusions, and coatings on peat fibres.

The polygonal terrain is a product of thermal contraction of the ground and development of ice wedges. In the contraction theory proposed by Lachenbruch (1962; Fig. 31), cool temperatures and rapid drops in temperature are required. Both conditions are met in the Churchill area, which has an annual mean temperature of -7°C. Rapid temperature drops in ice-rich frozen soils lead to contraction of the frozen ground and development of fissures (frost cracks). In spring, water and snowmelt percolate down the crack and freeze, preventing the crack from closing as the ground re-expands. This produces a vertical ice vein that penetrates the permafrost. Horizontal expansions of the ground the following summer result in plastic deformation of the ground and upturning of the earth or peat near the wedge, forming a berm at the surface. The following winter, renewed thermal tension reopens the icy crack, which is a zone of weakness. Another increment is added the following spring, and eventually the process produces a vertical wedge of massive, foliated ice.

The ice wedges divide the peat surface into polygonal nets. Lachenbruch felt that wider-spaced cracks reflected greater thermal tension and more severe climates than did closely spaced cracks. It is not known whether the cracks here developed more or less simultaneously, or whether they developed sequentially. Theoretically, cracks formed simultaneously by uniform cooling in homogeneous media (e.g., peat) should intersect at 120°. The ice wedges at the rocket launch roughly follow this geometry. In contrast, cracks formed sequentially usually form orthogonal networks. Once a crack exists a second crack will develop perpendicular to the direction of greatest tension, which is at right angles to the first crack. Multiple, sequential nested systems of ice wedges can be observed from the train in the peatlands between Churchill and Gillam.

Continue south from the ice wedge polygons across a flat wetland comprised of stony marine silt. Proceed to Twin Lakes about 12 km south of the launch site.

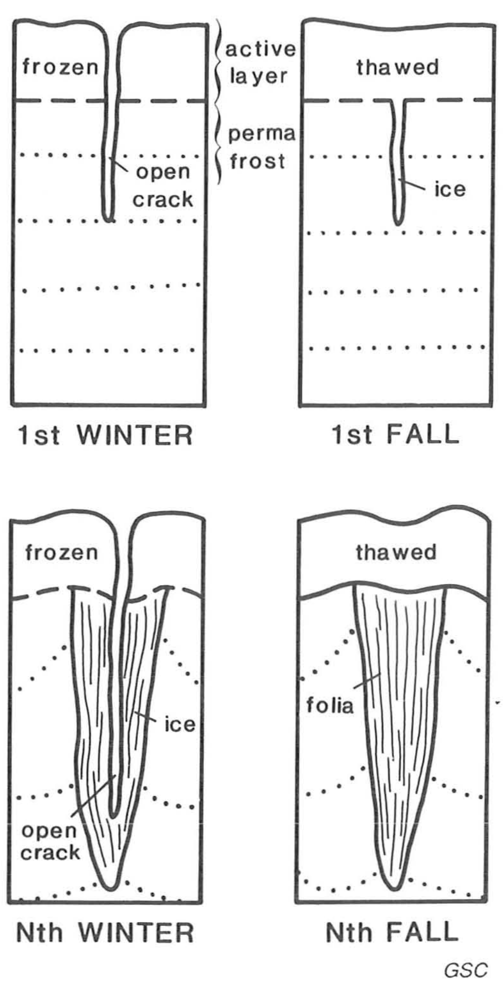


Figure 31.
Development of an ice wedge (after Lachenbruch, 1962).

Stop 15 Twin Lakes kame

15a Kettle lakes. The Twin Lakes kame is a flat-topped sand and gravel deposit abruptly rising 20 m above the surrounding plain and is the highest feature for many kilometres. The deposit is thought to be an isolated kame, deposited by meltwaters within the Keewatin glacier about 8200 years ago. Many boulders are granitic, a marked contrast to the carbonate bedrock that underlies the area. The three lakes that pit the surface fill kettle holes that formed by the melting of remnant blocks of glacial ice buried in the gravel. The top of the kame was later flattened by wave action during the regression of the postglacial high sea. Waves and currents redistributed the kame sands and formed beaches along the southwestern and southeastern flanks. Radiocarbon dates on *Mytilus edulis* indicate that sea level was at the top of the kame (39 m elevation) about 3190 ± 140 years ago (GSC-685).

15b Icing and tundra. *Turn east onto the dirt track at the end of the gravel road and proceed to the end of the track.* A large icing along the east edge of the kame develops in the spring where groundwater escapes from the base of the gravels. This site affords a good view of the marine plain and subarctic tundra (Fig. 32). Small isolated palsas can also be seen from the outer edge of the kame.

Stop 16 Knight's Hill

The mound forming Knight's Hill, 20 km to the east, is a kame, and is composed entirely of granitic erratic cobbles (Fig. 33). The core of the north-south ridge attached to it consists of mixed limestones and granitic rocks and is probably an esker, formed within a meltwater tunnel in the Keewatin glacier. The surface of the esker has been reworked by waves and formed into beaches when sea level was higher.

Farnworth Road: peat landforms in permafrost terrain

The road east of Farnworth Lake displays a variety of palsas and related peat forms (palsas, peat plateaus, earth hummocks, and drunken forest) in various stages of development and collapse (Fig. 34).

Palsas are rounded mounds of peat and mineral soil with a frozen core. Peat plateaus are related but more extensive, flat-topped features that result from the growth and coalescence of adjacent palsas. Both are permafrost features typical of discontinuous permafrost; Brown (1978) considered them to be the only reliable indicators of permafrost in the Hudson Bay Lowlands. They are almost exclusively associated with boggy wetlands and occur where winters are harsh and snow cover is thin. Near Farnworth Lake they have developed over wetlands, apparently at random, but linear groups of palsas are striking features along the creeks draining into Warkworth Lake.

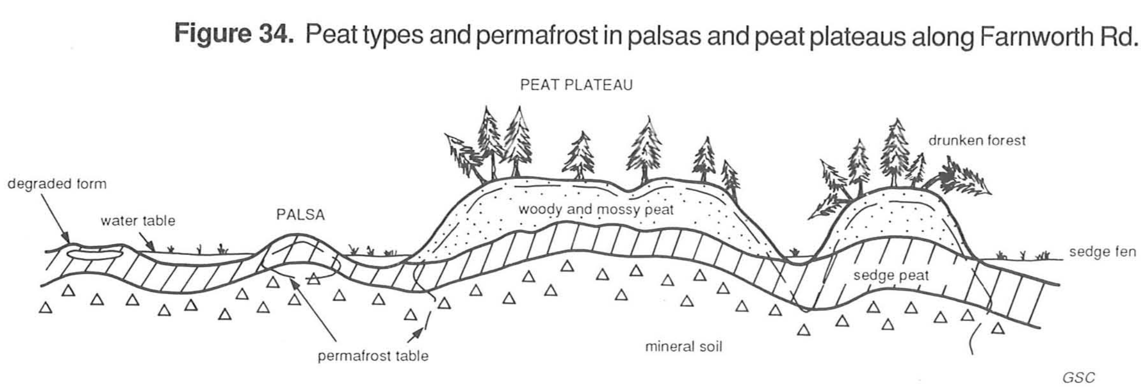
The mechanism of palsa formation is uncertain, but is related to the freezing of shallow ponds to the bottom in winter and the doming of the underlying peat as ice lenses grow in various places. Palsa mounds preferentially develop in exposed areas where snow cover is thinnest and frost penetrates most.

Once the low mound is elevated above the pond level, the thermal conductivity properties of the peat become important. The dry layer of exposed peat has a very low thermal conductivity and thus insulates the underlying frozen mass from summer thawing. This marks the beginning of permafrost conditions. Conversely,

Figure 32. Tundra and icing (white patch) seen from Twin Lakes kame. (GSC 205050-B)

Figure 33. Knight's Hill: piles of water washed and abraded Precambrian boulders form the remains of an esker which developed within the Keewatin ice sheet. (GSC 204036-F)

Figure 34. Peat types and permafrost in palsas and peat plateaus along Farnworth Rd.



in autumn the peat generally becomes saturated as the evaporation rate falls. The high thermal conductivity of wet and icy peat relative to the adjacent drier areas permits preferential frost penetration in winter. Permafrost conditions are further augmented because winter winds remove or reduce the insulating snow cover over the exposed palsa mound. The mean annual temperature of the peat is thus lower than for adjacent areas. Mean annual temperatures are +2° in fenland in this area, and -2° to -4° in adjacent palsas (Fig. 13).

The processes of growth and updoming of the palsas are unclear. Some people have suggested that hydrostatic pressure may control the initial growth of the palsa mound but that later, water and heat transfer accompanying the growth of interstitial and segregated ice are probably more important. Because peat has a high capillarity, segregated ice lenses develop as considerable quantities of water are drawn to the freezing front from the adjacent fenlands. In addition, considerable quantities of interstitial water are frozen into the upper part of the peat each autumn.

As peat continues to accumulate each year, accompanied by the increase in permafrost thickness each winter, the mounds grow and coalesce to form peat plateaus.

The Farnworth Lake area is an extensive wetland with low relief. The area is very poorly drained because of the impermeability of the substrate (gritty silty marine clay and glacial till), and flatness of the terrain. The vegetation in the area is typically a mixture of sedge, willow, and tamarack swamp supporting white and black spruce. Drier sites support open spruce forest, low shrubs and a lichen understory. A peat layer 60-100 cm thick mantles much of the terrain. In bogs the peat is typically woody at the base, with amorphous and fibrous peat above. The bog peat is perennially frozen below a depth of about 50 cm. Ice crystals and thin discontinuous ice lenses are interstratified with the peat. The mineral soil directly below the peat mounds is also ice-rich. Permafrost is generally absent in surrounding fenlands.

The maximum age of the palsas around Churchill is 2500 years, based on emergence curves. Those around Farnworth Lake should be less than 1500 years old because they lie below an elevation of 15 m a.s.l. Other studies in northern Ontario have indicated that most palsas are less than 200 years old. In the Farnworth Lake area trees on mature palsas are at least 250 years old; so at least some of the features here have developed over a longer period. Sequential observations indicate that both small palsa mounds and coalesced forms near Churchill have proceeded through a developmental cycle of growth and collapse over a period of 10 years. Because palsas in various stages of growth and decay are found here together, collapse is not an indicator of climate change. The collapse of individual forms is caused by differences in heat exchange, moisture, vegetation, snowfall, or cracking.

Stop 17 Emergent and degrading palsa

Small mounds near stop 17 east of Farnworth Lake are typical palsa mounds in the early stages of development. Low mounds protrude above the water level in small shallow fens in the spruce swamp. The tops of emergent palsas are dry and dark, and there is no living vegetation on the peat surface. On degrading palsas, the peaty surface is cracked, possibly as a result of doming (dilation cracking), but more likely as a result of desiccation. Figure 35 shows a palsa in its emergent phase in 1978. It

Figure 35.
Emergent palsa. Note unbroken, unvegetated surface.
(GSC 203121-J)

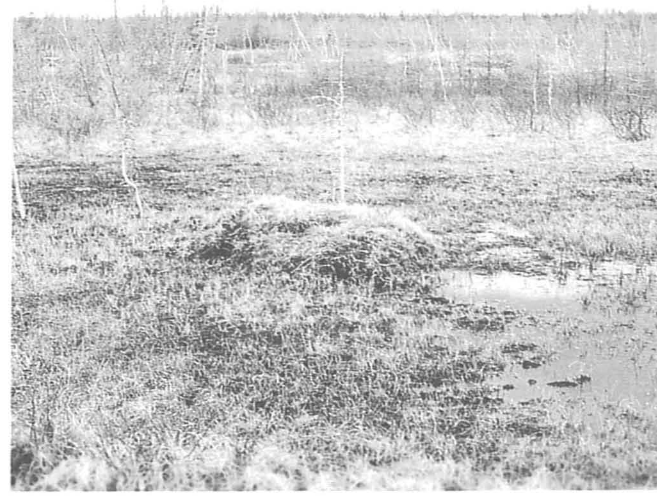


Figure 36.
Small, mature revegetated palsa.
(GSC 204314-P)

was about 2 m in diameter and stood about 75 cm above the water in the surrounding fen. The mound was frost-cored; it consisted of 15 cm of thawed peat (on June 20), over 15 cm of ice-rich peat, and was cored by frozen silt. Most of the ice took the form of crystals and random inclusions in interstices, although thin discontinuous ice lenses occurred in similar mounds elsewhere. The permafrost wedged-out beyond the edge of the palsa. By 1988 the palsa was in its degrading phase; the top was cracked and partially collapsed, and the volume of the mound was only about 30% of that observed 10 years earlier.

Figure 37.
Wooded peat plateau near the tower. Spruce-tamarack woodland with lichen ground cover.
(GSC 204314-M)

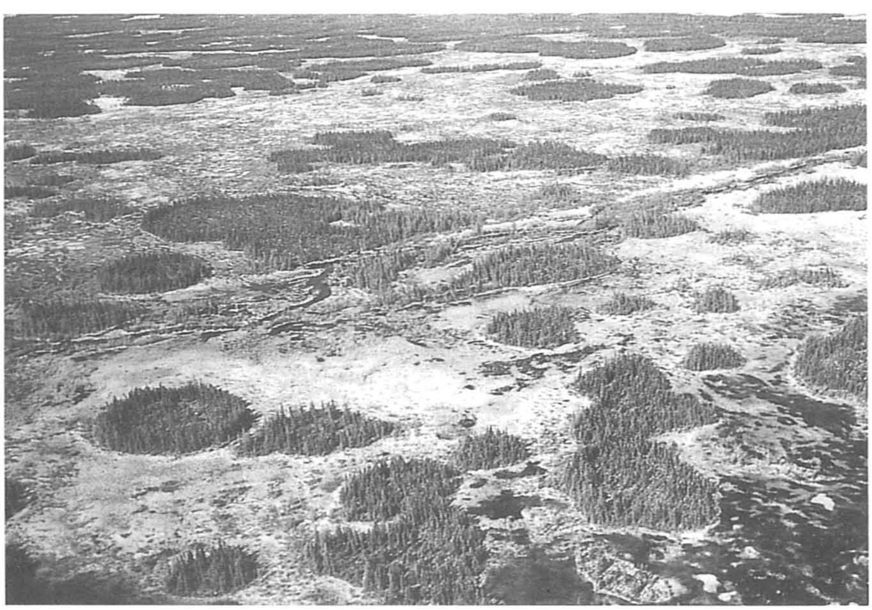


Figure 38.
Aerial view of wooded degrading peat plateaus in fenland south of the tower
(GSC 203314-K)

Stop 18 Mature palsa

Farther along the road are other small palsas in the state of maturity (Fig. 36). Like the previous site, they are situated in Carex fens. These mature palsas have been colonized by dryland vegetation: shrubs, lichens and sphagnum moss. The mounds measure about 60 cm high and 1.5 m across.

Stop 19 Peat plateaus

Proceed to the transmission tower at the end of Farnworth road. The tower is surrounded by peat plateaus (Fig. 37). These features are flat- or hummocky-topped peat forms which stand about 3 m above the surrounding fen. Many cover areas of up to several square kilometres. The peat surface is relatively dry and supports an open spruce and tamarack forest, with an understory of lichen (Cladonia) and shrubs (Labrador tea). The trees are up to 4 m tall; crooked, stunted krumholtz and lobstick forms are prevalent. The peat plateaus have developed in a wetland area. However, small depressions between plateaus are drying out and switching from fenland to drier bog vegetation. There are two reasons for this change: (1) the migration of water to the freezing front in the frozen peat plateaus is gradually exhausting the local water supply, and (2) the updoming process progressively raises the rims of the shallow ponds, which eventually drain.

These peat plateaus are perennially frozen, and permafrost extends into the mineral subsoil below. In those cored between June and August 1979, the upper 30 cm of the peat was unfrozen. Frozen, mossy peat grading to amorphous fen peat, extended for an additional 30-60 cm and contained high amounts of interstitial ice, discontinuous laminae of segregated ice, and lumps of massive ice up to 10 cm thick. The underlying substrate consisted of icy silt and clay, or gravel.

Palsas and peat plateaus are related in origin and development, and some people regard peat plateaus as coalesced, mature palsas. In the Farnworth Lake area this idea is borne out, as many intermediate forms are visible on air photographs of this area.

Stop 20 Degrading peat plateaus

Degrading peat plateaus can be seen well off the road 7 km south of Farnworth Lake (Fig. 38). These features form very low, circular pads about 200 m in diameter in stringed fen. The outer rims of the features are raised and support a forest vegetation, but the inner parts are wet, depressed, and are now vegetated only with moss, although coring has shown that the centres also once had a forest vegetation. Ice content in these features is very high. Their form and peat stratigraphy suggest that the features are degrading. Although most of the peat plateaus appear to have a random distribution, those near Stop 20 are aligned along drainageways. Similar linearly coalesced mounds near the mouth of Nelson River relate to improved drainage conditions along beach ridges. The reason for the riparian association of palsas in the area south of Farnworth Lake is unclear.

Stop 21 Drunken Forest

Seasonal frost heaving of peat plateaus and random degradation of ice bodies is also manifested in this area by the varidirectional tilting of spruce trees, resulting in the "drunken forest" appearance (Fig. 39). Compression wood develops when trees are tilted by intense forest heave. French and Gilbert (1982) examined tree rings in this area. On the basis of darker colour and asymmetry, they recognized 12 periods of compression growth since the pith date of 1727, and a period of severe tipping in 1927.

Stop 22 Turf and earth hummocks

A field of small vegetated mounds with frozen earth(?) cores can be seen at Farnworth Lake (Fig. 40). Most are 20-40 cm high and are randomly distributed over the area. An interesting question is whether these features are related to palsas, or whether they are soil extrusion forms. The peat cover here is much shallower than at previous stops, which may be the reason why the mounds have not developed into true palsas.

Ground temperature cables have been installed across Beech Bay from a point about 5 m above mean high tide to about 2 m below high tide. The cables are used to monitor how permafrost develops in areas that have recently emerged from the sea as a result of glacioisostatic uplift. The temperatures suggest that permafrost conditions have developed above extreme high tide where vegetation is sparse, but that no new permafrost has formed where a band of willow shrubbery affects snow cover, which in turn insulates the ground in winter. Permafrost is developing in the tidal zone and continues to about 2 m below high tide. It is absent below that level. The understanding of coastal permafrost gained here will be used to predict conditions at other arctic coast locations.

Churchill to Akudlik

Stop 23 Monitoring site for permafrost development

West side of the Churchill River estuary: history and prehistory of the Churchill area

Many of the sites relating to the cultural prehistory and history of the Churchill area lie on the west side of the estuary (Fig. 41). *Several individuals in Churchill operate boat tours for transport across the river. During the crossing you may see pods of whales which dwell in the estuary each summer.*

The first occupants in the Churchill area, known as the Pre-Dorset people, belonged to the Arctic Small Tool Tradition (Taylor, 1968; Meyer, 1979). These people, who are thought to have originated in Siberia, were nomads who entered western Hudson

Figure 39.
Drunken forest; the tilting of trees is caused by the development or melting of ground ice.
(GSC 204314-J)

Figure 40.
Small peat or earth hummocks near Farnworth Lake.
(GSC 204314-K)

Bay about 4000 years ago and lived here until about 2700 years ago. They hunted ringed seal in the bay and caribou farther inland. They wore fur clothing. Their culture is characterized by delicately chipped small stone tools such as burins, blades, scrapers and weapon points. Their living areas are marked by stone tent rings, small rectangular depressions which were the lower portion of their winter huts, and the stone remnants of mid-passage houses.

The Dorset culture originated in the eastern Canadian Arctic. It developed from the Pre-Dorset culture, with possible influence from interior Indian groups. Dorset people occupied the area until about 1000 years ago. Like the Pre-Dorset people they were nomads, but their artifacts reflect a closer affinity to the sea. Their equipment included harpoons, sleds, skin boats, soapstone lamps, snowknives, slate blades, and implements of ivory, bone, or wood tipped with chipped blades of quartzite. Small carvings have also been found at Dorset sites. The people lived in partly underground pit houses probably with skin roofs, in summer tents, and in snowhouses.

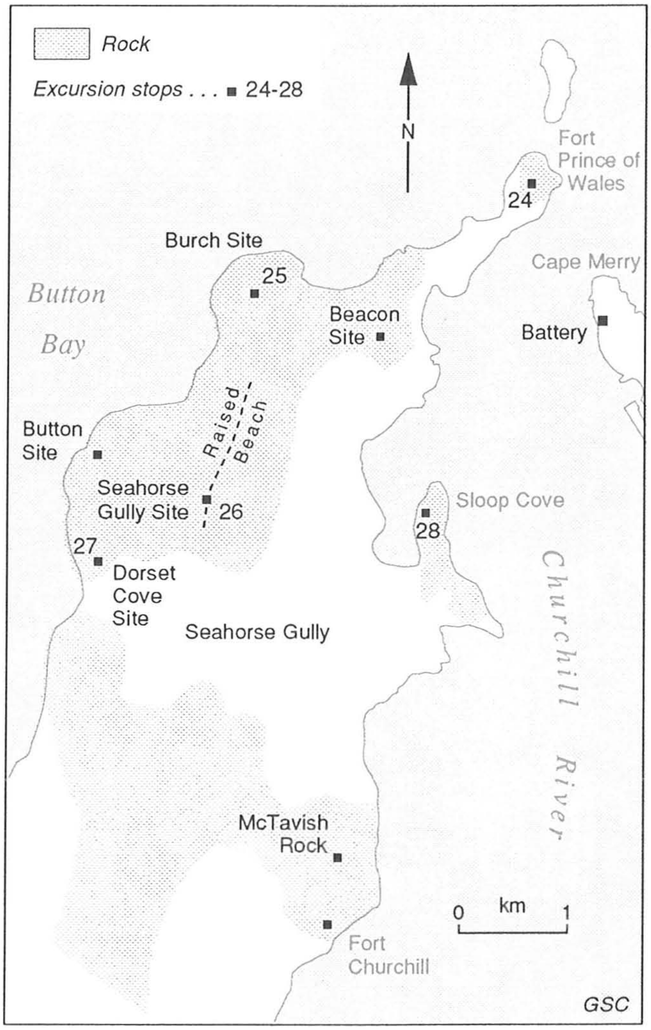


Figure 41. Archeology sites, west side of Churchill estuary.

About 1000 years ago the Dorset culture was replaced by the Thule people who pushed in from the western Arctic. These people were also adapted to tundra living, but differed from the Dorset people in two ways: they domesticated dogs and they had more whaling gear. The increased opportunity for whaling resulted from an influx of whales into this part of Hudson Bay during a relatively warm climate period known as the Medieval Warm Period. Thule artifacts include kayaks, sleds, harpoons and bows, ulus, soapstone lamps, adzes, and knives. Their permanent houses were of stone and sod on whalebone frames, and were partly underground. They had sleeping platforms. The Thule people also used skin tents in summer and snow houses in winter. The present Caribou Eskimo culture evolved from the Thule culture.

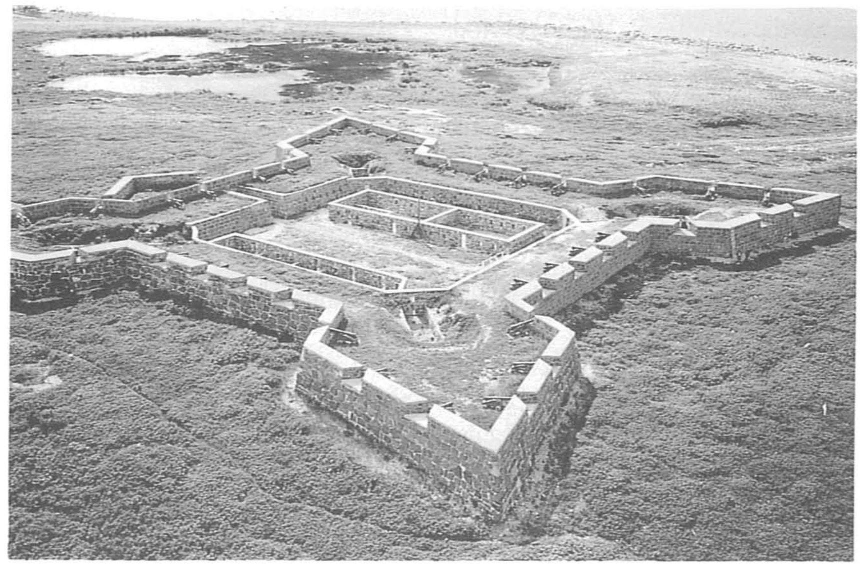
The first Europeans to arrive in the Churchill area were searching for the elusive northwest passage to the Orient. Jens Munck (Danish) led an ill-fated expedition that wintered in the Churchill estuary in 1619-20. Later the English and French, realizing the economic potential of the fur industry, battled for territorial control of Hudson Bay. The Hudson's Bay Company established a fur trading post and whale factory here in 1689, which subsequently burned down; in 1717 they re-established the fur trading post under the direction of James Knight. Fort Prince of Wales was built later to protect their interests from the French, but the fort was taken in 1782 by La Pérouse. In 1783 the Hudson's Bay Company moved the operation 8 km upstream to the site of its former old wooden fort, and this post operated until the early 1900s.

The port of Churchill was completed in 1931 so that prairie wheat, transported by the Hudson Bay Railway, could be transferred to ships for passage to Europe. The Hudson's Bay store, Anglican mission, and the residents of the old town on the west side of the river moved to the other side (MacIver and MacIver, 1982). St Paul's Anglican church, erected in 1892 and considered to be the oldest prefabricated building in North America, was re-erected on the new townsite. The Roman Catholic mission, originally started in 1929 in the lower dock area where the port activities and personnel were located, is now in town. The church and Oblate mission, which were begun in 1931, are the oldest buildings constructed on site.

Stop 24 Fort Prince of Wales

Fort Prince of Wales (Fig. 42) has been partially restored by Environment Canada - Parks. The fort guards the west bank of Churchill River. It was built of local stone between 1731 and 1771, and was constructed to protect the Hudson's Bay Company's interests in western Hudson Bay. The fort was meant to be impregnable, with its ravelin, cannon mounts, and 4-m thick walls. However, in 1782 it fell to the French, who captured it without firing a shot. Visitors can walk through the remains of this massive stone fortress with a tour guide. Displays and film presentations about the fort can be seen at the Visitor Information Centre for Environment Canada-Parks in the Bayport Plaza Building.

Figure 42. Fort Prince of Wales. (GSC 205050-A)



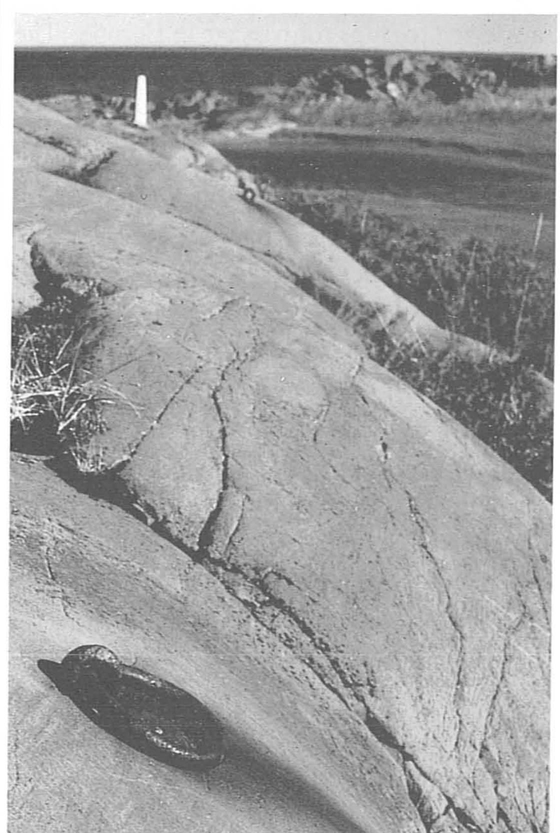


Figure 43.
Mooring rings at Sloop's Cove, which are now inland of, and high above, the cove, indicate that the land has emerged in the last 200 years
(GSC 205050-E)

Do not disturb any objects at the archeological sites.

Stop 25 Historic Caribou Eskimo sites

Historic Inuit camps are situated on raised beaches along the east coast of Button Bay and in the centre of the peninsula southwest of the fort (Meyer, 1979; Meyer and Linnamae, 1980). The Burch Site and Button sites were occupied between the late 1700s and 1850s. Beacon Site was occupied until the early 1900s. The camps consist of large circular bilobate rings of stones (tent rings), kayak rests, rock piles (caches), stone fox traps, and graves (above-ground chambers). Smaller artifacts consist of Inuit items such as harpoons, bows, snowgoggles, and blubber beaters, as well as square nails, clay pipes, glass bottles, and pieces of copper and brass of European manufacture.

Evidence of earlier Thule occupation at the site is limited to chert flakes and quartzite cores, but other Thule artifacts are on display at the Churchill Museum.

Stop 26 Pre-Dorset site

Remains of Pre-Dorset cultures have been found along the gravelly ridge on the upland north of Seahorse Gully. The gravels are now 35 m above sea level but were near high tide when occupied. A marine shell from the ridge has a radiocarbon date of 3560 ± 105 years (S-738), indicating that the ridge was then still covered by the sea. The sea level curve for the area (Fig. 10) suggests that the ridge emerged from the sea about 3000 years ago. Artifacts have been dated at 2900 ± 100 years (S-521). Remains of rectangular houses with mid passages mark living areas. Knife blades, microblades, circular steatite vessels, gouges, picks, scrapers, and adzes have also been found at the site. Nash (1972) related the presence of the larger tools to more wood being available at that time.

Stop 27 Dorset Site

Dorset remains are found on the north side of Seahorse Gully about 20 m above present high tide. Charcoal from the site has a radiocarbon age of 2080 ± 95 years (I-3973). Nash (1972) believed that the site lay on the shores of a low island and formed a base for seal hunting. The principal features of the site are five stone-slab pavements, which mark the remains of summer houses. Rectangular hearths, soapstone vessels, burins, microblades, knives and flakes were found within, as were bone harpoon heads. The presence of seal hunting equipment and the absence of large tools makes this site distinctly different from the Pre-Dorset site at stop 26.

Stop 28 Sloop's Cove

As you return to Churchill it is possible to arrange to stop at Sloop's Cove, which today is a muddy embayment 2 km upriver from Fort Prince of Wales. The Hudson's Bay Company moored and repaired their small vessels in the cove, which provided protection against storms and ice pressure-ridges. Various employees, including the famous explorer Samuel Hearne, carved their signatures on the rocks. The mooring ringbolts emplaced by Hearne in 1758 are now well above sea level (Fig. 43). The position of the mooring rings has sparked considerable debate about the rate of emergence of the land. On the basis of the relatively high elevation of the mooring rings, R. Bell (1878) reported that the land was rising at a rate of more than 200 cm per century. J.B. Tyrrell (1896, 1904) visited the site later, and compared the coastline with descriptions by Jens Munck in 1619 and the survey by Robson in

1752. He concluded that the land was rising only very slowly, if at all. His results compare well with the relatively low rate of 40 cm per century determined from tide gauge records at Churchill (Barnett, 1970). However, there is still some disparity of opinion. The rate determined by geodetic relevelling at Cape Merry is about 82 cm per century and a rate of 145 cm per century was measured in Beech Bay in the Churchill estuary (Hansell et al., 1983).

There are several other historic sites south of Seahorse Gully but they are not described in this guide; they include the remains of the wooden Hudson's Bay post, foundations of the original townsite, and McTavish rock, where townfolk have carved their names for more than a century.

To Gillam on the Hudson Bay Railway

The Hudson Bay Railway was constructed to transport prairie wheat to a seaport on Hudson Bay for export to Europe. In the original plans, the terminus of the railway was to be Port Nelson. The location of the port was later changed to Churchill, which has a much better harbour. Line construction began at The Pas in 1910 but the Churchill section was not completed until 1929. The building of the railway was a pioneer effort in permafrost engineering, because the entire 800 km line lies either in discontinuous permafrost (The Pas to Gillam) or continuous permafrost (Gillam to Churchill), and the last 200 km are through muskeg. Drainage of muskeg areas was the first operation (Charles, 1959). Hundreds of miles of ditches were dug by hand, and frozen materials were stripped off in layers about 15 cm deep. Where workers needed to drain the land immediately, they actually chopped out the ground ice with axes. Timber bridges were built in winter when pile drivers could be hauled over the frozen muskeg. Steam was forced down holes to drive the piles through frost. The track was laid when the unconsolidated roadbed was frozen, and embankments were improved and ballasted the following summer.

Attempts were made to preserve the original thermal character of the substrate, because small thermal changes can cause major settlement or heave. As much as possible, culverts and other heat conductors were placed where permafrost was absent. Drainage ditches were periodically excavated to prevent the accumulation of standing water. In continuous permafrost areas, the track was built almost entirely by embankment rather than by cutting. The embankments were constructed from sand and gravel borrowed from nearby raised beach ridges and, in a few cases, from organic fill.

The Hudson Bay railway has operated for more than 50 years but requires constant, expensive maintenance. The effects of differential heave and settlement in ice-rich permafrost terrain are apparent on the branch line at Gillam, which was abandoned more than 10 years ago. Some parts of the track are suspended in mid-air as a result of thermal erosion and streamflow around culverts, whereas other parts are like a roller-coaster track.

As you travel from Churchill to Gillam, notice the tripole supports for the hydroline along the track (Fig. 44). This simple design effectively allows the poles to adjust to random heaving or settlement without breaking the continuity of the line.

You will cross three wetland ecotones between Churchill and Gillam: spruce-swamp and fenland, an open tundra heath riddled with ice wedge polygons, and forested bog with waterfilled depressions resulting from the melting of icy soil. The land surface rises gently from sea level at Churchill to about 130 m at Gillam. No major landforms interrupt the topographic monotony of the region, which forms the world's largest tract of muskeg.

The region from Churchill to Gillam is particularly sensitive to changes in thermal regime because ground temperatures are generally only slightly above or below zero (see Fig 13). Changing the soil temperature by only a few degrees creates changes of state leading to aggradation or degradation of ground ice, liquefaction of the clayey soils underlying the area, seasonal churning of soils, and frost heave of bedrock.

Churchill (milepost 510) to Lamprey (milepost 475)

The first 50 km out of Churchill consist of wet fenland and spruce tamarack swamp characteristic of the subarctic maritime environment (Fig. 45). The water table remains high throughout the summer and much of the area is covered with slow-flowing water. The substrate is stony marine silt and tidal clay overlying glacial till. This stretch of terrain emerged from the Tyrrell Sea less than 3500 years ago, so there has been less time for peat to accumulate here than in areas farther south, which are at higher elevations and emerged earlier. The peat is commonly less than 1 m thick, and in relatively dry patches mudboils erupt through the sedge and grass peat. Seasonal thawing extends through the peat and deep into the mineral substrate. The palsas and peat plateaus near Farnworth Lake are part of this terrain complex.

Figure 44. Tripole construction for powerline supports. (GSC 205050-G)

Figure 45.
Spruce tamarack swamp near Churchill.
(GSC 205050-D)

Figure 46.
Aerial view of tundra heathlands with ice wedge polygons and thermokarst ponds.
(GSC 1-16-78)

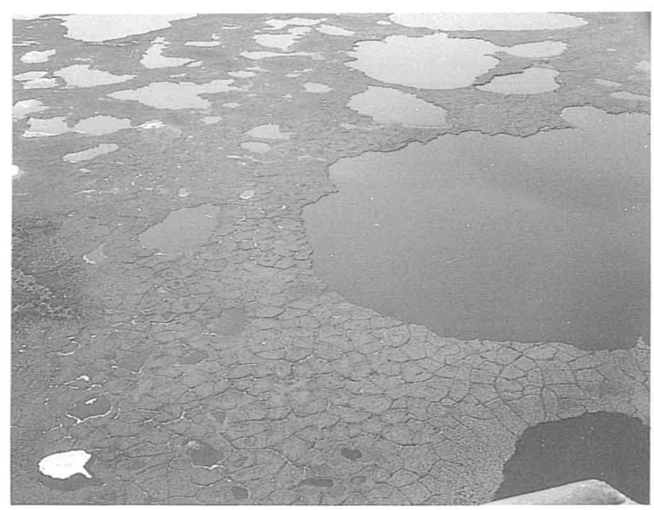


Figure 47.
Ground view of ice wedge troughs: coring the wedge.
(GSC 203121-C)

Lamprey (milepost 475) to Back (milepost 435)

Open tundra heathland with ice wedge polygons extends for 70 km between Lamprey and Back and covers extensive areas of the Hudson Bay Lowlands (Fig. 46). This ecotone lies within the zone of continuous permafrost. The present vegetation consists of a ground cover of lichen, with small shrubs. The peat, which is 2-3 m thick, is riddled with large ice wedges in polygonal networks. Typical polygons measure about 15 m on a side; the troughs are depressed about 60 cm below the flat bog surface (Fig. 47). Quasi-circular thermokarst depressions, created by the melting of ground ice and generally less than 1 m deep, occupy 30-50% of the surface area. They vary in size from small pools at the junctions of ice wedges to large shallow lakes.

Upper parts of the peat are fibrous and mossy, being derived from a lichen-moss-heath type of tundra vegetation. A basal woody layer, very commonly encountered in cores, suggests that lower parts may have developed from an arboreal vegetation community. The moisture content of the peat varies spatially and seasonally. In summer the surface is dry and the thawed layer is usually partly drained. The peat is frozen below a depth of about 70 cm. About 22% of the volume of the peat is ice. Both stratified and random ground ice are present within the peat and an ice layer several centimetres thick is commonly present at the boundary between peat and mineral soil. Massive ice lies below ice wedge troughs. The active layer varies in thickness from 50 cm in dry peat to about 1 m in wet peat. Thus, thawing does not extend into the mineral substrate except where there are large lakes.

On the basis of air temperature, the boundary between continuous and discontinuous permafrost should pass through Churchill. However, the thermal properties of the peatlands that mantle the region allow permafrost conditions to prevail up to 250 km farther south.

The peatlands are one of the world's major polar bear denning areas.

Back (milepost 435) to Gillam (milepost 324)

Forested bog with thermokarst depressions (Fig. 48,49) and narrow fens begin to appear near Back and continue to the Nelson River area and Gillam. Stunted, scattered spruce trees gradually become larger and more numerous towards the south. A mature boreal forest surrounds Gillam. Forested bog overlies not only the raised marine sediments along the railway, but also all the lacustrine clays in the Gillam area. The peat is commonly 2-4 m thick. It is yellow to brown in colour and consists of a stratified mixture of amorphous to fibrous sphagnum moss peat and woody peat, with some layers of charcoal. Deposits are derived from the accumulation and partial preservation of a spruce forest vegetation cover with a lichen-moss-shrub understory. The bottom of the peat at Charlebois (about milepost 362) has a radiocarbon date of 6280 ± 80 years (GSC-2760). North of Amery, permafrost is present below the top 15-30 cm. Random ice crystals and thin ice strata make up 30-50% of the volume of the peat in many places. Small mounds of massive ice underlie some of the more hummocky bog areas. These ice bodies are not present in areas of forest cover, but palsas are now developing in adjacent thermokarst depressions and fens. Permafrost is discontinuous at Gillam.

Gillam area (Fig. 50)

The town was named after Zachariah Gillam, who sailed the first Hudson's Bay Company ship, the *Nonsuch*, into Hudson Bay and established a company trading post near the mouth of Nelson River in 1682. The Gillam townsite was first established in 1912 during construction of the Hudson Bay Railway. Gillam has served as a railway town and administrative centre for northern Manitoba since then. In the early 1970s the upper Churchill River was diverted into the Nelson River system and dams were constructed to harness the hydroelectric potential of the region. In 1974 the Kettle Generating Station went into production and in 1977 Long Spruce started production. Work continues at the Limestone Dam, and two more dams are planned downstream at Conawapa and Gillam Island.

Figure 48.
Aerial view of forested bogs and intervening fen areas.
(GSC 204034-Q)

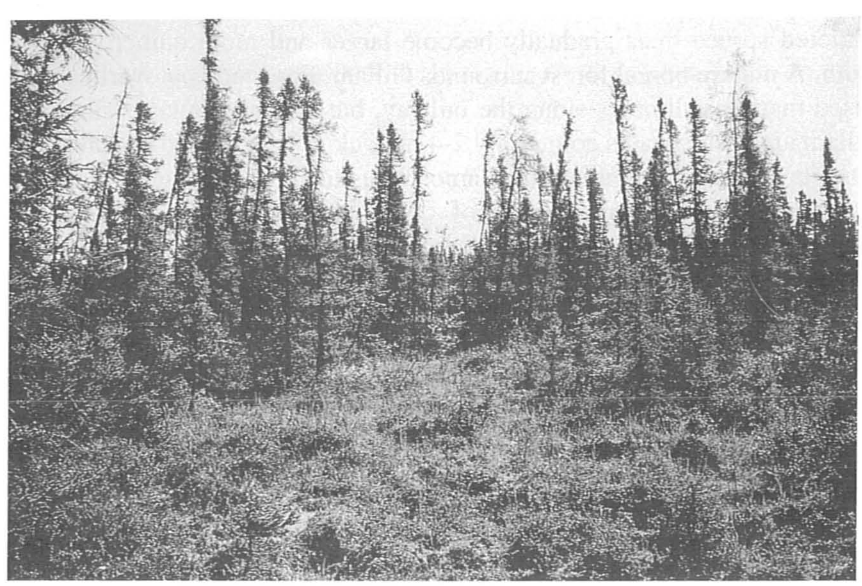


Figure 49.
Forested boggy woodlands near Gillam: spruce trees with herbaceous or sphagnum ground cover.
(GSC 204035-P)

Most geological deposits near the townsite were formed either beneath glaciers during recession of the ice sheets, or in postglacial lakes and seas that once covered the region. The townsite is situated on an esker complex consisting of a ridge flanked by sandy fans. The core of the esker developed beneath the Hudson glacier, but the bulk of the deposit developed later where a meltwater conduit within the glacier debouched into Glacial Lake Agassiz (Fig. 4).

Stop 29 Gillam Railway station

Several sections 4-5 m high have been cut into the small hills directly south of the railway station at Gillam (Fig. 50). The material is very sandy, reasonably well sorted, and substratified. Many clasts have glacial scratches. This material was deposited in a glacial lake environment and is part of the Gillam esker complex. The tiny abraded shell fragments within the sediments are recycled marine sediments and are more than 75 000 years old.

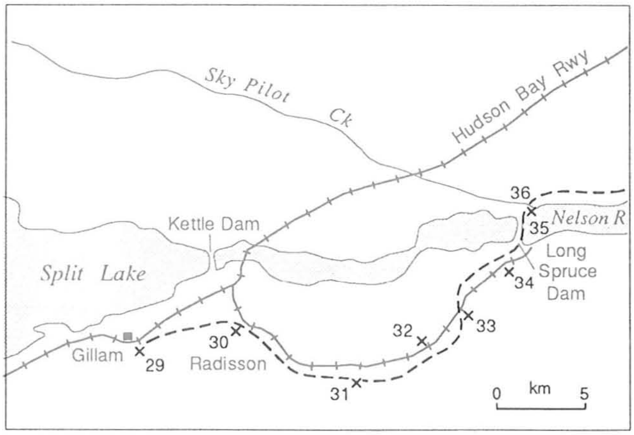


Figure 50.
Gillam area excursion route and stops.

Figure 51.
Hanging track along the abandoned railway spur line, illustrating problems encountered with maintaining the trackline in permafrost. (GSC 205050-C)

Stop 30 Radisson switching station

Follow the road from Gillam towards Radisson. The Radisson switching station converts AC power produced at the Kettle Generating station to DC for transmission to Winnipeg.

The road between Gillam and Radisson Switching Station follows the Gillam esker. Sand with only minor gravel is seen near Landing Lake whereas at Radisson coarse gravel forms the core of the 20 m high ridge. The upper half and flanks of the ridge are finer textured sand. The long axis of the ridge trends east-west and current directions measured on crossbedded sand vary between east and southeast. The core of the Radisson deposit was formed by meltwater depositing sediment in a tunnel within the Hudson glacier. The upper part of the ridge and flanks were deposited subaqueously where the meltwater tunnel debouched into Glacial Lake Agassiz.

Stop 31 Tyrrell Sea beach

Fourteen kilometres east of Gillam, the road to Long Spruce intersects a beach that marks the highest elevation reached by the postglacial sea — 131 m above present sea level. The beach deposit is more than 100 m wide and at least 3 m deep, and consists of well sorted sand. At its western end, the beach overlies sandy silty brown sediment from Glacial Lake Agassiz. The beach is part of a feature which extends for more than 800 km across northeastern Manitoba and northern Ontario. Marine molluscs from the beach, dated by accelerator mass spectrometry, have an age of 6980 ± 60 years (TO-220).

Stop 32 Railway branch line

The railway running parallel to the road is a branch line that was abandoned prior to 1980. The line provides a good example of engineering problems encountered in permafrost terrain (Fig. 51). Stop 32 shows a length of track suspended in midair. Disruption of the insulating peat cover has led to melting of ground ice, as pools of standing water lie along the track berm. The thermal conductance of the standing water further increased the depth of thaw. A small creek developed and eventually eroded through the berm. Thermal erosion created by streamflow around ice-blocked culverts has created similar problems along other parts of the track.

Stop 33 Railway crossing

At the railway crossing (Stop 33; Fig. 52), a roller-coaster section of track illustrates differential frost-heave and settlement in ice-rich permafrost.

Figure 52. Roller-coaster spur line resulting from the melting of ground ice. (GSC 205197)

A field of palsas (Fig. 53) near the southern approach to Long Spruce Dam illustrates natural features created by ice segregation and frost heave. The origin and development of these features was discussed for the Farnworth Lake sites (stops 17-20) at Churchill. These palsas have developed in wetlands — a mixture of fen and peat plateaus. The site lies near or within the zone of discontinuous permafrost. In the Gillam area, permafrost is commonly present in peat-mantled terrain but is generally absent where mineral soil is exposed at the surface.

Stop 34 Palsas

The mounds are 1-2 m high and consist largely of sphagnum peat, which is ice-rich below about 70 cm, the depth of summer thaw. The mineral substrate directly below the peat is also domed and frozen, but it is not known to what depth permafrost conditions prevail.

Stop 35 Long Spruce Dam

Long Spruce Dam was completed in 1979, as one of a series of dams to generate hydro power along Nelson River. This magnificent river has re-occupied a large preglacial valley that may date back to the Precambrian. The dam lies along the contact between the Precambrian basement rocks (visible in the river at the foot of the dam), and Ordovician dolomite, which outcrops downstream.

Stop 36 Long Spruce section

Park at the gravel access road on the north front side of Long Spruce Dam. This road leads to a small section that clearly illustrates the deposits of Glacial Lake Agassiz and the overlying marine deposits (Fig. 54).

The lowermost unit is a poorly sorted sandy deposit with sand inclusions, and pebbles suspended in a siltier matrix. Flow folds and streamlined fluid forms indicate rapid deposition under turbid conditions. Faint horizontal lineations near the top of the unit suggest a change to laminar flow and a less dense sediment-water mix. This unit was deposited where sediment laden meltwater debouched out of conduits in the ice sheet. The second major unit is a lacustrine varve sequence composed of alternating beds of brown clay and grey silt which were deposited

Figure 53.
Wooded mature palsa near the dam.
(GSC 205197-B)

farther into the glacial lake. The brown clay layer contains angular fragments ripped up from the grey unit and is thus considered to have been deposited under higher energy conditions. Eighty couplets were counted at this site. Both parts of the couplet thin upwards from a maximum of about 1 cm at the base, reflecting increasing distance from the source sediment. The upper 50 cm is a 'massive' or micro-laminated red-brown clay.

The red-brown clay is overlain by grey-brown marine clay deposited into the Tyrrell Sea after glaciers disappeared from Hudson Bay. The fact there is so little disruption between the upper part of the lacustrine sediment and the base of the marine unit suggests that the two water bodies might have been at about the same level at the time of the change-over. The marine clay grades upwards into a poorly bedded buff sandy silt containing marine molluscs. The uppermost part of the section is a brown wavy-laminated silt, which may be a tidal deposit. No radiocarbon dates were obtained from shells at this site. However, dates from marine beds in nearby cliffs gave ages of 7760 ± 80 years (GSC-3916) and 8000 ± 200 years (BGS-812).

Proceed along the paved road to Sundance. The road base between Long Spruce and Sundance was built in the mid 1970s and paved in 1981. During road construction, the peat cover was removed, exposing the underlying icy marine and lacustrine silt. Lateral ditches were excavated to channel melted ground ice away from the road berm. However, unless the ditches are constantly excavated and graded, water collects in depressions where pockets of ground ice have melted out; the pools act as heat sinks and can actually increase the depth of thaw and accelerate the melting

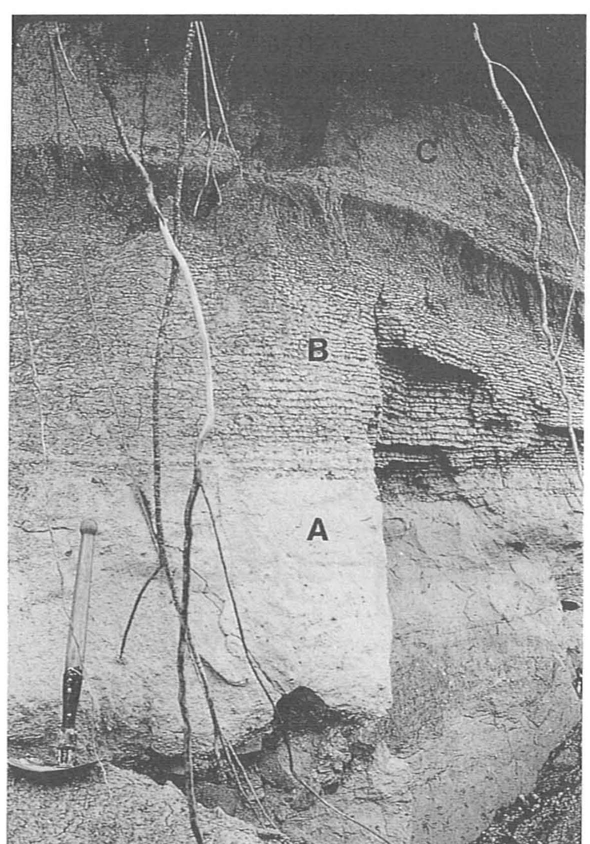


Figure 54.
Long Spruce section: marine silt (**C**), laminated glacial lake clays (**B**), and turbidity flow sediments deposited where melt-water issued from the base of the ice (**A**) (GSC 204314-X)

of ground ice. They also serve as a supply of moisture, which is attracted to the frozen substrate beneath the roadbed each autumn. This roadway exemplifies many of the construction difficulties associated with sensitive permafrost conditions.

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REFERENCES

Barnett, D.M.
1970: An amendment and extension of tide gauge data analysis for Churchill, Manitoba; Canadian Journal of Earth Sciences, v. 7, p. 626-627

Bell, R.
1878: Report on the country between Lake Winnipeg and Hudson's Bay, 1878; Geological Survey of Canada, Report of progress for 1877-78, part 6.

Brown, R.J.
1978: Influence of climate and terrain on ground temperatures in the continuous permafrost zone of Manitoba and Keewatin, Canada; Proceedings, 3rd International Conference on Permafrost, Edmonton, p. 15-21.

Charles, D.
1959: Permafrost aspects of Hudson Bay railroad; Journal of the Soil Mechanics and Foundation Division, American Society of Civil Engineers, December, p. 125-135.

Dredge, L.A. and Nixon, F.M.
1992: Glacial and environmental geology of northeastern Manitoba; Geological Survey of Canada, Memoir 432.

Dredge, L.A., Morgan A.V., and Nielsen, E.
1990: Sangamon and PreSangamon interglaciations in the Hudson Bay Lowlands, Manitoba; Géographie Physique et Quaternaire, v. 44.

Dyke, L.D.
1984: Frost heaving of bedrock in permafrost regions; Association of Engineering Geologists, Bulletin, v. 21, p. 389-405.

French, H. and Gilbert, R.
1982: Periglacial phenomena near Churchill, Manitoba; Naturaliste Canadien, v. 109, p. 433-444.

Hansell, R.I., Scott, P.A., Svoboda,J. and Staniforth,R.
1983: Permafrost development in the intertidal zone at Churchill, Manitoba; Arctic, v. 36, p. 198-203.

Lachenbruch, A.H.
1962: Mechanics of thermal contraction cracks and ice wedge polygons; Geological Society of America, Special Paper 70, 69 p.
MacIver, A. and MacIver B.
1982: Churchill on Hudson Bay; Churchill Ladies Club, Churchill, Manitoba, 217 p.

Meyer, D.
1979: The Churchill archeological investigations, August, 1978; Parks Canada Manuscript report 368, 136 p.
Meyer, D. and Linnamae, U.
1980: Churchill archeological research, August, 1978; Parks Canada Research Bulletin 148, 8 p.
Nash, R.J.
1972: Dorset culture in northeastern Manitoba, Canada; Arctic Anthropology, v. 9-1, p. 10-16.
Nelson, S. and Johnson, R.
1966: Geology of Hudson Bay Basin; Canadian Petroleum Geology, Bulletin, v. 14, p. 500-508.
Nichols, H.
1967: Central Canadian palynology and its relevance to Northwestern Europe in the late Quaternary period; Review of paleobotany and palynology; v. 2, p. 231-243.
Norris, A.W. and Sanford, B.V.
1968: Paleozoic and Mesozoic geology of the Hudson Bay Lowlands; Geological Survey of Canada, Paper 68-53, p. 169-205.
Schledewitz, D.C.P.
1986: Geology of the Cochrane and Seal River areas; Manitoba Department of Energy and Mines, Geology Report 80-9, 139 p.
Taylor, W.E.
1968: Prehistory of Hudson Bay Part 1; in Science, History and Hudson Bay, C.S. Beals, (ed.), v. 1, Queens Printer, Ottawa, p. 1-25.
Tyrrell, J.B.
1896: Is the land around Hudson Bay at present rising?; American Journal of Science, series 4, v. 2, p. 200-295.
Tyrrell, J.B.
1904: The stability of the land around Hudson Bay; Geological Magazine, ser. 4, no. 7, p. 266-267.

FIELD NOTES

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Grain elevator and tundra pond/rocks at Port Churchill