GEOGRAPHICAL BULLETIN

No. 13 1959

GEOGRAPHICAL BRANCH

Department of Mines and Technical Surveys

OTTAWA, CANADA

GEOGRAPHICAL BULLETIN

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The Queen's Printer—L'Imprimeur de la Reine
Ottawa, 1960

$1.50 Cat. M65-1/13

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GLACIER ICE-THRUST FEATURES OF THE YUKON COAST*

J. Ross Mackay

ABSTRACT: Deformation of Pleistocene or earlier sediments found along the Yukon coast between King Point and Herschel Island are believed to have been caused by glacier ice-thrust. The paper describes major deformations occurring at Herschel Island, Kay Point, King Point, and Stokes Point. The extent of glaciation within the immediate area is discussed, and three mechanisms are suggested as possible causes for the deformation of the sediments: slumping, tectonic disturbance, and ice-thrusting. In support of the ice-thrust theory, the most acceptable of the three, the following methods have been advanced to explain disturbed deposits: the frictional drag of glacier ice over weak strata, the incorporation of subjacent beds as englacial material, the bulldozing effect of glacier ice, and the overriding pressure of glacier ice over topographical obstructions. It is believed that deformation was caused by the overriding pressure of glacier ice over sediments whose shear strength was reduced by high neutral stresses in entrapped pore water.

RÉSUMÉ: On croit que les déformations des sédiments pléistocènes ou plus anciens qui se trouvent le long du littoral du Yukon, entre la pointe King et l'île Herschel, sont attribuables aux actions glacitectoniques. La présente étude décrit les principales déformations aux endroits suivants: île Herschel, pointe Kay, pointe King, pointe Stokes et bassin Herschel. On y traite de l'étendue de la glaciation dans cette région et l'on attribue à l'un des trois phénomènes suivants la déformation des sédiments: glissement, mouvement tectonique et chevauchement glaciaire. A l'appui de la théorie du chevauchement glaciaire, qui est la plus acceptable des trois, on a tenté d'expliquer ainsi la déformation des sédiments: friction au passage du glacier sur des strates peu résistantes, incorporation de couches sousjacentes comme matériaux intra-glaciaires, action refoulante du glacier et, par la pression de chevauchement du glacier sur les obstacles topographiques. Cependant, on est fondé à croire que cette déformation a été causée par la pression de chevauchement du glacier sur les sédiments, et que la force de cisaillement a été amoindrie par l'influence neutralisante considérable de l'eau contenue dans ces sédiments.

Deformation of Pleistocene or earlier sediments is present along most of the Yukon coast between King Point on the east and Herschel Island on the west (Figure 1). Tilted, folded, and contorted sediments with truncated beds, thrust faults, closely spaced shear planes, and clastic dykes are exposed along many miles of coastal bluffs. Inland from the coast, arcuate to irregular ridges, cuestas, linear streams, and lake shapes give additional evidence for deformation. These disturbances are believed to be caused by glacier ice-thrust.

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* Presented at the Ninth Annual Meeting, Canadian Association of Geographers, Saskatoon, May, 1959.

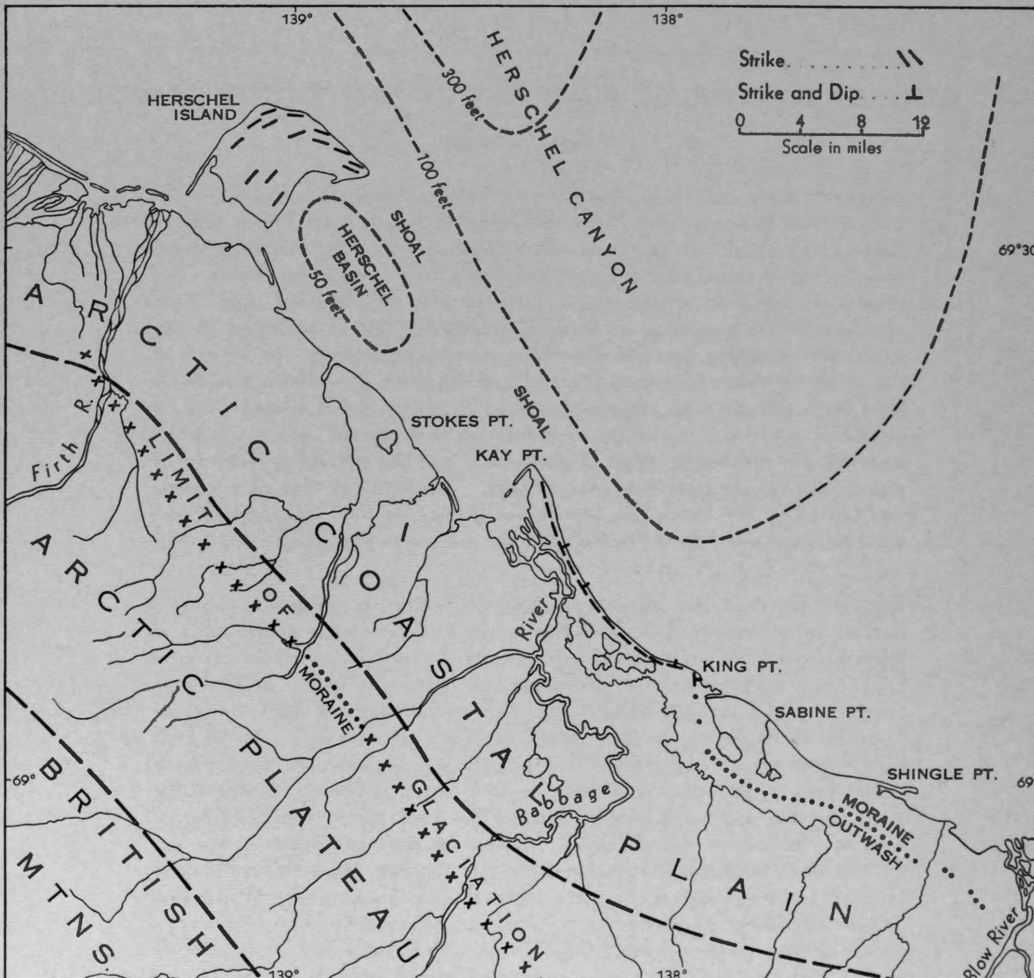

Figure 1. General location map showing the major structural lines, limit of glaciation, Herschel Basin marked by an approximate 50-foot isobath, and Herschel Canyon.

Ice-thrust features have been reported from most glaciated areas in the world, (Charlesworth, 1957, p. 255-262; Flint, 1957, p. 88-91). Subglacially induced disturbances have been observed in glacial drift, older unconsolidated sediments, and even in bedrock. Ice-thrust features are of restricted thickness, rarely exceeding 600 feet in any place.

The deformed sediments of the Yukon coast are in many respects similar to those of Nicholson Peninsula, (Mackay, 1956; Mackay, 1957) 200 miles to the east. Other areas with glacially disturbed sediments in

North America occur, for example at Tit Hills, Alberta (Gravenor and Bayrock, 1955; Hopkins, 1923; Slater, 1927); Long Island, New York (Fuller, 1914); and in south-central Iowa state (Lamerson and Dellwig, 1957).

FIELD WORK AND ACKNOWLEDGEMENTS

In the summer of 1956, Dr. W. H. Mathews and the writer observed some of the deformed features at Herschel Island. Field work was done for the Geographical Branch in 1957, in the area between King Point and Herschel Island, and in 1954, 1955, and 1958 evidences of deformation were seen to the east at Garry Island, northern Richards Island, Tuktoyaktuk, Eskimo Lakes, and Nicholson Peninsula.

The writer wishes to express his thanks to Dr. Mathews for his helpful discussions on the problems of ice thrusting, and in particular, on the possible movement of ice lobes along the Yukon coast.

DESCRIPTION OF DISTURBED AREA

Herschel Island

Herschel Island is separated from the Yukon coast by a shallow channel 2 to 4 miles wide and mostly less than 10 feet deep. The rhombic-shaped island is about 43 square miles in area. The highest point, which is 560 feet above sea level, is a mile west of the centre of the island thus making the west slope steeper than the east. The surface has been dissected by numerous streams flowing in valleys and gorges incised to depths as great as 150 feet. Most of the coast is bordered by a narrow beach, only a few feet in width, above which are wave-cut bluffs of 100 feet or more in height.

Tabular sheets of ground ice are exposed in a few places near the coast, the ice having formed *in situ*. Melting of the ice causes local slumping. Although the entire coast was examined by boat, and the northern coast was traversed several times, no large ground-ice segregations were seen near sea level. Any ground ice observed close to sea level was in thin veins, stringers, and pellets but not in thick sheets; the thick sheets all occurred just below the active layer and near to the ground surface. Even though some ground ice near sea level might have escaped notice, because of burial by slumping, it could not be abundant. This is stressed, because it has a bearing upon the origin of the deformed beds, discussed later.

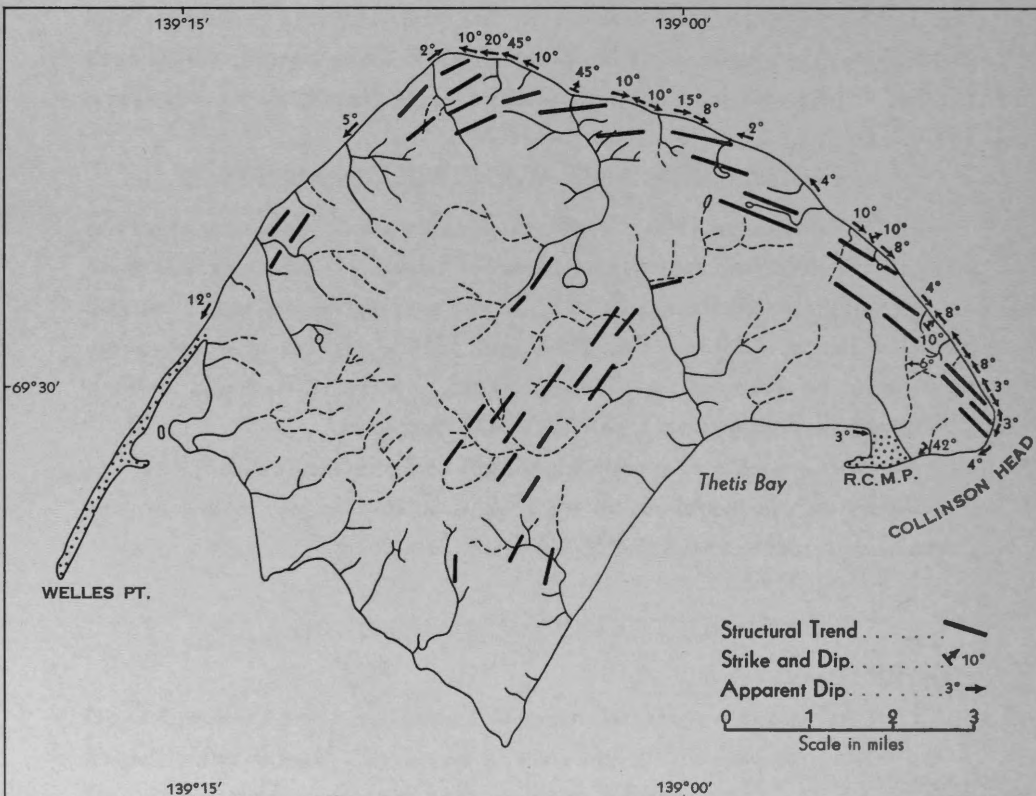

Figure 2. Structural lines of Herschel Island as plotted from air photographs. Dips and strikes were measured in the field.

Most of Herschel Island (Figure 2) is composed of deformed beds of sands, silts, and silty clays. In the eastern part of the island, some gravel beds contain twigs, snail and clam shells. The most abundant deposits are crossbedded to finely laminated sands, silts, and silty clays. Slickensided shear surfaces are common where clayey laminae and sands are intercalated. Some silty clays have veinlets and stringers of ice, especially as "fillings" between slickensided surfaces. Pebbles are common in the silty clays. Twigs, branches, and logs are found in the sands, silts, and silty clays throughout the vertical range of all coastal and inland exposures that were seen. About 2 miles northwest of the Royal Canadian Mounted Police post and at an altitude of approximately 200 feet, is a horizontal bed of peat 2 to 3 feet thick exposed for hundreds of feet. Marine Pleistocene fossils (O'Neill, 1924, p. 12A) occur in many exposures. A sample of clay from an altitude of 250 feet near the large lake in the centre of the island contained specimens of foraminifera, pelecypods, and ostracods. (identified by Dr. Wagner, Geological Survey of Canada). The forms, which live off the northern coast at present, are also reported from Pleistocene deposits in the area. No fossils (either macrofossils or microfossils) were found in a single sample from the highest point of the island.

On the mainland glacial erratics are scattered along the beaches and on the surface inland, but none are known to occur in the mountains to the south. Most of the larger erratics are coarse-textured pinkish granitic rocks, coarse-textured gneisses, medium-grained mafic rocks, buff sandstones, white quartzites, and gray fossiliferous Devonian limestones. On the island, however, large erratics 5 feet or more in diameter occur within 50 feet of the highest point, that is, to an altitude of 500 feet above sea level. Smaller erratics lie as high as a few feet from the summit.

The beds of Herschel Island show evidences of considerable deformation. Some deformed beds extend through the full vertical range of the bluffs. Those along the coast are folded, tilted (Figure 3) and thrust faulted. Open anticlines and synclines with dips of 3° to 5° are common.

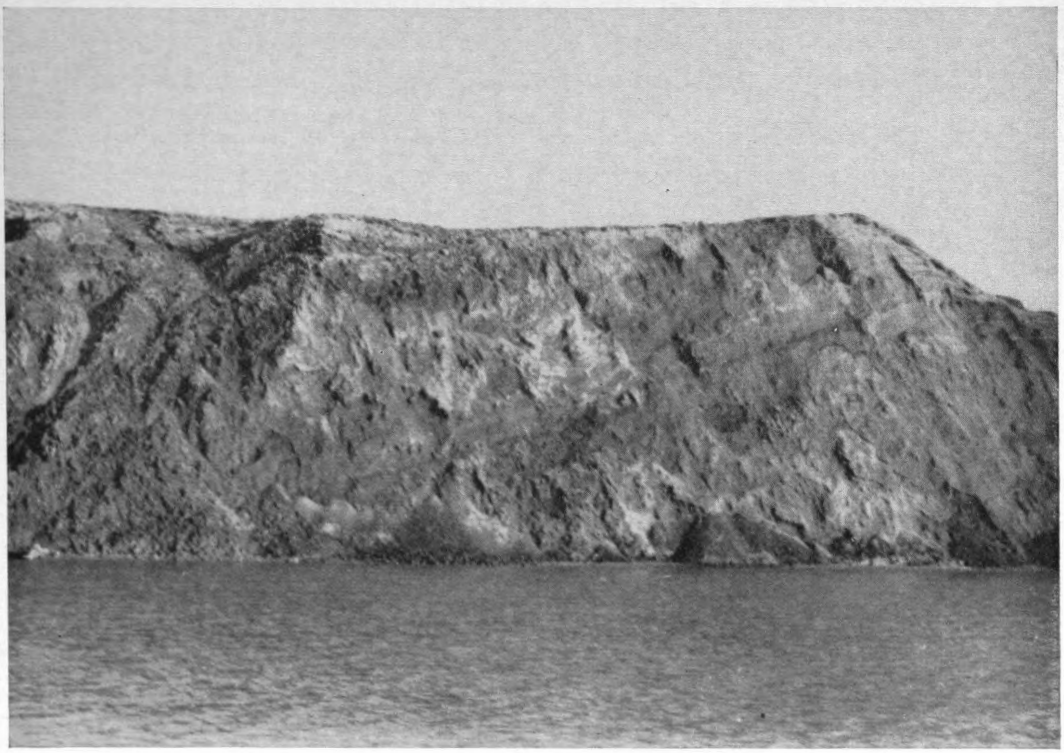

Figure 3. Tilted beds, Herschel Island.

There is little evidence for severe folding, but a few beds are overturned to the west. Apparent dips of beds exposed along the sea cliffs usually range from 5° to 20°. A few beds are nearly vertical. There are several conspicuous thrust planes on the north coast.

Shear planes are especially abundant in the clays, which are now frozen. The shear surfaces are smooth and spaced only a few inches apart (Figure 4). Some of the shear planes can be traced along the coast for 100 feet or more. Most clay exposures have several intersecting sets of slickensided shear planes as illustrated by the following two examples from the north side of Herschel Island (Table 1).

TABLE 1

	Strike	*Dip*	*Slickensides*
Set No 1	N22°E	12° to SE	along trend of strike
	S48°E	vertical	8° dip towards SE
	N52°E	63° to NW	variable
Set No 2	S83°E	vertical	24° dip towards east
	N80°E	vertical	nearly vertical
	S88°E	38° to S	trend along dip slope

The structural lines crossing the surface of Herschel Island show with clarity on air photographs (Figure 5). The surface trends do not always correspond with those at depth, because deformed beds, with varying attitudes, lie superimposed one above the other. The most distinct linear trends are close to the coast where the greatest amount of differential stream erosion has taken place. There, cuestas, in some places with a trellised stream-lake pattern, are present.

Herschel Basin

A most unusual basin, here called the Herschel Basin, lies southeast of Herschel Island between the series of shoals extending from the eastern tip of Herschel Island toward Kay Point and the mainland. This basin, shown in Figure 1, with the approximate 50-foot isobath sketched, is a unique feature of the offshore portion of the Arctic coastal plain where the sea floor is as flat as the flattest prairie. The existence of Herschel Basin has an important bearing on the theory of ice-thrust as it relates to the origin of Herschel Island. A sectional view of Herschel Island and Herschel Basin is shown as Figure 6.

Figure 4. Closeup, looking upward, of a slickensided shear plane in a silty clay, Herschel Island. The shear plane may be seen extending into the bluff. The overhang shown in the picture is about one foot in width.

Kay Point

Kay Point is only 20 to 30 feet high, but the land rises along the coast to the southeast to altitudes of 200 to 250 feet; the coastal bluffs are 100 feet in height. The Kay Point beds probably represent the same horizon as the Pleistocene beds of Herschel Island (O'Neill, 1924, p. 11A).

In general, sands and gravels are most abundant at the higher altitudes, sands and silts near sea level. Individual sand and gravel beds range in thickness, from a few feet to more than 25 feet. The gravel is apparently of local origin, as no Canadian Shield or "foreign" stones were found in it. Many of the gravel beds are stained brown and partially cemented with iron oxides. The sands, some crossbedded, contain twigs and logs, many having been flattened. A log, one foot in diameter, protruded from sands at an altitude of 200 feet. Silty beds are more common near the northwest end of Kay Point than in the more gravelly and higher areas to the southeast.

The higher seaward-facing bluffs of Kay Point reveal very extensive deformation. Disturbed beds are also present on the Babbage River side of Kay Point. Surface exposures of the thicker gravel beds give rise to ridges and cuestas that, in general, parallel the coast.

King Point

The deformed King Point beds (Figure 7) are probably Pleistocene in age, but may be older. Numerous pelecypods identified by Dr. Wagner as *Macoma balthica*, are present in deformed beds similar to those of Kay Point.

The sediments of King Point are predominantly of gravels, sands, and silts, containing some logs with interbedded peat and turf layers. Peaty beds are more abundant than at Kay Point. The depositional environment seems much like that of the nearby recent floodplains and deltas of the Blow, Babbage, and Firth rivers. Search in the gravel failed to show any typical granitic or gneissic Canadian Shield pebbles; all were of local origin. The only foreign boulders are erratics that have been concentrated from a surface veneer of glacial drift. There are no large ice segregations near sea level. The few ice segregations present are the usual ice-wedges and lenses that have developed just beneath the active layer.

Stokes Point

The coast from Kay Point to Stokes Point terminates in bluffs, 10 to 30 feet high, cut into sands, silts, and silty clays. No tilted beds were observed. However, many clayey beds have numerous nearly horizontal shear planes. Where measured, the slickensides trended southeast-northwest. The clayey beds contain a few pebbles, like similar beds of Herschel Island.

EXTENT OF GLACIATION

The Yukon coast as far west as Herschel Island and the lower Firth River have been glaciated (Bostock, 1948, p. 35; Glacial Map of Canada, 1958). The ice that moved northward down the Mackenzie River valley to the coast was not thick enough to override the north-south trending Richardson Mountains on the west side of the Mackenzie River delta. The ice spread seaward to at least the northern end of Richards Island. The surface gradient of the ice resulted in a northwestward movement along the Yukon coast to Herschel Island.

About 2 miles west of Firth River and 10 miles from its mouth is an overflow channel from a former ice-dammed lake the floor of which is 560 feet above sea level. This is the westernmost known limit of glaciation along the Yukon coast. No meltwater channels, eskers, moraines, deranged hydrography, or other evidences of glaciation are to be seen west of the overflow channel, by field observation or on air photographs. On Herschel Island, erratics are present within 20 feet of the summit, thus indicating that glacier ice overtopped it.

Between Shingle Point and Firth River, lateral meltwater channels trend from southeast to northwest across the present drainage systems. Flow was parallel to the coast for long distances, rather than directly to the coast, probably because the ice front blocked direct drainage to the

Figure 5. Air photograph of Herschel Island showing well defined linear structural lines with stream and lake patterns along the north coast. (RCAF photograph A13470-142.)

northeast. For example, a tributary of Babbage River flows, in a former meltwater channel, parallel to the coast for 30 miles—although being nowhere more than 6 miles from the sea, before it joins the Babbage River delta. As meltwater channels lie within 300 feet of sea level from Firth River to Blow River, sea level was below 300 feet at the time of deglaciation.

The evidence of meltwater channels and moraines indicates that during deglaciation the front of the ice roughly paralleled the present coast. As the direction of ice flow would have been at right angles to the margin of the glacier, the movement would be expected to range from southwest (normal to the coast) to northwest (along the coast) depending upon the time and location under consideration.

METHOD OF DEFORMATION

The three principal areas of deformed sediments, namely Herschel Island, Kay Point, and King Point rise as topographic highs above adjacent areas with similar sediments. This is likewise true of Nicholson Peninsula with its deformed sediments (Mackay, 1956). Herschel Island, in particular, has long been a puzzle because it rises at least 400 feet above any known area with similar deposits along the Yukon coast. Leffingwell (1919, p. 169), recognizing the singular character of Herschel Island many years ago, suggested, without elaboration, that Herschel Island and Barter Island, Alaska, were local domes whose deformation may have taken place at the end of the Pliocene or in the Pleistocene. Later, O'Neill (1924, p. 18A) suggested that Herschel Island was a remnant of a Pleistocene Mackenzie River delta, augmented by material from the neighbouring mountains.

Three mechanisms of deformation may be suggested: slumping, tectonic disturbance, and glacier ice-thrust.

Slumping

The deformed areas occur on such a grand scale and are of such a type, that they cannot be attributed to slumping. As Herschel Island, Kay Point, and King Point rise well above adjacent areas, there are no nearby higher lands which could have provided sources for their deposits. The widths of the deformed zones together with their continuity of structural lines over several miles are incompatible with slumping. Moreover, the type of deformation is that associated with thrusting (e.g. shear planes and overturned folds) and not slumping.

As ground ice is present along the Yukon coast, the possibility of slumping, resulting from the melting of ground ice, should be considered. However, as all the thick sheets of ground ice seen in the field were subsurface features, lying just below the active layer, present melting could only produce surface slumping on a minor scale. Even if ice sheets formerly occurred at depth, the structure and magnitude of the features seen cannot be attributed to slumping resulting from the melting of such deep ice.

Tectonic Origin

The disturbed sediments do not appear to be of tectonic origin, for reasons advanced by others (e.g. Jessen, 1931; Slater, 1926-7) to explain the origin of similarly disturbed sediments elsewhere. The principal arguments against a tectonic origin are: (1) As the disturbed sediments are Pleistocene in age and are covered with glacial deposits, a tectonic origin would require deformation during the Pleistocene, but there is no other evidence for a tectonic disturbance at that time. (2) So far as is known, the disturbance has affected only the superficial deposits; it has not been of deep-seated origin. Pleistocene beds west of Herschel Island and those by the Mackenzie River delta are undeformed. (3) It is difficult to conceive how cohesionless gravels, sands, and silts could be extensively deformed except under a confining pressure, which a tectonic theory does not provide, unless deformation were to occur at a fortuitous time when glacier ice was present.

GLACIER ICE-THRUST THEORY

According to the glacier ice-thrust theory, proposed here, the overriding action of glacier ice, possibly against a topographic obstruction, supplied confining pressure to produce deformation. The shearing strength of the sediments may have been reduced by hydrostatic neutral stress in entrapped pore water and disturbances caused by the melting of ground ice.

Although glacier ice may deform deposits in a number of different ways, the principal methods that have been advanced to explain disturbed deposits are:

1. By the frictional drag of glacier ice as it moves over weak strata (Slater, 1926).
2. By the incorporation of subjacent beds as englacial material with its later preservation by slow ice wastage (Woodward, 1903; Slater, 1926-7; 1926-7a).
3. By the bulldozing effect of glacier ice forming a push moraine before it (Charlesworth, 1957, p. 410-411).
4. By the overriding pressure of glacier ice as it advanced over a topographic obstruction (Fuller, 1914, p. 201-207; Hopkins, 1923; Jessen, 1931).

Frictional drag of glacier ice is known to produce surficial deformation, usually restricted to the upper few feet of the subjacent strata, but the disturbances along the Yukon coast are on a larger scale. Slater has strongly supported the englacial theory for similar disturbances in Denmark but his reasons are not convincing (Jessen, 1931). Slater has suggested that strata were cut up into slices, incorporated into glacier ice, and let down as a fossil glacier whose "hard parts" were preserved by slow melting to give tilted beds. If such had been the case, englacial morainic material should now be intercalated with the deformed beds. However, such englacial fill does not occur in Denmark (cf. Horberg, 1952; Jessen, 1931), at Nicholson Peninsula (Mackay, 1956), nor along the Yukon coast.

Push moraines are well known from many glaciated areas but they differ from the disturbances of the Yukon coast in size and material. A push moraine is a narrow ridge, about 25 feet in height, made by the bulldozing of drift by the margin of an expanding glacier (Flint, 1957, p. 133).

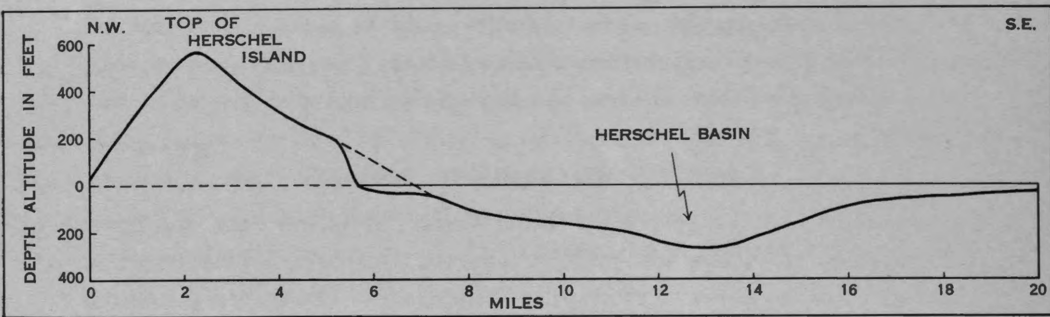

Figure 6. A section, with minor irregularities omitted, through Herschel Island and Herschel Basin with a vertical exaggeration of 26.4.

The preceding three methods might have contributed, from time to time, to local deformation, but the fourth method seems to best explain deformation of the Yukon coast. A working hypothesis of the fourth method of deformation, as applied to the Yukon coast follows, although some parts are quite speculative.

As the glacier moved down the Mackenzie River valley to the present location of Aklavik, it was confined on the west by the Richardson Mountains. In moving north beyond Aklavik the ice, being no longer restricted by the mountains, was free to spread northwestward along the Yukon coast. From an altitude of about 3000 feet, west of Aklavik (Camsell, 1906), the limit declines northwestward. Several miles east of the Firth River the altitude of the highest overflow channel is about 1000 feet; just west of the Firth River the altitude of the floor of a proglacial lake overflow channel is about 560 feet. Apparently, therefore, the ice was thin at the west side of the Firth River. As no indication of glaciation has been observed west of the westerly overflow channel, it seems unlikely that the ice moved more than a few miles farther west.

The movement of the glacier in the southern part of Mackenzie Bay was probably influenced greatly by a submarine valley known as Herschel Canyon (Carsola, 1954), which extends in a northwest direction with its apex pointing toward the broad estuary of the Napoiak channel (Shallow River) of the Mackenzie River. The valley lies about 10 miles northeast of Herschel Island where its depth exceeds 500 feet. About 80 miles north of the Yukon-Alaska border the canyon may be 1,500 feet deep; and 130 miles north of Midway Islands (Alaska) depth may considerably exceed 10,000 feet (Bathymetric Chart of the Arctic Ocean, 1957). As the glacier advanced over the canyon, active calving in the deeper waters would likely have induced an embayment and, therefore, a lobe to the southwest, i.e. a Herschel Island lobe. The Herschel Island structural lines, both in trend and curvature, suggest such a lobe.

If the material of Herschel Island, which has a total volume of 1.91 cubic miles measured above sea level (Table 2), was ice-thrust into position, then its source should lie in the direction from which the ice had moved; moreover, the source should be marked by a "deficiency" of material. Such an apparent source is Herschel Basin which is a unique topographic phenomenon along the Arctic coast. Herschel Basin is elongated in the inferred direction of ice movement with its long axis pointed directly at the highest point of Herschel Island. The long axis is therefore normal to the structural lines in the centre of Herschel Island, as would be expected if the features were formed by ice-push. Herschel Basin is close to Herschel Island. The gradual slope of about 1° from the summit of Herschel Island to the deepest part of Herschel Basin is unbroken, except for the wave-cut cliffs (Figure 6). This continuity in land surface and underwater profiles suggests that the island and basin are genetically related. Furthermore, the volume of Herschel Basin is reasonably proportionate to that of Herschel Island, considering that infilling by sediment has reduced the basin's original volume and that sea level is an arbitrary datum from which to measure a volume. The volume of the basin below the 25-foot submarine contour is .96 cubic miles; that directly above the 25-foot submarine contour is .55 cubic miles, the two volumes totalling 1.51 cubic miles.

TABLE 2

Herschel Island		*Herschel Basin*	
Altitude (feet)	Volume Above (cubic miles)	Depth (feet)	Volume Below (cubic miles)
0	1.91	0 (see text)	1.51
25	1.78	25	.96
50	1.51	50	.58
100	1.14	100	.24
150	.81	150	.08
200	.54	200	.02
250	.34		
300	.20		
350	.11		
400	.06		
450	.03		
500	.02		
550	.01		

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If Herschel Basin did not exist, then, in terms of the ice-thrust theory, it would be difficult to account for the source of the Herschel Island sediments. Therefore, the existence of such an unusual feature as Herschel Basin with its orientation, location, and size appropriate to the ice-thrust theory, is most significant. The relationship between Herschel Island and Herschel Basin cannot easily be reconciled with a tectonic or slumping theory of deformation.

TABLE 3*

King Point

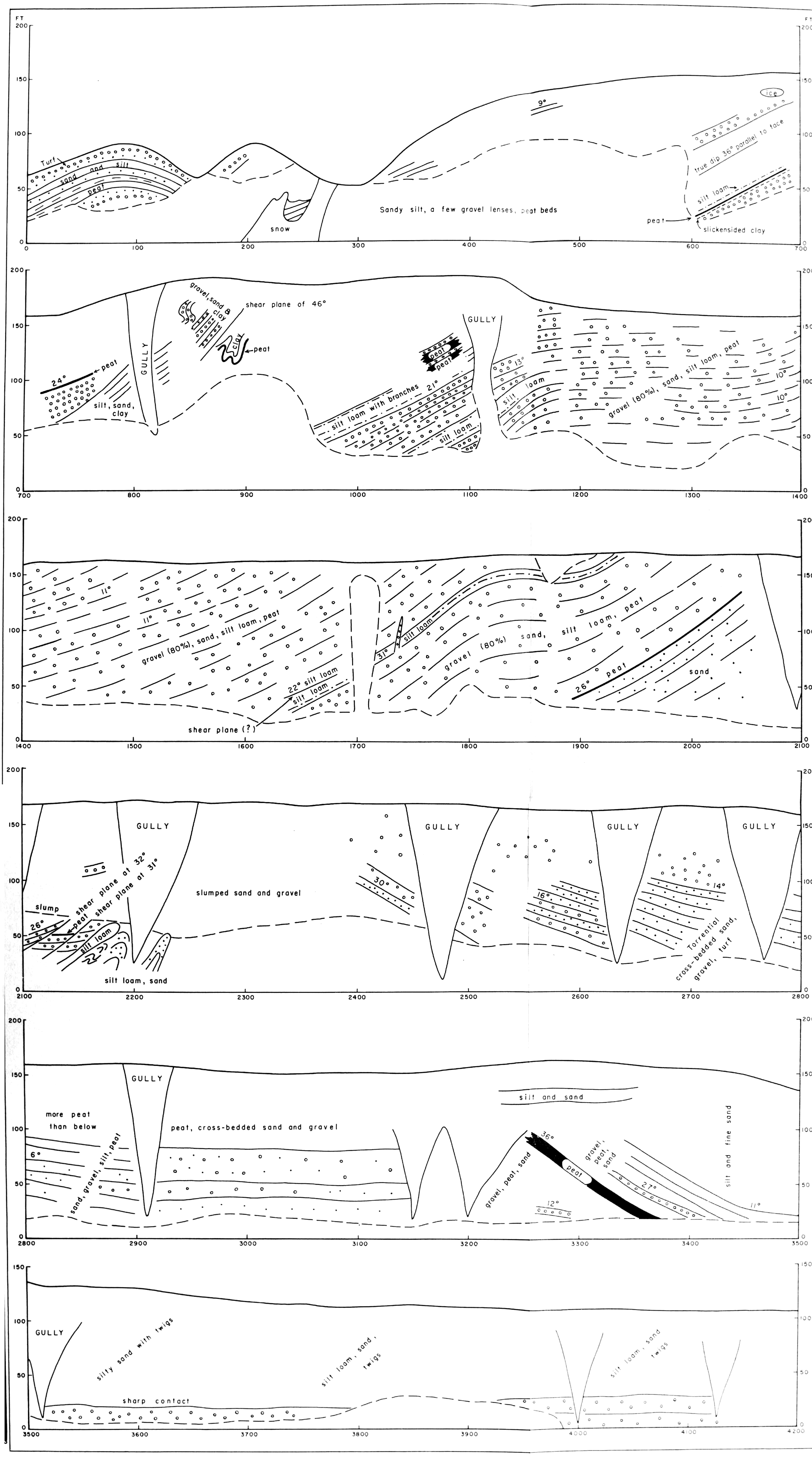
Distance along section of Figure 7 (in feet)	Dip	
	Direction	Amount
650	S 45° E	36°
1125	S 34° E	13°
2050	S 43° E	29°
2600	N 12° W	20°
2775	N 14° E	28°
2900	N 45° E	20°
3125	N 45° E	15°
3500	N 45° E	2°

Kay Point

Distance along a SE-NW coastal section at Kay Point Isthmus (in feet)	Dip	
	Direction	Amount
150	N 55° E	20°
400	N 55° E	5°
475	N 59° E	11°
750	N 61° E	30°
900	S 41° E	31°
1100	N 11° E	61°
1600	N 55° E	50°
1700	N 55° E	40°
1850	N 71° E	46°
2000	N 41° E	41°

* The measurements of the direction and amount of dip were made on shear planes and on the attitude of disturbed sediments. As the primary dips of the disturbed sediments were unknown, the measurements are subject to errors of a few degrees.

Figure 7. A section, from southeast to northwest, along the sea cliffs at King Point. The horizontal distances were measured, dips measured, and altitudes interpolated from measurements. Vertical and horizontal scale in feet.



FT
Turf
sand and silt
peat
snow
Sandy silt, a few gravel lenses, peat beds
9°
ice
true dip 36° parallel to face
silt loam
peat
slickensided clay
gravel, sand & clay
shear plane of 46°
clay
peat
GULLY
24°
silt, sand, clay
peat
silt loam with branches
21°
silt loam
13°
gravel (80%), sand, silt loam, peat
10°
11°
shear plane (?)
22° silt loam
31°
26°
sand
slump
shear plane at 32°
peat shear plane at 31°
slumped sand and gravel
silt loam, sand
30°
16°
14°
Torrential cross-bedded sand, gravel, turf
more peat than below
6°
sand, gravel, silt, peat
peat, cross-bedded sand and gravel
silt and sand
gravel, peat, sand
36°
12°
27°
silt and fine sand
silty sand with twigs
sharp contact
silt loam, sand, twigs

The structural lines of the Kay Point-King Point area suggest push to the southwest from an ice front that roughly paralleled the coast, a trend that agrees well with that of the lateral drainage channels. At King Point (Table 3, and Figure 7), there was apparently a later thrust of sediments from the southeast over those produced by the Kay Point disturbance. These sediments probably came from the depression forming King Point Harbour. At about this time, an outwash plain was built along the ice front south of Sabine Point, Shingle Point, and Blow River. There is insufficient evidence to indicate when thrusting took place (e.g. late Wisconsin or earlier).

The disturbed slices are not a surface phenomenon but, as Figure 7 shows, involve strips at least 200 feet thick. As the surface beds show no more contortion than those below, shearing probably occurred at depth or else more disturbed surface beds were removed by glacial erosion. The thickness and extent of the disturbed sediments show that relatively large and thick slices were sheared off. This suggests that the sediments may have been frozen when deformed.

Permafrost, in land areas in thermal equilibrium with the existing climate, was probably hundreds of feet thick when the glacier passed over them, judging by a present depth of over 1,000 feet at Point Barrow, Alaska (MacCarthy, 1952; Brewer, 1958). If conditions at Point Barrow are typical it could be assumed that the offshore sea bottom had a thin zone of permafrost (Lachenbruch, 1957; Brewer, 1958.)

If an area of thick (e.g. 1,000 feet) permafrost were covered by glacier ice, the lower permafrost surface would likely recede upward, because temperatures at the basal part of the glacier would be higher than the temperatures that produced the permafrost. According to Terzaghi (1952), the maximum rate at which the lower boundary of permafrost could recede would approximate 2 centimeters a year, or 200 meters in 10,000 years. Therefore, during a prolonged period of glaciation, considerable reduction in permafrost thickness might occur. On the other hand, if glacier ice overrode a portion of the sea bottom that was underlain by a moderate thickness of permafrost (e.g. 100 feet; cf. Brewer, 1958; Lachenbruch, 1957), the thickness of permafrost should increase if the mean annual temperature at the basal portion of the ice were lower than the former sea-water temperature.

It seems likely, therefore, that if the glacier advanced over a land area, thick permafrost would thin from below; if it advanced over the sea floor, permafrost of limited thickness, e.g. 100 or 200 feet, would be retained

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beneath the glacier. In either case, permafrost would tend to be of moderate thickness and the permafrost zone, with its glacier cover, would act as an impervious horizon to prevent easy upward escape of pore water from below. Near the margin of the ice, an unequally distributed glacial load, resting on topographic irregularities, might create high neutral stresses in entrapped pore water. As neutral stresses increased, shearing strength of the unfrozen soil beneath the permafrost would decrease, especially if the melting of ground ice had created weakening disturbances and settling in the soil. Under such conditions, an overriding glacier might provide the confining pressure to shear off thick slices of frozen sediments along the basal portion of the frozen ground (cf. Hubbert and Rubey, 1957 for a parallel explanation for the mechanics of overthrust faulting in bedrock).

CONCLUSION

Although much remains to be discovered about the mechanism of ice-thrusting, the theory seems to explain the type of disturbed sediments of the Yukon coast better than any other theory. It accounts for: a confining pressure for the deformation of gravels, sands, silts, and clays; the remarkable agreement of the deformed sediments with the glaciated area; the shapes, orientations, and dips of the disturbed beds at Herschel Island, Kay Point, and King Point; the topographic anomalies of Herschel Island, Kay Point, and King Point; and the presence, specific location, orientation, and size of Herschel Basin. The disturbances may have occurred during the closing stages of glaciation, but not necessarily in late Wisconsin. Perhaps high neutral stresses in pore water, coupled with disturbances resulting from the melting of ground ice in the basal part of a permafrost zone, helped to reduce the shearing strength of the sediments.

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A REVIEW OF THE STUDY OF PERIGLACIAL PHENOMENA IN CANADA

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ABSTRACT: The study of periglacial phenomena in Canada is in its infancy and as yet, very little is known of the distribution of these phenomena. Before World War II most of the area under the influence of a periglacial climate was relatively inaccessible and consequently there are only casual references to periglacial phenomena in Canadian literature prior to 1940. The opening up of the north has increased the interest of Canadian geographers and geologists in the active periglacial forms, principally patterned ground and permafrost. This paper brings together selected references and discusses the present stage of development of the study of periglacial processes and phenomena in Canada.

INTRODUCTION

The term "periglacial" was introduced by Lozinski (1909) following studies of weathering in the Carpathian Mountains where he recognized traces of the action of a special climatic environment in areas bordering Pleistocene glaciers. He applied the term to: the area adjacent to the borders of the Pleistocene ice sheets; the climatic characteristics of that area; and by extension to phenomena induced by that climate even if located outside that particular zone. Considerable discussion has ensued through the years over the definition of the term periglacial. Some workers, like Büdel (1953), wished to restrict its use to relief features of the immediate margins of the former ice sheets, although they fully recognized that, geomorphologically speaking, the effects of periglacial processes are much more important than glacial influences. Other workers, like Charlesworth (1957), gave the term a much broader interpretation, applying it to processes and phenomena which, although not glacial, were active and owed their existence and character to ice and frost-action. His interpretation would embrace the processes and phenomena found on nunataks and in areas of intense freeze-thaw action such as the Canadian Arctic Archipelago today. Troll (1944) considered that periglacial phenomena occurred in high mountains in temperate and tropical regions.

In this paper the Lozinski definition will be used, that is, the term periglacial will include all processes and phenomena, whether fossil or active, induced by a frost climate, even if located today outside a presently active frost region.

PROCESSES AND PHENOMENA

As with the definition of the term periglacial no universally accepted classification of periglacial processes or forms has been devised. For the purpose of organization of data a simplified classification is presented here (Table 1). It should be appreciated that some forms result from the action of more than one process, and that for the sake of convenience they will be classified under the process considered the most important.

Peltier (1950) developed the concept, previously introduced by Bryan (1946) and Troll (1948), that the processes of intense frost-action in periglacial areas constitute a cycle comparable with Davis' (1899) "normal" cycle of erosion in humid temperate areas. He considered that this cycle, although active only in remote parts of the Arctic and on high mountains, had, in Pleistocene time, far-reaching effects on the periglacial areas of present-day temperate regions. The periglacial morphogenetic region, as defined by Peltier, has an estimated range of average annual temperature of from 5 to 20 degrees F., and an estimated range of average annual rainfall of from 5 to 55 inches. He considered it to have the following morphological characteristics: strong mass movement; moderate to strong wind action; and weak effect of running water. The periglacial cycle follows the pattern set by Davis (1899) of three stages: youth, maturity and old age.

In the absence of parameters it is impossible to outline the exact zone of active periglacial influence in Canada today. All of Canada at one time or another experienced a periglacial climate. Fossil frost rings, involutions, and dry valleys are among fossil periglacial phenomena noted in southern Canada, although reportings are not as numerous as might be expected. This may be because interest in periglacial phenomena in Canada is as recent as the last decade, or because of a paucity of fossil phenomena owing to lithology, vegetation cover, or an unduly short period of time in which an intense periglacial climate prevailed, following a rapid retreat of the last ice sheet.

STUDY IN CANADA

Prior to 1940, there were only casual references to polygonal structure, solifluction and permafrost in the Canadian literature. World War II brought a renewed interest in the north, and accessibility followed the establishment of the northern weather stations.

Active interest in the study of periglacial phenomena in Canada dates from the publication of Washburn's (1950) basic paper. This important paper was based on field work on Victoria and Melville islands in the

District of Franklin, Northwest Territories (Washburn, 1947) and strongly influenced the study of periglacial phenomena in Canada, particularly that of patterned ground. This process has dominated the study of periglacial phenomena by Canadian geographers and geologists, almost to the exclusion of the study of fossil forms, such as involutions and loess, which has dominated the work in Poland and the United States. Furthermore Canadian workers have almost unanimously adopted Washburn's classification of patterned ground, a situation which has resulted in much less confusion of terminology in Canadian literature than elsewhere.

The study of periglacial phenomena in Canada, apart from permafrost, has been carried on largely by field officers of the Department of Mines and Technical Surveys. The writer (Cook, 1959) has prepared an annotated bibliography of periglacial phenomena in Canada. Geologists of the Geological Survey of Canada (Blackadar 1954, 1956; Henderson, 1956; and Thorsteinsson and Fortier, 1954) have made increasing reference to patterned ground. Little detailed mapping, however, has been attempted. Mackay (1953) mapped the distribution of fissures and mud circles on a small area of raised beach at Resolute, Cornwallis Island. Robitaille (1958, 1959) mapped some types of periglacial phenomena in the vicinity of Mould Bay, Prince Patrick Island, and in southeastern Cornwallis Island.

The mapping of periglacial phenomena in Canada is greatly complicated by problems of scale. The area in Canada that has been influenced by a periglacial environment at one time or another is so vast, and the number of workers so few, that only an infinitely small part has been examined in any detail. It is only now that adequate topographic maps of the northern areas are becoming available.

Aerial photographic analysis is a recent scientific aid in the mapping of periglacial phenomena. With improved techniques it should be possible to gain much information on patterned ground, and to map its distribution in many areas still difficult of access, although a number of problems are involved.

On vertical aerial photographs at 1:15,000 a circle 20 feet in diameter shows as a dot about .015 inch in diameter. Photographs on a scale of 1:10,000 or better would be more easily interpreted, but only limited areas are photographed on this scale. Only the larger forms, such as tundra polygons are visible at a scale of 1:20,000.

Much valuable work has been done in aerial photographic analysis of permafrost and patterned ground. Frost (1952) and Sager (1951) based their work on experience obtained in Alaska, but used Canadian examples for illustration. The Purdue University Joint Research Project (1953) conducted field work along the southern part of the Alaska Highway in British Columbia and Yukon Territory, in the entire basin of the Mackenzie River, and in the vicinity of Great Bear Lake. This work was to extend the range of Arctic and sub-Arctic aerial photographic analysis for the interpretation of soil patterns, permafrost, and other periglacial phenomena from aerial photos.

Little attempt has been made in Canada to recreate past climates using periglacial indicators. Odynsky (1958) studied U-shaped dunes on aerial photographs of Alberta and reconstructed the effective wind direction at the time of their formation.

TABLE 1.—Classification of Periglacial Processes and Phenomena (Cook, 1959)

Process	*Resulting Phenomena*
Cold (negative heat balance)	permafrost
Cryoturbation (freeze—thaw)	strata deformation—contortions, plications, involutions, convolutions blockfields (felsenmeere) ground ice forms—ice wedges, fissures, earth mounds, pingos patterned ground—sorted and nonsorted circles, nets, polygons, steps, stripes,and other patterned ground altiplanation terraces nivation hollows
Water	asymmetric valleys dry valleys
Wind	loess sand dunes ventifacts—wind-faceted pebbles, sand-blasted stones. wind-etched stones oriented lakes
Mass Movement	solifluction stabilized talus slopes
Thermokarst	ponds and small lakes hollows
Snow	nivation hollows avalanche scars
Ice	lake ramparts ice-shoved ridges

The first report to the Commission on Periglacial Geomorphology of the International Geographical Union (IGU) was prepared by Brochu (1956) for presentation to the Rio de Janeiro Congress. In this report the inadequacy of periglacial research in Canada was stressed and certain suggestions made for the improvement of research. At this congress Canada was made a member of the Commission. Dr. Louis-Edmond Hamelin, the Canadian member, attended the IGU symposium held in Poland in September, 1958. He has since (Hamelin, 1958) outlined a program of co-ordinated research for Canada.

Thus the study of periglacial phenomena in Canada is in its infancy, and a great deal of work remains to be done. The inventory of periglacial forms is incomplete. Although detailed studies of individual phenomena are indispensable to an understanding of periglacial process, few have been attempted.

The field of periglacial geomorphology can be rewarding for one prepared to devote considerable time and effort to its study. In addition to contributing to the knowledge and understanding of geomorphological processes, the study of periglacial phenomena has practical applications. It has immediate application to engineering problems, such as the siting of buildings and airstrips, and to transportation problems involving the movement of vehicles across tundra terrain.

PERIGLACIAL FORMS

Process of Intense Cold (negative heat balance)

In all periglacial regions permafrost exists due to a negative heat balance between the atmosphere and the earth. Permafrost is widespread in the northern hemisphere, and may occur in both active and fossil forms. It is of the utmost importance in the processes of solifluction and the formation of patterned ground.

Permafrost

References to permafrost in Canada have been brought together by Cook (1958b). Jenness (1949) published the first comprehensive paper discussing its formation, growth and distribution in Canada. Since that time many isolated references have been made to permafrost encountered by mining and engineering specialists. However detailed and scientific work has been accomplished by recording devices installed in permafrost at Resolute, Cornwallis Island in the eastern Arctic Archipelago, and at Norman Wells and Aklavik in the Mackenzie River area.

Drilling operations were carried out at Resolute during the summers of 1950 to 1953 under a project jointly sponsored by the Dominion Observatory, Department of Mines and Technical Surveys; Meteorological Branch, Department of Transport; the Associate Committee on Soil and Snow Mechanics of the National Research Council of Canada; and the United States Weather Bureau. Numerous important papers have resulted. Thomson and Bremner (1952) provided preliminary general observations from shallow-hole readings obtained in the first two years of drilling. Bremner (1955) discussed problems encountered in the 4 years of permafrost drilling. Cook (1955) analysed near-surface soil and air temperatures and solar radiation for 1950-53, and the freeze-back of the active layer in 1955. Misener (1955) studied the heat flow in the permafrost and established that the lower limit of permafrost at Resolute was at 1,280 ± 10 feet. Misener, et al., (1956) discussed the heat-flow measurements and drilling problems in permafrost at Resolute in general terms. Goguel (1956) saw the thermal anomaly reported by Misener (1955) as the result of quaternary variations in climate. Lachenbruch (1957) offered nearby bodies of water as an explanation for the anomalously large outward earth-heat flow reported by Misener (1955). Cook (1958c) analysed temperatures in permafrost at Resolute to depths of 650 feet for the period 1952-57.

The drilling operations at Norman Wells, carried out by Imperial Oil Co., Ltd., in association with the National Research Council of Canada, have been summarized by Hemstock (1953). The permafrost investigations in the Mackenzie River delta carried out by the National Research Council in connection with the relocation of Aklavik have been outlined by Brown (1956).

Much work remains to be done on characteristics and distribution of permafrost in Canada. Little work on the physical properties has yet been attempted. The southern boundary is ill-defined because of lack of field data. Currently, work in Canada is being co-ordinated by a subcommittee of the Associate Committee on Soil and Snow Mechanics under the National Research Council.

Cryoturbation—Process of Freeze-thaw Action

The process of freeze-thaw is undoubtedly the most important single factor in the breakdown of rock and the modification of surface materials in periglacial regions. A wide variety of phenomena owe their being to the action of frost in the soil, and to the alternate freezing and thawing of the soil which occurs especially in the spring and the fall.

Strata Deformation.—Contortions, plications, involutions and convolutions are deformations of essentially horizontal strata caused by frost action. They have been widely reported as fossil forms in European literature, and recently numerous references have been made to involutions in northwestern United States. In Canada, however, few reportings have been published. Lee (1956) reported involutions and contortions near Fredericton, N.B. Hamelin (1958) noted convoluted banks of some streams in the Abitibi district of northeast Quebec and suggested that the features might be of periglacial origin and might be related to former occurrences of ground ice-lenses, later enlarged by contemporary fluvial action. Mackay (1958b) observed considerable contortion of bedding in cross-sections in stratified silts, sands, and gravels in the Anderson River map-area, and considered that these complicated upfolds and downfolds might have been produced by lateral thrusting induced by growing ice wedges, or vertical thrusting by frost heaving.

Blockfields (felsenmeere, mountain-top detritus).—Flat terrain in an area at present, or formerly, under a periglacial climate is often covered with a sea of angular blocks variously called "blockfields", "felsenmeere" or "mountain-top detritus". Composed almost wholly of local rocks, this feature may be many feet deep and may completely cover the bedrock. It is produced by frost-splitting and is indicative of periglacial conditions at the time of its formation. The presence of blockfields at higher elevations is often taken as evidence that the area stood as a nunatak, or ice-free area, during the last glaciation.

Blockfields are widespread in Canada, although there are few detailed references to their formation or distribution in geological literature. However, there are references to blockfields in northern Labrador and in southernmost Baffin Island.

There has been considerable discussion about the age of the Torngat blockfields in northern Labrador, and whether the Torngat Mountains themselves existed as nunataks in the Wisconsin Ice Age. Odell (1933) and Tanner (1944) believed that favourable climatic conditions since the last glaciation induced rapid formation of blockfields in the Torngats, hence the blockfields post-date the last glaciation, the Torngat Mountains being completely inundated by ice in the Wisconsin. Coleman (1921) considered that blockfields take thousands of years to form and that the Torngat phenomenon was pre-Wisconsin. Recently Ives (1957, 1958a, 1958b) spent the summers of 1956 and 1957 in the area and concluded that the Torngat blockfields pre-date the Wisconsin glaciation. He found blockfields above 2,700 feet on the upper slopes of the Nakvak Valley at the trimline of a former outlet glacier, and in "Shoreline Valley," they were observed above 2,376 feet.

In southernmost Baffin Island, Mercer (1954, 1956) found very restricted occurrences of blockfields on Kingaite Peninsula and indicated that they were of great age. They occurred only on the coastal plateau remnants which stand slightly above the level of the main plateau surface. Mercer considered the blockfields were not post-glacial in origin, but did not know whether they were interglacial and protected during the Wisconsin by stagnant ice, or were formed on ice-free terrain in the Wisconsin.

Ground Ice Forms.—Ice wedges are commonly exposed along the Arctic coast, and probably result from frost-cracking, due to contraction during intense cold. They were first reported in Alaska by Leffingwell (1915, 1919) and have been widely reported elsewhere, generally in association with fissures and ice wedge (tundra) polygons. Little, if any, detailed work has been attempted on ice wedges in Canada.

Fissures or furrows are one of the most widespread of all periglacial features occurring in Arctic Canada, and are especially common along the coast where they occur on raised beaches in both longitudinal and transverse positions, generally joinging at right angles. Like the ice wedges which normally underlie them, they result from frost-cracking due to contraction during intense cold. Fissures were studied in some detail by Washburn (1947) at Cambridge Bay, Victoria Island, and by Mackay (1953) at Resolute Bay, Cornwallis Island. Neither fossil ice wedges nor fissures have been reported from southern Canada, although Mackay (personal communication) believes there are some near Kazubazua in the Gatineau River valley, Quebec.

Henderson (1952) described till mounds in the Watino area of Alberta, and suggested that they were fossil forms, formed in a periglacial environment when the ground was permanently frozen. Gravenor (1955, 1956) discussed the origin and significance of prairie mounds on the western prairies and in the Peace River area, interpreting them as originating from debris-filled pits on a stagnant ice surface which became mounds when the ice eventually melted.

Although small seasonal ice mounds have been reported from isolated points along the Arctic coast and in the tundra region, most interest in Canada has been centered on pingos, a rather spectacular periglacial feature frequently found in the Mackenzie River delta and the Kotzebue region. Porsild (1938) first described these pingos and speculated on their formation. Stager (1956) examined 1,380 pingos from air photographs in the area east of the Mackenzie River delta, and mapped them, as well as classifying them into distinct types. Pihlainen, et al. (1956) examined one pingo in the Mackenzie River delta in some detail, preparing sketches and plans in cross-section, and drilling test holes for temperature measurements and core samples. Mackay (1958b) reported a few large pingos in the Anderson River map-area, and in the low, outer part of the Mackenzie River delta noted mud lumps, some of which had ice-cores and were possibly incipient pingos.

Patterned Ground is a group term introduced by Washburn (1950, 1956) for the more or less symmetrical forms, such as circles, polygons, nets, steps and stripes, that are characteristic of, but not necessarily confined to, surface mantle that is subject to intensive frost action. Patterned ground probably has a wider distribution than any other periglacial feature, and occurs in both active and fossil forms.

Although there are references to polygons, stone circles, etc., in earlier literature, the systematic reporting of patterned ground in Canada dates from Washburn's basic paper "Patterned Ground" which appeared in *Revue Canadienne de Géographie* in 1950.

Patterned ground is widely distributed over the Arctic, and references to it have been chiefly descriptive in nature, although some quantitative work has been done. Washburn (1947) examined the internal structure of "mud" circles on Victoria Island. Mackay (1953) mapped the distribution of mud circles on a Cornwallis Island raised beach at Resolute Bay and applied Davis' concept of youth, maturity and old age to their development. In youth they are represented by plugs beneath conical pits. When they have grown sufficiently to break into the pits, maturity may be considered to have commenced. As more and more plugs reach the surface they begin to coalesce, at which stage old age may be considered to have set in. Individual circles may eventually lose their identity as they merge to form other types of patterned ground. The writer (Cook, 1956) made detailed excavations of fifty mud circles at Resolute Bay, studying the orientation of enclosed particles, and (Cook, 1958a) examined the geometry and composition of some sorted stone circles at Resolute Bay in detail.

Mackay (1957) outlined the need for additional study of patterned ground and indicated the type of data most urgently required.

TABLE 2.—Patterned Ground Observations

Type and Description	*Location*	*Source*
Active Forms		
Polygons		
Incomplete polygons	Southampton Island, N.W.T.	Bird, 1953
Nonsorted, average diameter less than 2 feet, depressed margin, 4 to 6 sided, maximum diameter 40 feet	Alert, Ellesmere Island	Blackadar, 1954
Not well developed polygons	Admiralty Inlet, Baffin Island	Blackadar, 1956
Small desiccation 20 cm. in diameter, medium 50 cm. in diameter, tundra 50 metres in diameter	Near Knob Lake, Que.	Derruau, 1956
Nets, average diameter less than 2 feet with high centres and depressed rims, tundra 150 feet in diameter with enclosed secondary polygons	Floeberg Bay, Ellesmere Island	Gadbois et Laverdière, 1954
Depressed centre 20 inches in diameter with raised rims. Tundra 50 to 100 feet in diameter	Darnley Bay, N.W.T.	Mackay*
Tundra 50 to 100 feet in diameter	Valley of lower Anderson River, N.W.T.	Mackay, 1958
Nonsorted	Coronation Gulf, N.W.T.	Marsden, 1956
Stone about 7 feet in diameter	Resolute, N.W.T.	Nichols, 1953
Stone with maximum diameter of 5 feet	Mugford Tickle, Labrador	Odell, 1933
Stone 2.5 feet in diameter, giant tundra	Akpatok Is., N.W.T.	Polunin, 1934
Tundra 25 to 75 feet in diameter with depressed border 2 feet wide	Mould Bay, N.W.T.	Robitaille*
Tundra, both depressed and raised centre	Fosheim Peninsula, N.W.T.	Sim, 1956
Occur in peat swamps, about 30 feet in diameter with interpolygon area barren peat in V-shaped depressions 1 to 4 feet wide and 1 to 3 feet deep	Shethanei Lake, Man.	Taylor, 1958
Mud polygons 1 to 2 feet in diameter, raised centre	Walker, Bay, Victoria Island	Washburn, 1947
Tundra	Wollaston Pen. Victoria Is.	Washburn, 1947
Stripes		
Nonsorted	Alert, Ellesmere Is.	Blackadar, 1954
Nonsorted	Darnley Bay, N.W.T.	Mackay, 1952
Nonsorted	Coronation Gulf, N.W.T.	Marsden*
Sorted and nonsorted	Fosheim Peninsula, N.W.T.	Sim*

TABLE 2.—Patterned Ground Observations—*Concluded*

Type and Description	*Location*	*Source*
Circles		
(Mud) nonsorted	Resolute, N.W.T.	Mackay, 1953 Cook, 1956
(Stone) sorted	Resolute, N.W.T.	Cook, 1958
Nonsorted	Coronation Gulf, N.W.T.	Marsden*
Fossil Forms		
Polygons.—Stone 6 to 10 feet in diameter	S. W. Yukon	Raup, 1951
Rings		
Stone	Lower Margaree Valley, Cape Breton Island N.S.	Raup, 1951
Stone	Alaska Highway, Y.T.	Denny, 1952
Stone	Near Portobelloe Creek, N.B.	Lee, 1956
Nets.—Stone	Wolf Creek area, Y.T.	Sharp, 1942
Stripes.—Stone	Northern B.C.	Denny, 1952

* Personal communication.

Table 2 lists references to patterned ground in Canada.

Altiplanation Terraces.—Eakin (1916) described well-developed altiplanation terraces in the subarctic landscape of the Yukon-Koyukuk region of central Alaska. However, they have rarely been reported from northern Canada. Robitaille (1958) recognized and mapped altiplanation terraces in the Mould Bay area, Prince Patrick Island.

Nivation Hollows.—Although snow is a contributory factor in the formation of nivation hollows, the processes of alternate freeze-thaw and solifluction are probably of greater significance in their development. Twidale (1956) has reported nivation vales in the area near Knob Lake in central Labrador. Henderson (1956) studied large nivation hollows in the highlands of the Labrador Lake plateau in the vicinity of Knob Lake, and reported them in considerable detail, giving a quantitative description of both simple and compound forms, and discussing the origin, distribution and age of the hollows.

Water

The action of running water in periglacial regions is minimal, owing to the short period of flow, and the generally scant precipitation in these regions. Asymmetric and dry valleys are among the features which may be indicative of former periglacial climates.

Although asymmetric valleys may be controlled by structure, or perhaps be due to the Coriolis force, many in periglacial regions have been attributed to one-sided stream erosion acting on the thawing, sunny northeast side while having little effect on the permanently frozen side.

Periglacial asymmetric valleys have not been reported in Canada, although undoubtedly they have a wide distribution.

It is considered that dry valleys may be developed by stream erosion over permanently frozen ground. In Canada, Brochu (1956) noted them in the Saguenay area.

Wind

Peltier (1950) included strong wind as one of the outstanding characteristics of a periglacial climate. Many features result from wind action, including loess deposits, ventifacts, oriented lakes and sand dunes.

Loess is by far the most important periglacial accumulation. The detailed study of periglacial loess deposits in Europe, particularly in Poland, is well advanced. Recently, considerable interest has been shown in the Pleistocene loess deposits that cover tens of thousands of square miles in the United States. In Canada, however, there has been a general neglect of the study of periglacial loess. Millette and Higbee (1958) compared the physical and mineral properties of periglacial loess and alluvial deposits of the Susquehanna River valley, Pennsylvania, with the deposits in a section of the Laurentians, in Quebec, as a means of correlating the field and laboratory observations of the morphological properties of the loess and alluvium.

The study of ventifacts is also well advanced in Europe, but as yet has received little attention in periglacial work in Canada. Mackay (1958a, 1958b) noted many textbook examples of ventifacts in a narrow coastal zone near Paulatak and Argo Bay in the Anderson River map-area of the western Arctic, and postulated that the abrasion had been accomplished by wind, sand or snow abrasion. He also reported (personal communication) that snow-blasted rocks occur on the west side of the Mackenzie River delta.

Mackay (1956) also reported a group of oriented lakes distributed through a 100-mile coastal zone in the Liverpool Bay area, Northwest Territories. Similar occurrences of oriented lakes in the north had been attributed to Pleistocene winds. Mackay postulated that the Liverpool Bay lakes were not the product of Pleistocene winds, but rather of contemporary cross winds, as the lakes are very recent in age, lying as they

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do within a few feet of sea level, and well below the limit of Pleistocene submergence. Mackay in a personal communication noted that oriented lakes, transverse to modern winds, also occur on the west side of Netteling Lake, Baffin Island, supporting the cross-wind theory. Brochu (1957) suggested that these lakes were thermokarst features and may have resulted from the melting of pingos or other ground ice forms, and were thus a fossil feature of buried glacial ice or ice action.

Mass Movement

Solifluction is probably the most important single mass-wasting process operating in the Canadian Arctic, although movement is generally very slow. It is essentially the progressive downslope movement of water-saturated waste, mainly by viscous flow. Movement normally is measured in inches over a period of time of a year or longer. Washburn (1947) discussed solifluction on Victoria Island in some detail. Elsewhere there are numerous isolated references in widespread areas in the Arctic.

Stabilized talus slopes are fossil periglacial phenomena, dating from a time when solifluction and downslope movement were active. The slopes have since become stabilized, usually by vegetation which has developed following the disappearance of the periglacial climate. Denny (1952) has reported stabilized talus slopes along the Alaska Highway in northern British Columbia.

Thermokarst

Periglacial phenomena resulting from thermokarst action are generally unreported in Canada, except for an occasional brief reference to ponds or hollows apparently thermokarst in origin.

Snow

Although nivation hollows are associated with snow action they have been discussed elsewhere under the section on cryoturbation as they are probably more intimately connected with freeze-thaw action.

Avalanches have a considerable geomorphological significance, eroding slopes, excavating cirques and building up screes and debris cones. In addition they form ponds in streams and produce temporary lakes. The work of avalanches has not been studied in Canada, although they were doubtless active in mountainous regions during periods before vegetal coverage had developed following the Pleistocene.

Snow creep may be an important agent in moving rocks downslope.

Ice

The work of ice as a periglacial agent in the formation of lake ramparts and ice-shoved ridges has received little attention in Canada. Malcolm (1912) noted ridges along the shores of lakes in the gold fields area of Nova Scotia. Jarvis (1928) attributed ridges paralleling Clear Lake in Renfrew County, Ontario, to ice pressure. Denny (1952) has discussed ice ramparts along the Alaska Highway in northern British Columbia.

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REVUE DES ÉTUDES CANADIENNES DE PÉRIGLACIAIRE

Frank A. Cook

RÉSUMÉ: L'étude des phénomènes périglaciaires au Canada n'en est qu'à ses débuts et l'on connaît encore très peu de choses au sujet de la répartition de ces phénomènes. Avant la Seconde Guerre mondiale, la plus grande partie de la région où régnait un climat périglaciaire était pour ainsi dire inaccessible et, en conséquence, les ouvrages canadiens antérieurs à 1940 ne font que rarement allusion aux phénomènes périglaciaires. Les régions nordiques étant désormais accessibles, les géographes et les géologues canadiens peuvent s'intéresser davantage aux formes périglaciaires actives, principalement les sols à figures géométriques et le pergélisol. La présente étude réunit des références de choix et examine l'état actuel de l'étude des processus et phénomènes périglaciaires au Canada.

INTRODUCTION

La création du terme "périglaciaire" est due à W. Lozinski (1909) qui, au cours de ses recherches sur les actions sub-aériennes dans les Carpates, y découvrit les traces d'influences climatiques spéciales, influences qui prévalurent à la périphérie des calottes glaciaires au cours du Pléistocène. Lozinski appliqua le terme aux zones localisées à la périphérie de ces calottes et aussi au régime climatique particulier de ces zones, et, par extension, aux phénomènes produits par ce type de climat, même complètement en dehors des marges glaciaires. Depuis 1909, il s'est produit de nombreuses controverses au sujet de la définition du terme "périglaciaire". Certains chercheurs, notamment J. Büdel (1953), ont voulu en restreindre l'application aux formes situées à la périphérie immédiate des anciennes calottes, tout en reconnaissant que les processus cryergiques (périglaciaires) y ont exercé une influence géomorphologique bien plus grande que les processus glaciaires proprement dits. D'autres chercheurs, par exemple J. K. Charlesworth (1957), ont employé le terme dans un sens beaucoup plus large, en l'appliquant à des processus et à des phénomènes qui, sans être glaciaires, sont essentiellement reliés à l'action de la glace et du gel. D'après cette définition, le mot "périglaciaire" comprend donc les processus et les phénomènes qui s'exercent sur les nunataks ainsi que dans les régions à cycles gel-dégel bien marqués, comme c'est le cas actuellement dans l'archipel arctique canadien. C. Troll (1944) considérait que les phénomènes périglaciaires se manifestent même dans les hautes montagnes des zones tempérées et tropicales.

Dans la présente étude, nous employons périglaciaire au sens de Lozinski, pour désigner tous les processus et phénomènes actifs ou fossiles, dus à un climat périglaciaire, et qui se rapportent à l'action de la glace, et cela, même dans les régions où la gélivation ne s'exerce pas actuellement.

PROCESSUS ET PHÉNOMÈNES CRYERGIQUES

De même qu'on prête au mot périglaciaire des acceptions diverses, ainsi on n'a pas encore mis au point une classification des processus et des formes périglaciaires qui satisfasse tous les chercheurs. On trouvera dans le Tableau I du présent travail un essai de classification. On notera que les formes influencées par plusieurs actions cryergiques ont été reliées, pour plus de commodité, au processus jugé le plus important.

On sait que L. Peltier (1950) a mis au point une théorie, esquissée antérieurement par K. Bryan (1946) et C. Troll (1948), suivant laquelle les processus cryergiques des régions périglaciaires s'insèrent à l'intérieur d'une évolution cyclique comparable au cycle "normal" de W. M. Davis (1899) dans les pays tempérés humides. D'après L. Peltier, ce cycle ne peut se dérouler que dans les régions arctiques ainsi qu'en haute montagne.

Au Pléistocène, toutefois, toujours d'après cet auteur, ces actions s'exercèrent dans des régions qui appartiennent maintenant au domaine tempéré. Peltier estime que les régions à régime morpho-climatique périglaciaire doivent avoir des températures annuelles moyennes de 5 à 20 degrés F., et que la précipitation annuelle moyenne doit y atteindre de 5 à 55 pouces. Suivant Peltier, la morphologie de ces régions se caractérise surtout par la prédominance des mouvements de masse du sol, par des actions éoliennes tantôt modérées, tantôt violentes, et aussi, par une influence limitée des eaux courantes. Le cycle périglaciaire de Peltier comprend un stade de jeunesse, un stade de maturité et un stade de vieillesse, comme le cycle normal de Davis.

Les paramètres nous faisant défaut, il est impossible de délimiter exactement la zone d'influence des actions périglaciaires actuelles au Canada. Il est certain qu'à un moment ou l'autre chaque région canadienne a connu un climat périglaciaire. Parmi les phénomènes périglaciaires fossiles qu'on a relevés dans le Sud du Canada, on compte des cercles de pierres, des involutions et certaines vallées sèches, en petit nombre d'ailleurs. Si on n'en connaît pas davantage, c'est sans doute parce qu'il n'y a pas plus de 10 ans qu'on s'intéresse aux phénomènes périglaciaires au Canada. Mais cet état de choses découle également du fait que, dans beaucoup de régions, la nature des roches et de la couverture végétale, la brièveté même du système morphogénétique périglaciaire, lors de la déglaciation, ont rendu impossible la création de formes cryergiques.

ÉTUDES CANADIENNES DE PÉRIGLACIAIRE

On ne trouve dans les publications canadiennes antérieures à 1940 que de très rares mentions de sols polygonaux, de solifluxion et de pergélisol. Toutefois, la Seconde Guerre mondiale devait susciter un renouveau d'intérêt dans le Nord canadien. Durant les années qui suivirent immédiatement la guerre, ces territoires devinrent plus accessibles par suite de l'établissement de stations météorologiques.

Mais ce n'est pas avant la publication de l'étude fondamentale de A. L. Washburn (1950) qu'un intérêt marqué se manifesta au Canada pour l'étude des phénomènes périglaciaires. Cette importante publication se fondait sur des travaux effectués sur place (Washburn, 1947) dans les îles Victoria et Melville (district de Franklin, Territoires du Nord-Ouest); elle a contribué nettement à l'orientation des études périglaciaires au Canada, tout particulièrement celle des sols à figure géométrique, car ce sont les sols géométriques qui ont surtout retenu l'attention des géologues et des géographes canadiens qui ne se sont guère préoccupés de l'étude des formes fossiles, telles que les involutions et le lœss, formes qui ont pourtant fait l'objet de nombreux travaux notamment en Pologne et aux États-Unis. Fait à signaler, les chercheurs canadiens ont presque tous utilisé la classification des sols à figure géométrique proposée par Washburn, de sorte qu'il y a beaucoup moins de différences terminologiques chez les auteurs canadiens que chez les auteurs étrangers.

Au Canada, à l'exception des recherches sur le pergélisol, l'étude des phénomènes périglaciaires a été faite surtout par les missions du ministère des Mines et des Relevés techniques. Ainsi, nous (F. A. Cook, 1959) avons préparé une bibliographie annotée des phénomènes périglaciaires au Canada. Les géologues de la Commission géologique du Canada (R. Blackadar, 1954, 1956; E. P. Henderson, 1956; R. Thorsteinsson et Y. O. Fortier, 1954) traitent de plus en plus des sols à figure géométrique. Cependant, les levés de cartes périglaciaires en sont encore à leurs débuts. J. R. Mackay (1953) a fait un relevé de la répartition des fentes en coin et des cercles de boue sur une étendue restreinte de la zone des plages soulevées, près de Resolute (île Cornwallis). B. Robitaille (1958, 1959), également, a cartographié certaines formes périglaciaires des environs de la baie Mould (île Prince-Patrick) et du Sud-Est de l'île Cornwallis.

La cartographie des phénomènes périglaciaires canadiens se complique grandement du fait des problèmes d'échelle. Si vaste est la portion du Canada où a régné un climat périglaciaire à une époque ou à une autre, si restreint est le nombre des chercheurs, que seulement une partie très petite du pays a-t-elle pu être examinée de façon un peu détaillée. En outre, il faut bien le dire, on ne dispose que depuis peu de temps de cartes topographiques convenables des régions septentrionales.

L'analyse des photographies aériennes apporte maintenant une aide précieuse dans ce domaine. L'emploi de méthodes d'interprétation de plus en plus perfectionnées devrait désormais permettre d'obtenir beaucoup de renseignements sur les sols géométriques et d'en établir la répartition dans bien des régions qui sont encore difficiles d'accès,

Tout comme la cartographie à grande échelle des phénomènes périglaciaires, les photographies aériennes posent aussi un problème d'échelle. Ainsi, sur des photographies aériennes verticales au 15,000^{e}, un cercle de 20 pieds de diamètre au sol ne constitue qu'un point d'environ 0.015 de pouce de diamètre sur la photo. Des photos au 10,000^{e} ou moins seraient évidemment plus adéquates, mais à date seules quelques régions restreintes ont été photographiées à cette échelle. Sur les photographies au 20,000^e^, on ne peut distinguer, à proprement parler, que les polygones de toundra.

L'analyse des photographies aériennes relativement au pergélisol et aux sols géométriques s'est révélée fort utile. Ainsi les études de R. E. Frost (1952) et R. C. Sager (1951) se fondent sur des travaux faits en Alaska, mais ces auteurs se sont servis d'exemples canadiens pour illustrer leur texte. On peut également noter que les travaux de la mission conjointe de recherches de l'Université Purdue (1953) se sont effectués le long de la partie sud de la route de l'Alaska, en Colombie-Britannique et au Yukon, dans tout le bassin du Mackenzie, ainsi que dans les environs du Grand lac de l'Ours. Ce travail avait pour but d'étendre le champ de l'analyse des photographies aériennes arctiques et sub-arctiques, en vue de l'interprétation des sols géométriques, du pergélisol, et d'autres phénomènes périglaciaires décelés sur les photographies.

TABLEAU 1.—Classification des processus et des phénomènes périglaciaires (F. A. Cook, 1959)

Processus	*Phénomènes résultants*
Froid (déficit thermique)	pergélisol;
Cryoturbation	bouleversement des lits: intrications, plications, involutions; champs de pierres; formes dues à la glace: coins de glace, fentes en coin, tertres, buttes; sols géométriques: cercles, réseaux, polygones, gradins, bandes, avec ou sans triage, et autres sols géométriques; terrasses d'altiplanation (replats goletz); niches de nivation.
Eau	vallées dissymétriques; vallées sèches;
Vent	lœss; dunes de sable; cailloux éolisés, cailloux à facettes, blocs éolisés; lacs orientés.
Mouvement de masse	solifluxion; talus d'éboulis stabilisés.
Thermokarst	étangs et petits lacs; creux.
Neige	niches de nivation; couloirs d'avalanches.
Glace	remparts lacustres; murs littoraux.

Au Canada, les reconstitutions paléo-climatiques établies d'après des critères périglaciaires ont été encore peu nombreuses. W. Odynsky (1958) a étudié les dunes au tracé en U visibles sur des photographies aériennes de l'Alberta. Cet auteur a pu indiquer la direction du vent dominant qui a permis leur élaboration.

Le premier rapport sur le Périglaciaire au Canada a été préparé par M. Brochu (1956) pour la Commission de géomorphologie périglaciaire de l'Union géographique internationale (U.G.I.), et présenté au Congrès de Rio de Janeiro. Ce rapport insistait sur l'insuffisance des recherches périglaciaires au Canada et contenait certaines recommandations en vue de l'amélioration de la recherche. Lors de ce Congrès, le Canada est devenu membre de la Commission. M. L.-E. Hamelin, délégué canadien, a assisté à une réunion de la Commission, tenue en Pologne en 1958. Depuis lors, ce dernier (Hamelin, 1958) a tracé les grandes lignes d'un programme de recherche systématique au Canada, dans le domaine du Périglaciaire.

Ainsi, on peut dire que l'étude des phénomènes périglaciaires en est, au Canada, à ses débuts et qu'il reste énormément de travail à faire. L'inventaire des formes périglaciaires reste incomplet. Des études de détail sur des phénomènes particuliers s'imposent actuellement si l'on veut comprendre les processus périglaciaires. Malheureusement, peu de travaux de ce genre ont été entrepris jusqu'à maintenant au Canada. Le champ de la géomorphologie périglaciaire peut être très enrichissant pour le chercheur qui consent à y consacrer beaucoup de temps et d'efforts. En plus de contribuer à mieux faire connaître et comprendre les processus géomorphologiques, l'étude des phénomènes périglaciaires ouvre la voie à des applications pratiques. Ainsi, elle fournit des données importantes pour les travaux de génie, tels le choix de l'emplacement des maisons et des pistes d'atterrissage, et pour les problèmes de circulation des véhicules dans le toundra.

FORMES PÉRIGLACIAIRES

Processus impliquant un froid intense (déficit thermique)

Dans toutes les régions périglaciaires, il existe un pergélisol déterminé par le déficit thermique de la température du sol par rapport à celle de l'air. Le pergélisol occupe de vastes surfaces de l'hémisphère septentrional; il peut être fonctionnel ou fossile. Son rôle est de toute première importance en ce qui concerne la solifluxion et la genèse des sols géométriques.

Pergélisol

F. A. Cook (1958b) a publié une liste de travaux relatifs au pergélisol au Canada. J. L. Jenness (1949) a, pour sa part, publié le premier rapport d'importance au sujet de la formation, du développement et de la répartition de ce phénomène au Canada. Depuis cette date, on a beaucoup écrit, dans des publications éparses, sur les problèmes que pose la présence du pergélisol pour l'extraction minière et pour les travaux de génie. Toutefois, des travaux scientifiques de détail ont été accomplis à l'aide d'appareils enregistreurs installés au sein du pergélisol à Resolute (île Cornwallis, Arctique oriental), à Norman Wells et à Aklavik (région du Mackenzie).

Au cours des étés de 1950 à 1953, on a procédé à des travaux de forage à Resolute, à l'occasion d'une étude conjointe de l'Observatoire fédéral du ministère des Mines et des Relevés techniques, de la Direction de la météorologie du ministère des Transports, du Comité associé sur la mécanique des sols et de la neige du Conseil national de recherches du Canada, ainsi que du *U.S. Weather Bureau.* Les résultats de ces travaux ont fait l'objet de plusieurs publications importantes. A. Thomson et P. Bremner (1952) ont pu fournir des renseignements généraux fondés sur des données acquises à partir des forages de faible profondeur pratiqués au cours des deux premières années de travail. P. Bremner (1955) lui, a traité des problèmes particuliers éprouvés lors des quatre années de forage au travers du pergélisol. Dans un autre domaine, F. A. Cook (1955) a fait l'analyse des températures de l'air par rapport à celles des couches superficielles du sol, ainsi qu'une étude du rayonnement solaire, de 1950 à 1953. Le même auteur a aussi décrit les modalités du regel du mollisol en 1955. A. D. Misener (1955) a étudié de façon particulière le mode de transmission de la chaleur au sein du pergélisol et il a attribué au pergélisol une épaisseur totale de 1,280 ± 10 pieds, à Resolute. A. D. Misener et ses collaborateurs (1956), à leur tour, publièrent une étude sur le degré géothermique local et sur certains problèmes généraux afférents aux forages dans le pergélisol. De l'avis de J. Goguel (1956), l'anomalie thermique positive rapportée par A. D. Misener (1955) serait le résultat de variations climatiques au Quaternaire. Pour A. H. Lachenbruch (1957) au contraire, ce sont les masses d'eau voisines qui expliqueraient cette anomalie. Enfin, F. A. Cook (1958c) a rendu compte de ses études sur les températures du pergélisol jusqu'à la profondeur de 650 pieds pour la période 1952-1957.

Dans une autre région, R. A. Hemstock (1953) a résumé les résultats des travaux de forage exécutés à Norman Wells par *l'Imperial Oil Co., Ltd.*, en collaboration avec le Conseil national de recherches d'Ottawa. R. Brown

(1956) a donné un aperçu des recherches relatives au pergélisol entreprises par le Conseil national de recherches dans le delta du Mackenzie, en vue de la relocalisation d'Aklavik.

Il reste beaucoup d'études à faire sur les caractéristiques et sur la répartition du pergélisol au Canada. Jusqu'à maintenant, on n'a effectué que peu de recherches sur les propriétés physiques de celui-ci. Sa limite sud, en outre, reste mal définie par suite de la pénurie actuelle de données de terrain. Dans le moment, la coordination des travaux canadiens sur le pergélisol est assurée par un sous-comité du Comité associé de mécanique des sols et de la neige du Conseil national de recherches.

Cryoturbation—Action du gel et du dégel

Dans les régions périglaciaires, le processus gel-dégel est sans aucun doute le plus important facteur du fractionnement des roches et des modifications apportées aux matériaux superficiels. Une grande variété de phénomènes doivent en effet leur existence à l'action même du gel dans le sol et aux alternances gel-dégel du sol, tout particulièrement au printemps et à l'automne.

Déformation des lits.—Les plications, les involutions et les convolutions sont des déformations de lits essentiellement horizontaux des dépôts meubles, lesquelles sont causées par l'action du froid. Ces formes ont été particulièrement bien étudiées en Europe où on les considère comme fossiles. Récemment, on a étudié des exemples d'involutions qui ont été observées dans le Nord-Ouest des États-Unis. Toutefois, les auteurs canadiens ont rarement décrit les formes de ce genre. H. Lee (1956) a découvert des involutions et des plications près de Fredericton (N.-B.). L.-E. Hamelin (1958) a décrit, pour sa part, les berges festonnées de certains cours d'eau de l'Abitibi (Nord-Ouest du Québec); il attribue au tracé particulier de ces berges une origine périglaciaire reliée à l'action de lentilles de glace et ensuite à celle des agents fluviatiles. J.-R. Mackay (1958b) a noté, lui, d'importantes plications dans des dépôts alternants de limon, de sables et de graviers de la région de la rivière Anderson. Il interprète ces formes comme étant reliées aux poussées latérales provoquées par la croissance de coins de glace et à des phénomènes de soulèvement cryergique différentiel.

Champs de pierres.—Il arrive souvent que les surfaces planes des régions périglaciaires soient recouvertes de concentrations d'éléments anguleux appelées "champs de pierres". Ces champs de pierres se composent presque exclusivement de roches locales, qui atteignent parfois plusieurs pieds d'épaisseur et qui recouvrent entièrement la roche en place, en certains cas. Ils résultent de la gélifraction et sont, par conséquent, un indice de conditions périglaciaires. La présence de champs de pierres sur de hautes surfaces est souvent considérée comme une preuve que ces surfaces n'ont pas été glaciées, au cours de la dernière glaciation.

Les champs de pierres sont nombreux au Canada, même si la littérature géologique contient peu de références sur leur mode de formation et sur leur répartition. Toutefois, on mentionne la présence de champs de pierres dans le Nord du Labrador et dans la pointe sud de l'île de Baffin.

On a beaucoup discuté sur l'âge des champs de pierres des monts Torngat (Nord du Labrador), qui semblent indiquer que les surfaces où ils se présentent n'auraient pas été glaciées au Wisconsin. N. Odell (1933) et V. Tanner (1944) ont exprimé l'avis que ces champs de pierres sont dus à l'intensité et à la rapidité avec lesquelles les agents sub-aériens ont travaillé depuis la déglaciation. A. P. Coleman (1921), au contraire, a attribué aux champs de pierres des Torngat un âge pré-Wisconsin. Plus récemment, J. D. Ives (1957, 1958a, 1958b) est venu à la conclusion que les champs de pierres de cette région étaient antérieurs à la glaciation Wisconsin. Ce chercheur a identifié des champs de pierres au-dessus du niveau de 2,700 pieds, dans la région de la vallée de Nakvak et en haut de 2,376 pieds dans la "Shoreline Valley".

Dans le sud de l'île de Baffin, J. R. Mercer (1954, 1956) a découvert de petits champs de pierres dans la péninsule Kingaite qui, selon cet auteur, seraient très anciens. Ils se présentent uniquement sur les témoins de la surface d'érosion supérieure de cette péninsule, donc en des points très localisés au-dessus de la surface d'érosion principale. Mercer pense que ces champs de pierres ne peuvent être postglaciaires, mais il n'a pu déterminer s'ils se sont formés au cours d'un interglaciaire pour être recouverts ensuite par de la glace stagnante durant les stades ultérieurs du Wisconsin ou s'ils n'indiquent pas, tout simplement, que la zone où ils sont situés a été respectée par la glace de cette glaciation.

Formes attribuables à la glace du sol.—Les coins de glace sont des phénomènes très fréquents sur les littoraux arctiques du pays. Ils résultent probablement de la contraction du sol au cours des périodes de froid intense. C'est E. de K. Leffingwell (1915, 1919) qui, le premier, a décrit certains coins de glace observés en Alaska. Depuis lors, on a identifié ailleurs de nombreux exemples de coins de glace, la plupart du temps en association avec des fentes en coin et des polygones de toundra. Les coins de glace n'ont encore fait l'objet d'aucune étude de détail, au Canada.

Les fentes en coin sont des formes très répandues dans tout l'Arctique canadien. Elles abondent surtout le long des littoraux, à la surface des plages soulevées, suivant des tracés tantôt longitudinaux, tantôt transversaux et se recoupent, en général, à angle droit. Tout comme les coins de glace dont elles sont dérivées, les fentes en coin résultent de mouvements de contraction du sol se produisant au cours des périodes de froid intense. Des études assez détaillées sur les fentes en coin ont été effectuées par A. L. Washburn (1947), près de Cambridge Bay (île Victoria), ainsi que par J. R. Mackay (1953) à Resolute (île Cornwallis). Ni coin de glace ni fente en coin fossiles n'ont encore été relevés dans le Sud canadien. J. R. Mackay (communication personnelle), seul, croit en avoir observé près de Kazabazua, dans la vallée de la Gatineau (Québec).

E. P. Henderson (1952) a fait la description de buttes de matériel morainiques de la région de Watino (Alberta), qui seraient, selon lui, des formes périglaciaires fossiles liées à la présence d'un pergélisol. C. D. Gravenor (1955, 1956) a traité de la genèse de tertres étudiés dans l'Ouest des Prairies et dans la région de la rivière de la Paix. Ces tertres seraient dus à des phénomènes de remplissage de cavités inscrites dans la glace, lors de la déglaciation, les matériaux restant en saillie après la fusion complète de la glace.

Bien qu'on ait découvert des tertres à lentille de glace saisonnière sur plusieurs points du littoral arctique canadien et de la zone de toundra, les chercheurs canadiens se sont intéressés surtout aux pingos, qui abondent dans le delta du Mackenzie et dans la région de Kotzebue. A. E. Porsild (1938) a été le premier à décrire ces pingos et a émettre une hypothèse pour expliquer leur formation. J. K. Stager (1956), pour sa part, a examiné quelque 1,380 pingos sur les photographies aériennes de la partie est du delta du Mackenzie. Il les a en outre cartographiés et classifiés suivant plusieurs types distincts. J. A. Pihlainen et ses collaborateurs (1956) ont étudié de façon détaillée un pingo du delta du Mackenzie. Ils ont fait un levé précis de ce pingo qu'ils ont illustré par de nombreuses coupes transversales et dans lequel ils ont fait des mesures de température et des prélèvements de carottes. J. R. Mackay (1958b) a signalé la présence de quelques pingos de grandes dimensions dans la région de la rivière Anderson. Cet auteur a également noté, près de la bordure externe du delta du Mackenzie, des pustules de boue contenant, en certains cas, une lentille de glace et qui semblent être des amorces de pingos.

Sols à figure géométrique (*sols géométriques*).—Ce terme générique, créé par Washburn (1950, 1956), désigne les formes plus ou moins symétriques (cercles, polygones, réseaux, gradins et bandes) qui caractérisent les couches superficielles du sol où peuvent s'exercer d'intenses actions cryergiques. Les sols géométriques comptent parmi les formes périglaciaires les plus répandues, que ce soit en tant que formes actives ou en tant que formes fossiles.

Même si on trouve les mots polygones, cercles de pierre, etc., dans les documents antérieurs, la première classification systématique canadienne des sols géométriques remonte à l'étude fondamentale de Washburn parue en 1950 sous le titre de "Patterned Ground", dans la *Revue Canadienne de Géographie.*

Les sols géométriques sont très répandus dans tout l'Arctique canadien. Les études qu'on en a faites jusqu'ici sont surtout descriptives, bien que certains travaux quantitatifs aient également été exécutés. Par exemple A. L. Washburn (1947) a décrit la structure interne de certains cercles de boue de l'île Victoria. J. R. Mackay (1953) a montré la répartition des cercles de boue d'une plage soulevée de l'île Cornwallis, près de Resolute, et il a émis l'hypothèse que ces formes passent par des stades de jeunesse, de maturité et de vieillesse. Au cours du stade de jeunesse, on peut observer la présence de bouchons de matériel durci sous-jacents au fond de petites dépressions coniques. Lorsque ces bouchons ont grossi au point d'atteindre le niveau de la surface du sol, les cercles entrent alors dans un stade de maturité. Les cercles de boue arrivent au stade de vieillesse lorsqu'ils se fusionnent à des cercles voisins. Perdant alors leur individualité, ils peuvent ensuite donner d'autres types de sols géométriques. Pour notre part, nous (F. A. Cook, 1956) avons effectué des excavations détaillées dans cinquante cercles de boue de la région de Resolute, pour y étudier l'orientation des éléments. Nous avons également fait (F. A. Cook, 1958a) des mesures quantitatives sur le dessin et sur la composition de quelques cercles de pierres de la même région.

Enfin, J. R. Mackay (1957) a souligné la nécessité d'études de plus en plus nombreuses sur les sols géométriques et a indiqué les domaines où devraient se porter les recherches

Dans le Tableau 2, on trouvera une liste et une brève description des sols à figure géométrique observés au Canada.

Terrasses d'altiplanation.—H. M. Eakin (1916) a décrit ce type de terrasses présentes dans la zone subarctique de la région Yukon-Koyokuk (Alaska central). Cependant, ces terrasses ont rarement été notées dans le Nord canadien. B. Robitaille (1958), toutefois, a cartographié les replats goletz de la région de Mould Bay (île du Prince-Patrick).

TABLEAU 2.—Observations sur les sols géométriques canadiens

Description	*Localité*	*Source*
FORMES ACTIVES		
Polygones		
Polygones incomplets.	Île Southampton (T. du N.-O.)	Bird, 1953
Polygones sans triage, diamètre moyen inférieur à 2 pieds; à bordure déprimée, de 4 à 6 côtés, diamètre maximum de 40 pieds.	Alert (île Ellesmere)	Blackadar, 1954
Polygones mal marqués.	Inlet de l'Amirauté (île Baffin)	Blackadar, 1956
Polygones de dessiccation: 20 cm de diamètre; Polygones de dessiccation: 50 cm de diamètre; Polygones de toundra: 50 mètres de diamètre.	Près du lac Knob (P.Q.)	Derruau, 1956
Réseaux de polygones; diamètre moyen inférieur à 2 pieds, centre bombé et bordure déprimée; Polygones de toundra de 150 pieds de diamètre contenant des polygones secondaires.	Baie Flœberg (île Ellesmere)	Gadbois et Laverdière, 1954
Polygones à centre déprimé et à bordure relevée, diamètre de 20 pouces.		
Polygones de toundra: 50 à 100 pieds de diamètre.	Baie Darnley (T. du N.-O.)	Mackay*
Polygones de toundra: 50 à 100 pieds de diamètre.	Basse rivière Anderson (T. du N.-O.)	Mackay, 1958
Polygones sans triage.	Golfe du Couronnement (T. du N.-O.)	Marsden, 1956
Polygones avec triage: environ 7 pieds de diamètre.	Resolute (T. du N.-O.)	Nichols, 1953
Polygones avec triage: diamètre maximum de 5 pieds.	Mugford Tickle (Labrador)	Odell, 1933
Polygones avec triage: diamètre de 2.5 pieds.	Île Akpatok (T. du N.-O.)	Polunin, 1934
Polygones de toundra: 25 à 75 pieds de diamètre, bordure déprimée, sillon large de 2 pieds.	Baie Mould (T. du N.-O.)	Robitaille*
Polygones de toundra à centre tantôt déprimé, tantôt bombé	Péninsule Fosheim (T. du N.-O.)	Sim, 1956
Polygones observés dans des tourbières: diamètre d'environ 30 pieds, séparés par des dépressions en V d'un à quatre pieds de largeur et d'un à trois pieds de profondeur.	Lac Shethanei (Man.)	Taylor, 1958
Polygones de boue d'un à deux pieds de diamètre, centre bombé.	Baie Walker (île Victoria)	Washburn, 1947
Polygones de toundra.	Péninsule Wollaston (île Victoria)	Washburn, 1947

TABLEAU 2.—Observations sur les sols géométriques canadiens—*Fin*

Description	*Localité*	*Source*
Bandes		
Sans triage.	Alert (île Ellesmere)	Blackadar, 1954
Sans triage.	Baie Darnley (T. du N.-O.)	Mackay, 1952
Sans triage.	Golfe du Couronnement (T. du N.-O.)	Marsden*
Avec et sans triage.	Péninsule Fosheim (T. du N.-O.)	Sim*
Cercles de boue, sans triage.	Resolute (T. du N.-O.)	Mackay, 1953 Cook, 1956
Cercles		
Cercles de pierres, sans triage.	Resolute (T. du N.-O.)	Cook, 1958
Cercles sans triage.	Golfe du Couronnement (T. du N.-O.)	Marsden*
FORMES FOSSILES		
Polygones.—Avec triage: 6 à 10 pieds de diamètre.	S.-O. du Yukon	Raup, 1951
Cercles		
Cercles avec triage.	Vallée inférieure Margaree (île du Cap-Breton)	Raup, 1952
Cercles avec triage.	Route de l'Alaska (Yukon)	Denny, 1952
Cercles avec triage.	Près du ruisseau Portobello (N.-B.)	Lee, 1956
Réseaux.—Avec triage.	Région du ruisseau Wolf (Yukon)	Sharp, 1942
Bandes.—Avec triage.	Nord de la Colombie-Britannique	Denny, 1952

* Communication personnelle.

Niches de nivation.—Bien que la neige contribue en partie à la formation des niches, il semble qu'elles soient dues surtout aux processus de gel-dégel et de solifluxion. C. R. Twidale (1956) a rapporté la présence de vallons de nivation dans le voisinage du lac Knob (Labrador Central). E. P. Henderson (1956) a étudié, également près du lac Knob, de larges niches de nivation, simples ou emboîtées. A l'aide de données quantitatives, il a pu montrer leur répartition et retracer leur genèse et leur âge.

L'eau

On sait que, dans les régions périglaciaires, l'action des eaux courantes est limitée du fait de la brièveté de la période d'écoulement et aussi de la maigreur des précipitations. Toutefois, les vallées dissymétriques et les vallées sèches se forment, en certains cas, à la faveur d'un climat périglaciaire.

Bien que les vallées dissymétriques résultent parfois d'accidents structuraux, ou encore de l'influence de la force de Coriolis, en domaine périglaciaire, ces vallées ont souvent été imputées à l'érosion fluviatile qui agit de façon exclusive sur la berge nord-est des cours d'eau, plus ensoleillée et donc soumise à l'action du dégel, la berge gelée en permanence ne subissant presque pas d'érosion.

Aucune vallée dissymétrique n'a encore été rapportée pour le Canada. Quant aux vallées sèches, elles semblent dues à l'érosion fluviatile agissant en présence d'un pergélisol. Au Canada, M. Brochu (1956) a relevé quelques vallées de ce genre dans la région du Saguenay.

Le vent

Nous avons déjà vu que Peltier (1950) considère le vent comme l'un des agents périglaciaires les plus importants. Effectivement, les actions éoliennes périglaciaires donnent des formations de lœss, des cailloux éolisés, des lacs orientés et des dunes de sable.

Le lœss constitue assurément la plus importante de toutes les accumulations périglaciaires. En Europe, tout particulièrement en Pologne, l'étude détaillée des dépôts de lœss périglaciaires est déjà très avancée. En Amérique, on s'intéresse vivement depuis quelque temps aux dépôts de lœss pléistocènes qui couvrent des superficies de plusieurs milliers de milles carrés aux États-Unis. Au Canada, cependant, on doit admettre que l'étude du lœss périglaciaire a été fort négligée. Seuls, J. F. Millette et H. W. Higbee (1958) ont produit une étude comparative des lœss et des pseudo-lœss de la vallée de la rivière Susquehanna (Pennsylvanie) et d'une région des Laurentides (Québec).

L'étude des blocs éolisés est déjà très avancée en Europe, mais, jusqu'à présent, on leur a accordé peu d'attention au Canada. J. R. Mackay (1958a, 1958b) a noté la présence de plusieurs exemples d'éléments éolisés par l'abrasion du sable et de la neige dans les régions côtières situées près de Paulatuk et de la baie Argo, dans l'Arctique occidental. Mackay nous a aussi souligné (communication personnelle) que l'abrasion de la roche par la neige est importante en plusieurs points de la partie ouest du delta du Mackenzie.

Cet auteur, en outre, a étudié certains lacs orientés, situés dans une zone côtière d'une centaine de milles de largeur de la région de la baie Liverpool (T. du N.-O.). Ces lacs avaient antérieurement été interprétés comme étant des formes pléistocènes. D'après l'hypothèse de Mackay, les lacs de la baie Liverpool seraient au contraire dus à des vents transversaux

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contemporains, étant d'âge très récent puisqu'ils se trouvent à quelques pieds seulement au-dessus du niveau actuel de la mer et, donc, à l'intérieur du domaine occupé par la submersion glacio-isostatique. Certains lacs orientés de la rive ouest du lac Nettiling, île de Baffin, corroborent d'ailleurs cette théorie. De l'avis de M. Brochu (1957), les lacs orientés de Mackay seraient des formes de thermokarst liées à la fusion de masses de glace du sol, probablement des culots de glace morte abandonnés par une calotte.

Mouvements de masse du sol

La solifluxion constitue probablement le plus important processus d'aplanissement actuellement à l'œuvre dans l'Arctique canadien. Ce processus se manifeste ordinairement par une lente progression vers le bas des pentes d'éléments saturés d'eau, principalement sous forme d'écoulement visqueux, les déplacements étant de l'ordre de quelques pouces tout au plus, par année. A. L. Washburn (1947) a étudié de façon détaillée les formes de solifluxion de l'île Victoria. D'autres chercheurs ont également décrit divers aspects de ce phénomène pour l'Arctique canadien.

Les talus d'éboulis stabilisés sont des formes périglaciaires fossiles qui se sont créées lorsque la solifluxion était possible. Leur stabilisation a été déterminée par la fixation d'une couverture végétale liée à la disparition du climat périglaciaire. La seule étude d'éboulis stabilisés, pour le Canada, est celle de C. H. Denny (1952) sur des formes observées le long de la route de l'Alaska (Nord de la Colombie-Britannique).

Thermokarst

Les seules mentions des phénomènes périglaciaires dus à l'action d'un thermokarst au Canada, consistent en de brèves allusions à des étangs ou à des creux liées à la fusion de la glace du sol.

Neige

Bien que les niches de nivation soient d'habitude rattachées à l'action de la neige, il est probable que ces formes dépendent davantage de l'action du gel-dégel, ce dont il a d'ailleurs été fait état antérieurement, lorsque nous avons parlé de cryoturbation.

Les avalanches ont une grande importance géomorphologique: érosion sur les pentes et approfondissement des cirques; création de cônes et de tabliers d'éboulis; formation d'étangs et de lacs de barrage fluviatile temporaires. L'action des avalanches n'a pas encore été étudiée au Canada, bien que leur influence morphologique ait dû être grande dans les régions montagneuses avant l'implantation de la couverture végétale, à la fin du Pléistocène.

La reptation (*creep*) sur la neige peut également jouer un rôle important dans l'évolution des versants.

Glace

Au Canada, on s'est encore peu occupé du rôle morphologique de la glace dans l'édification des remparts lacustres et des murs littoraux. W. Malcom (1912) a étudié des remparts lacustres de la région de Gold Field (Nouvelle-Écosse). G. Jarvis (1928) a attribué à la pression latérale des glaces certains alignements parallèles au lac Clair, dans le comté de Renfrew (Ontario). C. H. Denny (1952) a également étudié des remparts lacustres observés en bordure de la route de l'Alaska (Nord de la Colombie-Britannique).

LAND TYPES IN THE PRECAMBRIAN SHIELD AREA OF SOUTHERN ONTARIO

*J. Howard Richards**

ABSTRACT: This is a land-classification study of the area stretching between Georgian Bay and the Ottawa River, historically known as the Ottawa-Huron Tract. The author points out the significant differences in soil and soil materials within the area, and the various land types or units of land classification, especially types most suitable for agriculture. Fifteen land types are studied in detail, grouped under the following four major regions: the clay plains, the sand and silt plains, the limestone plains and the rock knob uplands. The report establishes a relationship between the intensity of agricultural land use and the major categories of land types Based on this study it is anticipated that there will be further modifications in the farm distribution pattern resulting in a reduction of the farm land area in the non-agricultural and marginal sectors and a redistribution of farming activities in more intensively used areas.

RÉSUMÉ: La présente étude porte sur la classification des terrains dans la région qui va de la baie Géorgienne à la rivière Outaouais, soit celle que les historiens ont appelée "Bande de terres Outaouais-Huron". L'auteur signale les grandes différences qui existent au sein de cette région, entre les sols ainsi qu'entre les matériaux dont ils sont dérivés, de même que les divers types de terrains ou éléments de classification des terres, tout particulièrement ceux qui conviennent le mieux à l'agriculture. Il étudie en détail quinze types de terrain, les groupant en quatre catégories principales, savoir: les plaines argileuses, les plaines sablo-limoneuses, les plaines calcareuses et les hautes terres à protubérance rocheuse. L'auteur établit la relation entre le degré d'utilisation des terres à des fins agricoles et les principales catégories de terrain. En se fondant sur cette étude, on peut prévoir qu'il y aura d'autres changements dans le mode de répartition des fermes et qu'il en résultera une réduction de l'étendue cultivée dans les secteurs non arables et marginaux, et une réorganisation des entreprises agricoles dans les régions où l'utilisation est plus poussée.

The area known as the Ottawa-Huron Tract lies between Georgian Bay and the Ottawa River, and is underlain by Precambrian rocks. The marginal nature of the soils of this area for agricultural purposes is well known, but little work has been done on the significant differences that occur in soils and in parent materials in various sections of the area. These differences have had a direct effect upon the distribution of farm land, and upon its use. In order to provide a fuller understanding of these differences, this report outlines a simple classification of land types in the area, and discusses their agricultural value.

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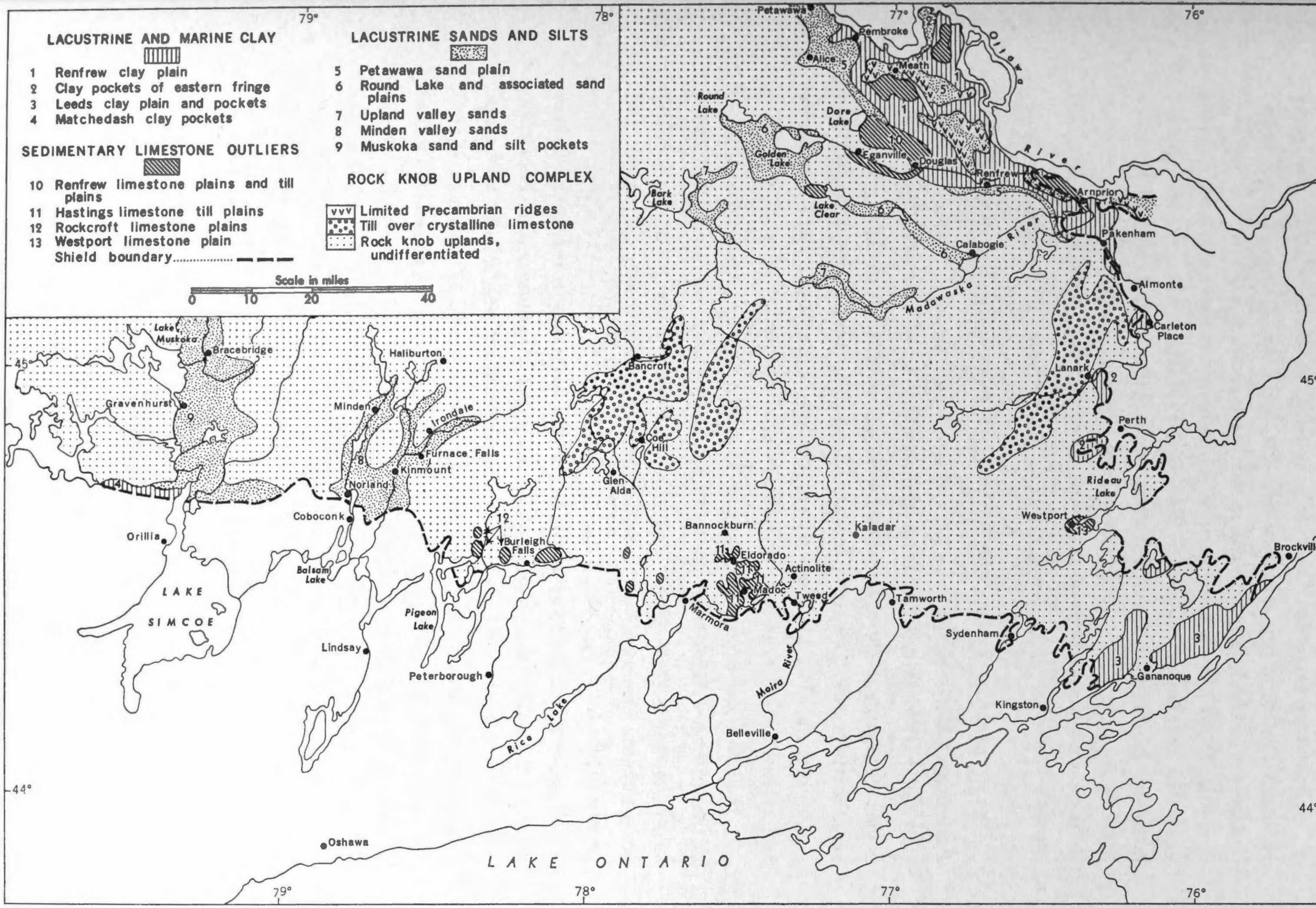

Figure 1. Distribution of natural land types.

The Ottawa-Huron Tract was opened to settlement in the early 1830s, and much of it is still considered to be in the "pioneer fringe" of old Ontario; it is thinly populated and extensive sections are still Crown land. Since the 1890s the abandonment of farms has been common, and in recent years has increased. Between 1941 and 1951 the total area of occupied farmland in the counties of Muskoka and Haliburton decreased by more than 40 per cent. Part-time subsistence farming, similar to that practiced in pioneer days, has become general. Only in a few parts of the area is it possible to use the land for specialized farming.

THE PHYSICAL BASIS OF THE LAND CLASSIFICATION

Parent Soil Materials

Soil materials derived from the weathering of bedrock, *in situ*, are generally lacking, although residual soils do occur, as in the Blue Mountain area north of the Kawartha Lakes, where deep weathering suggests pre-glacial origin. The common parent materials are boulder till, lacustrine and marine deposits, and organic and alluvial deposits.

Ice scour has produced a terrain in which bedrock frequently appears at the surface. Areas thinly covered by sandy ground moraine, interrupted by knobs of bare rock, are common. Depressions in the bedrock frequently have pockets of clays, but these are usually small, widely dispersed, and poorly drained.

The most extensive areas of deeper soil materials occur in the former beds of the Champlain Sea and glacial lakes Algonquin and Nipissing. In these areas the underlying rock is covered by sands, silts and clays and the relief varies from level to gently rolling.

Most of the parent soil materials transported by glacial action originated in the Precambrian Shield. The granites and gneisses of the Shield have a high silica content and the soils derived from them are acidic. In a few localities, where the till lies upon crystalline limestone or dolomite of Precambrian or Palaeozoic age, the soils are less acid. The most striking contrast exists between the soils on the outliers of sedimentary limestone and those overlying the surrounding granites and gneisses as, for example, in Hastings county. Lesser contrasts also exist; the clays of the Frontenac Axis incorporate lime materials that originated outside the Axis, and are slightly more calcareous than those of Renfrew county. The Renfrew clays were derived mainly from the Shield.

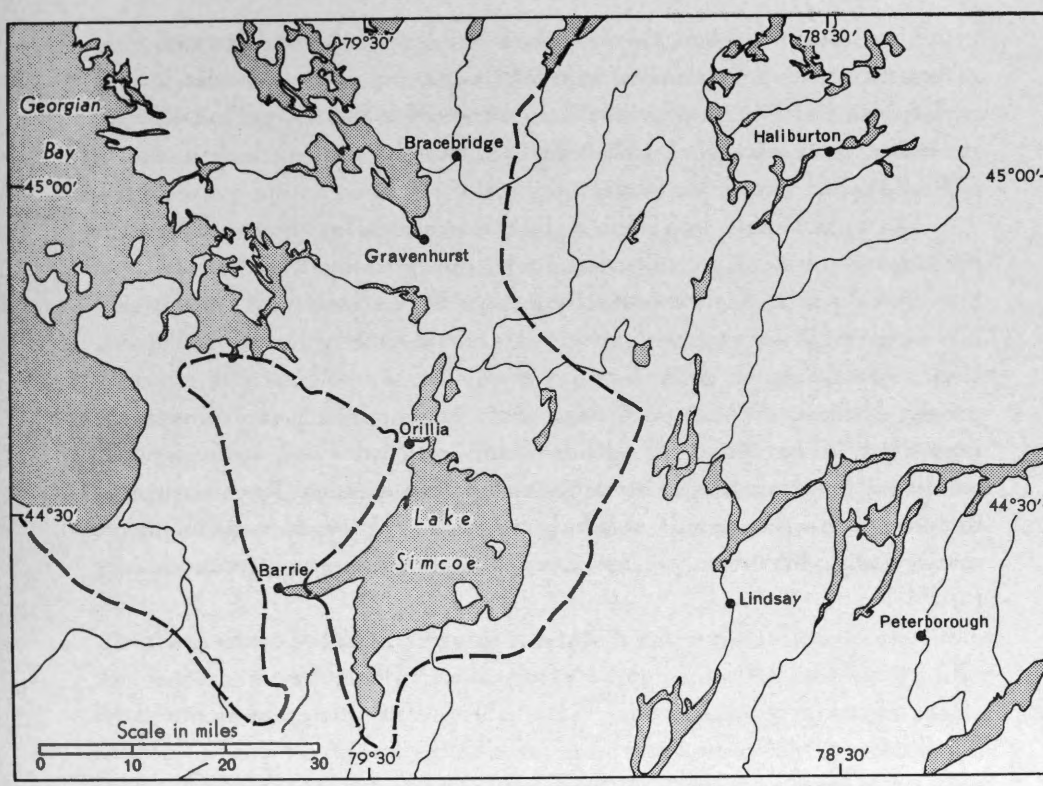

Figure 2. Limit of postglacial submergence, Georgian Bay area.

Soils

The podzol is characteristic of northern Ontario where the climate is subarctic and the natural vegetation is coniferous forest. In the southern part of the Shield the climate is less severe and the natural vegetation consists of mixed hardwoods and conifers. Podzolisation is still dominant but the process is continuing mainly in water-logged or poorly drained areas. The zonal soil of the southern part of the Shield is brown podzolic soil, representing a transition between the grey-brown podzolic zone of the hardwood forests of southern Ontario, and the podzolic zone of northern Ontario.

Because of the effects of climate and vegetation on brown podzolic soils, they differ appreciably from the true podzol as follows: the light-grey, leached A2 horizon is not so well developed and may be thin, or even absent; the colour of the solum is mainly brown to yellow-brown; the cemented B horizon of the podzol is not present; and the differentiation between the leached A and B horizons of clay accumulation soils is not so apparent.

The brown podzolic soils are of the zonal types, but the great variety of parent materials, slope and drainage conditions, and vegetation associations within a single climatic province have so modified the normal soil-forming processes that intrazonal soil types are more widespread than brown podzolic soils.

The soils of this area present special problems in the use of land for agriculture. Inherent acidity has to be corrected by the application of lime and the lack of phosphorus by fertilizer. Coarse sandy areas with a low water table are excessively drained, and are usually useless for cultivation. Areas of gentle relief, such as the clay and sand plains, are frequently poorly drained. Where peat bogs occur the problems of drainage are intensified. The successful use of these poorly drained areas depends partly on lowering the water table and partly on incorporating organic material with the parent mineral material. The soils require expert management, but in only a few areas is such management economically feasible.

At the present time the main farming areas lie in the continuous belts of good soils in the counties of Renfrew, Leeds, Frontenac and Hastings, where mixed or general farming is prevalent. Elsewhere the cleared land is used for subsistence or part-time farming. Unproductive rock barrens, shallow soils, peat bogs, and droughty sands and gravels, have resulted in farm abandonment or part-time employment of the farmers in forestry or other seasonal activity.

Variations in the zonal groups of soils stem mainly from the nature of the parent soil materials, thickness of the sub-soil, surface relief and drainage, and upon local differences in vegetation and climate. These variations are numerous and changes frequently occur within so small an area that a detailed map cannot be compiled. No detailed soil surveys have been undertaken, and it is unlikely that large-scale soil maps will be prepared for much of this region.

THE NATURAL LAND TYPE UNIT OF LAND CLASSIFICATION

Although it is not feasible in this study to discuss the minor soil units and their distribution, it is possible to distinguish certain broad groupings or "natural land types".

This concept was developed by J. O. Veatch* and has resulted in a simplification of land inventory and land classification. It prescribes that any land type must be a distinct and separate physical unit, and must

* Veatch, J. O., "Agricultural Land Classification and Land Types of Michigan", Agric. Exper. Sta.; M.S.C., S.P. Bul. 231; 1933, p. 6–20.

correlate with the main geomorphic units. In this study, only those natural land types that are considered to be of importance to agriculture are discussed. Figure 1 shows fifteen natural land types grouped into four major classes: (i) lacustrine and marine clays (ii) lacustrine sands and silts (iii) sedimentary limestone outliers (iv) the rock knob upland complex. This order indicates roughly the agricultural potential of each class.

The origin of the lacustrine clays, sands, and silts is associated with the glacial lakes that developed along the retreating ice front as the last glaciers receded from southern Ontario. In the western part of the area toward Georgian Bay (Figure 2), the largest and earliest of the glacial lakes, Lake Algonquin, extended over much of the present land area of the Lake Simcoe-Georgian Bay district. Not all the glacial border lakes were of this extent; numerous smaller ponds, such as existed in the Minden area of Haliburton county, occurred along the ice front. Their size and shape varied with local relief configuration and also with the location and level of the drainage outlet.

Following the Algonquin stage in the development of the Great Lakes the ice barrier retreated from the St. Lawrence River. The burden of the former ice-sheet had depressed the level of the Ottawa-St. Lawrence lowland so it remained for some time below sea level. As a result, the sea invaded this lowland, forming the Champlain Sea (*see* Figure 3). These conditions changed as the land recovered from its subsidence and warped upward, northeast of a "hinge line" running through central Michigan and southern Ontario. From this time the Great Lakes drainage system began to assume its present form.

Sands, silts and clays were laid down in these waters and today they are exposed as small flats or as relatively extensive plains. Soils derived from these are most significant in their effect upon land use.

Lacustrine and Marine Clay

This class may be divided into four main categories; the Renfrew clay plains; the clay pockets of the eastern fringe; Leeds clay plain and pockets; and the Matchedash clay pockets.

The Renfrew Clay Plains (Figure 1) form the most extensive natural land type within the lowland section of Renfrew county. These lowlands occupy the clay plain that extends from Arnprior, where it is 4 or 5 miles wide, northward to Pembroke, a distance of 48 miles; its greatest width is about 12 miles.* The surface of the plain is broken frequently by ridges of

* These lowlands occupy a structural depression (graben), which is part of the great series of parallel northwest-southeast faults of the Ottawa-St. Lawrence lowland.

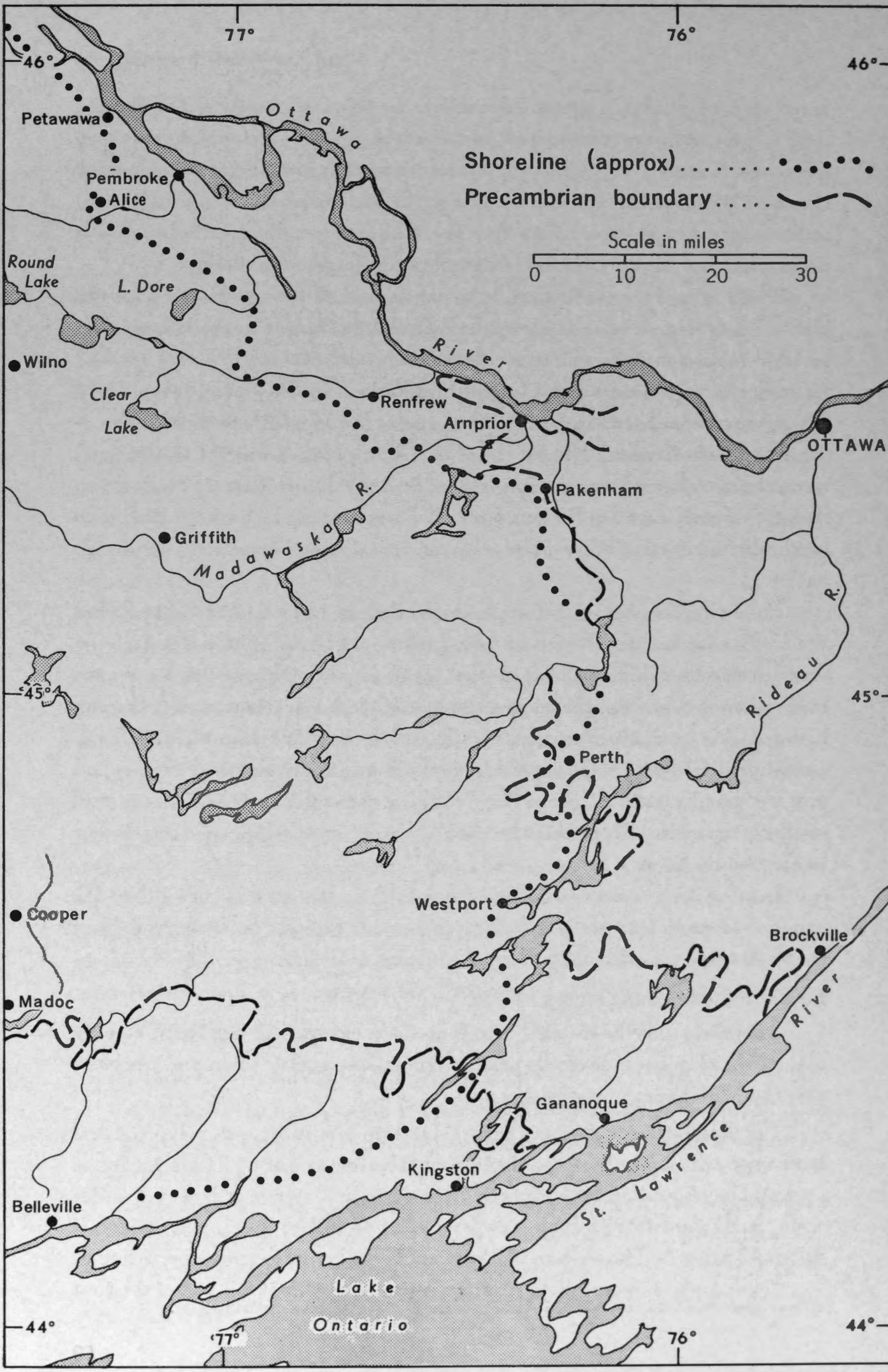

Figure 3. The shoreline of the Champlain Sea.

Precambrian rock and by outliers of Palaeozoic limestone. Precambrian scarps separate the clay plain into eastern and western sections along a line linking Renfrew and Pembroke.

The soils are developed in stone-free, grey, deep silty clay deposits of the Champlain Sea (Figure 3) under forest cover dominated by spruce and pine. Most of this level-to-gently-undulating area is cleared. Surface drainage is moderate to slow, but swamps are uncommon. The B horizon of the soil profile is a compact heavy clay which slows down the internal flow of water. The soils are intra-zonal podzols and exhibit the typical grey leached A2 horizon. On poorly drained soils a specimen soil sample from Bromley township, had the following profile:

A0 — ½" — litter

A1 — 3" — grey-brown clay

A2 — 3" to 4" — light grey silty clay

A3 — 2" to 3" — greyish clay speckled with brown

B2 — 10" — grey-brown compact clay

In better-drained soils the mottled A3 horizon is lacking, and the B2 is a grey-brown clay. Although the parent material is slightly acidic, the soils range from slightly to strongly acidic.

Where low-lying limestone outliers occur and where Precambrain ridges rise above the general level of the land, shallower soil phases are present and the clays abut against these areas with tongues entering the lower elevations. However, the higher parts of both the limestone outliers and the Precambrian ridges are free of clay deposits.

To the north, the boundary of the soils formed on marine clays follows approximately the 475-foot contour. In the south, near Pakenham, where the Precambrain presents a steep face toward the Ottawa lowland, similar soil materials occur only in pockets above the 425-foot level.

The soils of the Renfrew clay plains are the best in Renfrew county and, for that matter, constitute the most important group of soils on the Shield fringe. Most of the area is cleared and much of it is cultivated; poorly drained soils remain in pasture or woodlot.

Clay Pockets of the Eastern Fringe.—Small pockets of clays deposited by the Champlain Sea occur on the Shield fringe in Pakenham, Ramsay and Bathurst townships. They are rarely more than a few square miles in extent and are frequently interrupted by Precambrian outcrops; they form part of the more extensive clay plains to the east, covering Palaeozoic rocks. These soils were important in early settlement as they provided the only good land in some of the townships that were settled in the 1820's.

The parent soil materials are shallow silty clays and are poorly drained. The soils are strongly leached podzols. These clay pockets have been cleared of forest and contrast sharply with the adjacent forested, rock knob areas.

Leeds Clay Plain and Pockets.—This land type covers parts of Pittsburgh, Leeds, Lansdowne, Escott and Yonge townships, that is, the area occupied by the Frontenac Axis. Its boundaries coincide approximately with the 350-foot contour. However, in the lowlands and especially near the St. Lawrence River, pockets of clay occur below this level. The terrain is level to gently undulating although the western section is rather more broken by fairly frequent Precambrian rock knobs. Marshy areas are widespread because of poor internal and external drainage.

Small pockets of clays are found in Crosby South, near Lyndhurst, between the granitic knobs surrounding Gananoque and in Olden and Hitchinbrooke townships. These latter pockets are frequently broken by rocky outcrop, and have a greater proportion of forest cover than the more extensive clay plains.

The Precambrian rock knobs are usually bare or thinly covered by ground moraine, whereas the clay flats are usually thicker and free of stones. The boundary between rock knob terrain and the clay plains is readily recognizable not only because of differences in soil materials and relief but also in the distribution of woodland, roads and settlements.

The clays range from grey to grey-brown. The associated soils are classed by Hills* as wet, intrazonal mull glei, and podzolic glei. Half-bog soils are found in poorly drained areas in both the larger clay plains and the smaller clay pockets. In the better drained areas the profile resembles that of the Renfrew clay soils—weakly acid and leached. These Leeds clays form the only useful agricultural soils on the Frontenac Axis and support a dairy economy.

The Matchedash Clay Pockets.—Silty clay deposits of Lake Algonquin are found in the northern parts of Matchedash and Orillia townships, and in small pockets in Rama and Dalton townships. They are most widespread in Matchedash where they are frequently deep enough to obliterate all

* Hills, G. A., "Pedology, 'The Dirt Science', and Agricultural Settlement in Ontario", Can. Geog. Jour., Vol. 29, No. 3, Sept. 1944, p. 108.

trace of bedrock. They are however not extensive, and in both Matchedash and Orillia near the margins of these clay sections the terrain is broken by rock knob uplands.

Wherever this land type occurs, whether in the form of isolated pockets or as part of the more continuous clay plains of the south, the chief characteristics are flatness and poor drainage. However, where the drainage is improved the clay loams are fairly productive. Some sections are still being cleared but most of the larger parcels are cleared, drained and under cultivation.

Lacustrine Sands and Silts

This class is divided into five main groups: the Petawawa sand plain, Round Lake and associated sand plains, Upland valley sands, Minden valley sands, Muskoka sand and silt pockets.

The Petawawa Sand Plain is the second largest land type in the Renfrew lowlands. It consists mostly of deltaic sands deposited by the pre-Ottawa River into the Champlain Sea. The largest continuous tract of the Petawawa sand plain runs from north of Petawawa southward to within a few miles of Lake Doré, a distance of about 30 miles. In the north the sand plain occupies most of the lowlands lying between the 475- and 550-foot contours. Farther south near Pembroke it is bounded on the east by the Renfrew clay plain and on the west, by the Precambrian border at the 550-foot level. The plain varies in width from about 5 miles in the north to a narrow broken fringe along the Precambrian upland edge in the south. Sand tongues penetrate some of the valleys, the larger ones entering the Indian River valley and the Madawaska River valley. Cleared land is less extensive than in the clay plains and the general appearance of the region is much poorer. The limit of cleared land is also, roughly, the limit of the sand plains.

The soils developed on deep deltaic sands under a vegetation of jack pine, spruce, maple, white and red pine, cedar, poplar and birch. In the Petawawa section the sands are of coarse texture and drainage is excessive. Farther south, in Alice township, the parent sands are finer in texture, and the soils developed on them are better suited for agriculture. Soil drifting and blowouts are common in both the coarse and finer-textured sands. The podzol type of soil is typical; the soils contain little organic matter, are strongly leached and are low in natural fertility.

About half the area has been cleared, but much of the cleared land is in pasture.

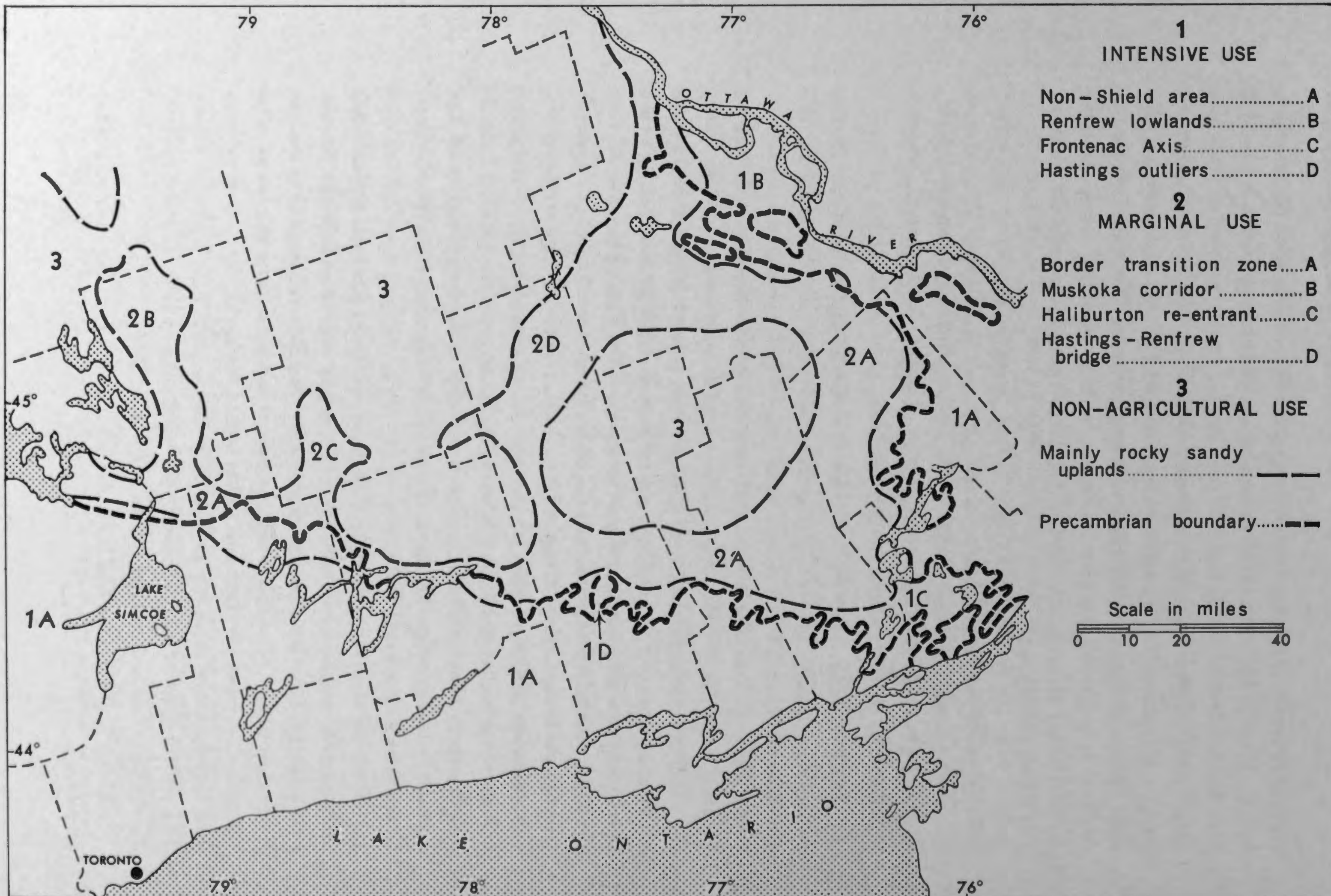

Figure 4. Agricultural land use areas.

The Round Lake and Associated Sand Plains.—It is possible that the sands at Round Lake, Golden Lake and Lake Constan are deposits of the highest level of the Champlain Sea. The extensive sand deposits of Round Lake cannot be traced, however, into the main (Petawawa) deltaic plain which opens up just west of Alice township and thus may have a different origin.

A mixed forest association is typical, with jackpine, pine, elm and maple predominating. The soils are podzols and are developed on well-drained sands. Farming has been attempted on various parts of the plain, but low fertility of the soils has prevented farming being established on a permanent basis. As a consequence, many farms have been abandoned. In addition, the difficulty of getting farm produce to markets has added to the difficulties of farming on these soils.

Upland Valley Sands.—Water-deposited sands are associated with the major river valleys but are extensive only near existing lakes or on valley floors. Fairly extensive deposits are present in the vicinity of Barry's Bay, and in the Madawaska River valley. In smaller valleys of the upland area, these horizontally bedded sands occur between Wilno and Killaloe, and in Lyndoch township.

Floodplain soils, in many instances, are poorly drained. Between Griffith and Camel Chute, in the Madawaska River valley, and also near Black Donald, muck soils occur. An excessively drained soil type with a podzol profile is common on upper slopes.

The distribution of the upland valley sands is patchy. Failure of farming operations has been common and may be ascribed to the lack of continuous tracts of good soils and to isolation from markets.

The Minden Valley Sands occur mostly along rivers such as the Gull, Burnt and Irondale, but are also found along smaller valleys of the uplands. The sands were deposited in glacial waters impounded in these valleys by glacial debris. The Gull River deposits can be traced from Norland to beyond Maple Lake in Stanhope township. Everywhere they are confined to lower elevations and are separated by rock knob uplands. Farming is fairly successful in this area and is in striking contrast to adjoining areas where the soils are developed on thin till, covering granite knobs. The surface of this land type is gently sloping to undulating.

The soils of the Minden land type have been developed upon the underlying fine sands, silts and silty clays under a mixed forest association represented by spruce, cedar, poplar, maple and elm. The podzolic soil profile is characteristic of the well-drained areas.

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These are the best soils in the Haliburton region; most of the area is cleared and supports mixed farming. Erosion is common where steep slopes and light-textured soils occur. However, despite favourable soil conditions, particularly in Minden township, many farms have been abandoned.

The Muskoka Sand and Silt Pockets.—The soil materials found at lower elevations in the Muskoka area were laid down mainly by glacial Lake Algonquin. Although lacustrine silts and clays occur as parent soil materials in some areas, as for example on the west side of Sparrow Lake, near Lake Muskoka, and locally in pockets extending northward to Huntsville and eastward into Ryde township, sands of glacio-lacustrine origin are more extensive. In the vicinity of Bracebridge these sands overlie silts and clays; fairly extensive areas of sands of similar origin occur in Rama and Dalton townships and extend northward toward Huntsville. The sands vary in texture, but are generally well drained. However, included in the sands are pockets of imperfectly drained silts and clays. In many of the sandy sections wind and sheet erosion are common.

Unlike the Renfrew sands, the lacustrine deposits do not occur as continuous plains. Between Georgian Bay and the Muskoka Lakes rock knob topography is dominant and the parent soil materials are shallow. Even in the central section, from Gravenhurst to Bracebridge, rock knolls are frequent and the Shield topography, rather than lacustrine plain, characterizes the local relief.

Hills classifies the soils of this section as mainly dry, intrazonal weak podzols. Actually, as would be expected because of varying textures and varying drainage conditions, in many localities peat-glei and podzolic glei soils are found. On the well drained lacustrine sands the soil profile is that of the podzol. The following example is a brown podzolic soil near Cooper Falls.

A0—Very thin—Matted leaf litter
A1—1" to 2" —Light brown sandy loam
A2—1" to 2" —Leached, greyish sandy loam
B —2" to 5" —Moderately dark brown sandy loam
C — — Yellow-brown sandy loam

On the flats near the lakes and in local pockets, poor drainage has modified the soil and the profile shows a surface layer high in organic matter, an ash-grey leached layer and a layer of mottled reddish-brown. The mottling is characteristic of the ground water podzol.

Although these soils are the most widely used, some, especially the droughty sandy soils, are of no agricultural value. Much of the area is in forest and only small areas have been cleared. The better farms are located within a few miles of Bracebridge.

Sedimentary Limestone Outliers

Outliers of Ordovician limestone occur occasionally along the edge of the Shield. These are remnants of extensive sheets of sedimentary rocks which formerly overlapped the Precambrian rocks. They stand above the general surface as small mesa-like forms and present steep faces on all sides, particularly on the north. Commonly, angular blocks of limestone are strewn around the edges. Some of the outliers are almost bare of overburden and, on them, exposures of bedrock are common; others are well covered by ground moraine. Because calcium from the limestone has been incorporated in the overlying till, the soils of the outliers are less acid than those of the surrounding Precambrian areas. These outliers frequently assume an importance, disproportionate to their size, in the agricultural and human geography of the region. This class consists of four main categories: Renfrew limestone plains and till plains; Westport limestone plain; Hastings limestone plains and till plains, and Rockcroft limestone plains.

The Renfrew Limestone Plains and Till Plains.—The limestone outliers of the Renfrew lowlands are not part of the cuestaform plains that extend over most of southern Ontario. They lie in the Ottawa graben as "infaulted outliers".

Two of the largest plains, the Lake Doré and the Eganville, are covered by very shallow sandy till through which bedrock frequently protrudes. A similar but smaller area occurs between Lake Clear and Cormay in Sebastopol township.

The natural vegetation consists of hardwoods with a mixture of conifers; elm, maple and cedar are the characteristic varieties. The terrain is level to undulating but is occasionally broken by rocky ledges. The overburden ranges from a few inches to a foot or more in thickness. As might be expected, the till contains a fairly high proportion of lime, and therefore tends to be alkaline.

Soils are generally shallow and range from sandy loams to loams. The shallower soils have a thin surface layer of organic material overlying a few inches of light yellow-brown to brown sandy loam. There is no zone of eluviation or of deposition, the shallow A1 horizon grading into the C, or parent material, and only in the deeper profiles is a leached layer present. Drainage is generally excessive and droughty conditions are common. Where the bedrock is close to the surface, keeping the water table at a high level, poor drainage results.

Large sections of the limestone plains have been cleared and are used for grazing and general farming. In many areas farms have been abandoned and former pasture is reverting to forest cover.

The Westport Limestone Plain.—In the vicinity of Westport Lake a narrow tongue of Cambrian sandstone projects from Upper Rideau Lake to West Rideau Lake, but most of the area is overlain by Ordovician limestone. The till cover is thin over these Palaeozoic formations. Most of the area is well-drained and forms the best farmland in Crosby North. Soils range in texture from sandy loams to loams. Not all the section is under cultivation; swampy areas occur in low-lying sections where the bedrock is close to the surface.

Hastings Limestone Till Plains.—The soils of the limestone outliers are of considerable importance to local agriculture. None of the outliers is of great extent, ranging from less than one square mile to over 6 square miles in area. Several small outliers occur in southern Madoc township (Hastings county), near Eldorado, Hazzard's Corners, Cooper and Queensborough; others occur in Marmora and in Hungerford townships.

The surface of the outliers is level to undulating. Rock outcrops are quite frequent although the depth of till in the Hastings group tends to be greater than on other limestone outliers. In all the limestone till plains there is an increase in the number of hardwoods, maple, elm and beech being the most important. The soils that developed under this forest cover vary from non-acidic to slightly acidic and their profiles represent the grey-brown podzol, characteristic of the well-drained soil. Where the soil materials are coarse and excessively drained, this profile is less well developed.

Many limestone plains are not suitable for agriculture. Some, such as those located east of Marmora are covered with boulders whereas others are stripped limestone plains; these occur where the unconsolidated materials have been removed from the surface by glacial action. However, good soils are associated with the limestone till, and, in general, they are well cultivated, the main emphasis being on dairy farming.

Rockcroft Limestone Plains are outliers of sedimentary limestone; they occur in Peterborough County close to the line of Precambrian-

Ordovician contact. One of the largest north of Lovesick Lake, covers fourteen square miles; others are located near Buckhorn, Burleigh Falls, Mount Julian and Round Lake.

Wherever this natural land type occurs there is a greater use of the land for agriculture, even though the quality of the farm may be little higher than that of the farms on the surrounding Precambrian land types. Farming on the Rockcroft outlier (Harvey township) or on similar areas of stripped limestone plain does not seem to be economically practicable. Most of the outliers in this section are either covered with very shallow, and often coarse ground moraine, or are bare limestone plains stripped of their overburden. The soil profile, shows a thin surface layer of organic matter overlying a yellow-brown to brown sandy loam layer.

The limestone plains, in general, have been cleared and farmed. Some areas still support good farms, but farm abandonment has occurred.

Rock Knob Upland Complex

This general title is applied to all parts of the Precambrian region of southern Ontario not included in the preceding land types. The rock knob upland complex class of natural land types may be divided into three main categories consisting of limited Precambrian ridges, till over crystalline limestone, and undifferentiated rock knob uplands. Essentially, this complex consists of a core of high ground rising above the lowlands of the Great Lakes and the Ottawa-St. Lawrence valleys to elevations between 1,400 and 1,700 feet above sea level. This central uplands includes the Haliburton highlands on the west, Algonquin Park and the Madawaska highlands in Renfrew county on the east.

The effect of glacial erosion was to roughen the landscape, accentuating minor relief differences in the pre-glacial surface. Relative relief is small, ranging up to about 200 feet. Locally, the minor topographic forms, such as small depressions and bare rock knolls, narrow lakes and steep ridges, swamp areas and roches moutonnées, give an impression of ruggedness. Except in depressions, the soil materials are shallow and sandy; and there are large areas of bare rock outcrop. Peat, muskeg or lakes occupy many of the hollows.

Glacial deposits are widespread, but despite their presence rock knobs and ridges barely covered by sandy drift extend over much of the area. Glacial deposition in this region is of the type associated with stagnant or retreating ice and with glacio-fluvial origin: eskers, kames, outwash plains and glacio-lacustrine deposits are all quite common and have produced a wide diversity of topographic forms.

Limited Precambrian Ridges.—Ridges of Precambrian rocks, mainly along the lines of the Doré and Muskrat faults, interrupt the clay plains of the Renfrew lowlands. The scarp faces, such as the Muskrat scarp, are devoid of overburden and bare rock is exposed even on the gentle slopes. Because of elevation, clays are absent and most of the higher portions of the ridges have a thin cover of sandy till which gives way to deeper, finer-textured sands on lower ground. The scarp faces are excessively steep, the rest of the area is rolling or undulating. The natural vegetation is mixed forest, composed mainly of pine, spruce, maple, elm, and poplar. As the parent sands are often coarse and drainage is excessive, the soil profile that has developed under this vegetation is a podzol with its excessively leached A3 horizon often absent. Occasionally, clay pockets occur within the sands.

The ridges, with their shallow till covering, together with the extensive sand deposits associated with them, cover large parts of northern Horton, northern Ross, eastern Bromley, southwestern and northern Westmeath counties. They are fairly continuous between Arnprior and Pembroke and range in width from less than a mile to about 6 miles. Much of the land has been cleared on the gentler slopes and here successful farming is carried on. Second-growth timber supports occasional logging operations.

The Undifferentiated Rock Knob Uplands consist mainly of Precambrian rocks overlain by a variable depth of unconsolidated deposits.

Some of these outwash plains and glacio-lacustrine deposits assume local importance by the fact that they provide the only cultivable soils within the rock knob uplands. The sand plain near Flinton and North Brook, in Kaladar township, is the only part of the township that is farmed. The kame moraine in northern Pittsburgh township (Frontenac county) is being abandoned as a farming area and is now used for grazing. Small lake plains such as the one lying north of Bancroft (Hastings county) are fairly prevalent. Areas underlain by clay materials usually have an intensity of land use unusual for this region.

Till Over Crystalline Limestone.—Where the underlying rock is crystalline limestone or dolomite the land type affords a better-than-average concentration of land suitable for agriculture. The soil materials consist of sandy till within which is incorporated lime derived from the underlying basic rocks. The soils of the typical shallow ground moraine show little profile development and consist essentially of a yellow-brown organic layer overlying the parent soil materials. Soils developed over deeper till are more acid and have a podzolic profile. However, where granites and granite gneisses form the bedrock there appears to be a definite association with shallow, sandy ground moraine and with the incidence of "rock barrens". In such areas there is no farming.

Along the periphery of the Precambrian Shield and within a corridor striking northward through Hastings county to southwestern Renfrew county, pockets of deeper sands and silts are more numerous than elsewhere in this natural land type. It is in these areas that agricultural settlement has become established, although neither the number nor the quality of farms is high.

Within the rock knob upland complex much land is still unalienated, and large areas remain in second and third growth forest. Free land grants failed to attract settlers as there was so little land suitable for farming, and eventually, the grants were withdrawn; grants in the Algonquin Park area were withdrawn in 1893.

AGRICULTURAL LAND USE

Areas in the Ottawa-Huron Tract with agricultural possibilities are far exceeded in extent by the non-productive rock knob uplands, and the number of part-time farms exceeds full-time, commercial farms. The soils and parent materials in the uplands are varied and, although some offer possibilities for localized agriculture, most are quite unsuitable. Those soils suitable are found only in pockets too small for settlement. Haliburton county, for example, has less than one tenth of its land surface in farms, and of this amount, less than a quarter is classed as improved land.

Marginal, transitional areas of low intensity farming extend into the rock knob uplands and lie along the Precambrian-Ordovician contact. Here, settlement is scattered and most farms provide no more than part-time occupation. In any other part of southern Ontario this land would be considered as non-agricultural.

The main agricultural areas fringing the Shield, lie in the clay, silt and limestone plains of the Renfrew lowlands, the clay plains of the Frontenac Axis and the Hastings limestone till plains.

Throughout most of the area there are too many people trying to eke out a living from land better suited to non-agricultural use. Much farm abandonment has taken place on sub-marginal land and the tendency will continue; such reduction should be actively encouraged in both the non-productive and marginal areas.

Even in areas of intensive use, a good proportion of the land is unfit for agricultural purposes. The economics of farming would seem to indicate that a rehabilitation program should include the withdrawal of such land from agricultural use.

SOME TYPES OF PATTERNED GROUND IN CANADA

Frank A. Cook

Among the periglacial features with a wide distribution in northern Canada are phenomena generally referred to in North American literature as "patterned ground". This term, suggested by Washburn*, is a group term for the more or less symmetrical forms that are characteristic of some mantle material that has been subjected to intensive frost action. The phenomena have the basic characteristics of pattern, and presence or absence of sorting.

The classification, established by Washburn and generally accepted in North America, includes sorted and non-sorted circles, nets, polygons, steps and stripes. Most circles, nets and polygons occur on relatively horizontal ground, whereas steps and stripes occur on slopes. Some forms are gradational in pattern and degree of sorting. In addition, qualifying words such as: large or miniature, clayey, silty or stony may be used to better describe the phenomena.

The origin and mode of development of patterned ground is still a matter of controversy among workers in the field of geomorphology, and is not discussed here. Patterned ground, does, however, develop in a periglacial environment such as is found in Northern Canada today, or in high mountains to the south where similar conditions exist. In other areas which experienced a periglacial environment following the last glaciation, fossil or inactive forms of patterned ground may remain.

Although patterned ground was 'discovered' by the memorable excursion of the Stockholm Geological Congress to Spitzbergen in 1910, and a vast European literature has developed, in Canada, interest dates from Washburn's basic paper of 1950. Before that date the Canadian north was relatively inaccessible, and field work was of an exploratory or reconnaissance nature, with little time or thought for the study of what some considered minor geomorphological phenomena. Recently, however, with the opening up of the Canadian north, observations of patterned ground have been made in a number of areas.

Many observations of patterned ground in northern Canada have been made by geographers of the Geographical Branch; this photo study has been prepared from Geographical Branch photographs, except where otherwise indicated.

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* Washburn, A. L., Patterned ground, *Rev. Can. Géog.*, Vol. IV, Nos. 3–4, 1950; Classification of patterned ground and review of suggested origins, *Bull. Geol. Soc. Amer.*, Vol. 67, 1956.

Sorted (stone) circle, Resolute Bay, Cornwallis Island, N.W.T., 1955. Scale is given by Kodak film box. Sorted circles have a wide distribution in the Canadian Arctic. They occur singly or in groups, and generally have diameters of from 1 to 3 meters, although miniature sorted circles occasionally occur.

Cercle avec triage (cercle de pierres), à la baie Resolute, île Cornwallis (T.N.-O.), 1955. L'étui à pellicules donne l'échelle. Ce type de cercles est très répandu dans les régions arctiques du pays. Ils se présentent isolément ou en groupes. Leur diamètre ordinaire est de 1 à 3 mètres, mais on en rencontre parfois de plus petits.

Sorted (mud) circle, Resolute Bay, Cornwallis Island, N.W.T., 1954. The diameter is 0.3 meter; doming is approximately 10 cm. Sorted (mud) circles occur widely in areas where finely comminuted material is associated with frost-shattered mantle. Although generally a single phenomenon, with a diameter ranging from 0.2 to 1 meter, it does occur in fields. When closely spaced and well-developed, mud circles tend to merge to form other types of patterned ground such as nets or polygons.

Cercle avec triage (cercle de boue), à la baie Resolute, île Cornwallis (T.N.-O.), 1954. Diamètre: 30 cm; hauteur du monticule: 10 cm environ. Les cercles de boue sont fréquents dans les régions où des matériaux fins accompagnent des matériaux de gélifraction. Ces formes sont généralement isolées, ayant un diamètre de 20 cm. à 1 m., mais elles se rencontrent aussi en groupes. Lorsqu'elles sont très rapprochées et bien agencées, elles tendent à former, par jonction des réseaux ou des polygones.

Non-sorted miniature polygons, Resolute Bay, Cornwallis Island, N.W.T., 1953. These polygons average 0.2 meters in diameter and are formed by dessication. Once established, the pattern persists, and eventually vegetation develops in the fissures outlining the polygon.

Polygones nains sans triage à la baie Resolute, île Cornwallis (T.N.-O.), 1953. Dimensions moyennes 20 cm. Une fois formé par les fentes de dessication le dessin persiste, et la végétation finit par envahir les fissures.

Miniature sorted net, Resolute Bay, Cornwallis Island, N.W.T., 1954. These individual polygons have an average diameter of approximately 30 cm.

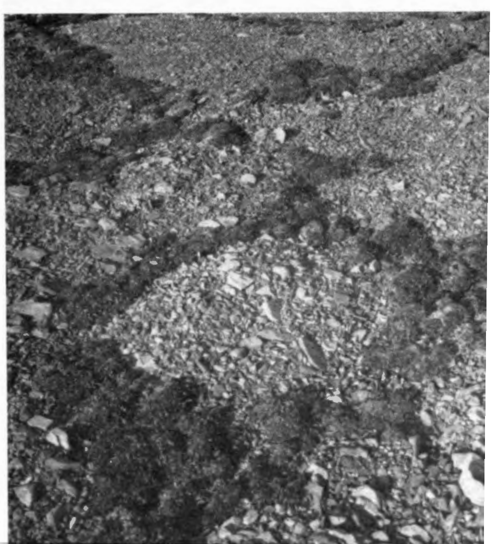
Petit réseau de pierres avec triage, à la baie Resolute, île Cornwallis (T.N.-O.), 1954. Diamètre moyen de chaque polygone: environ 30 cm.

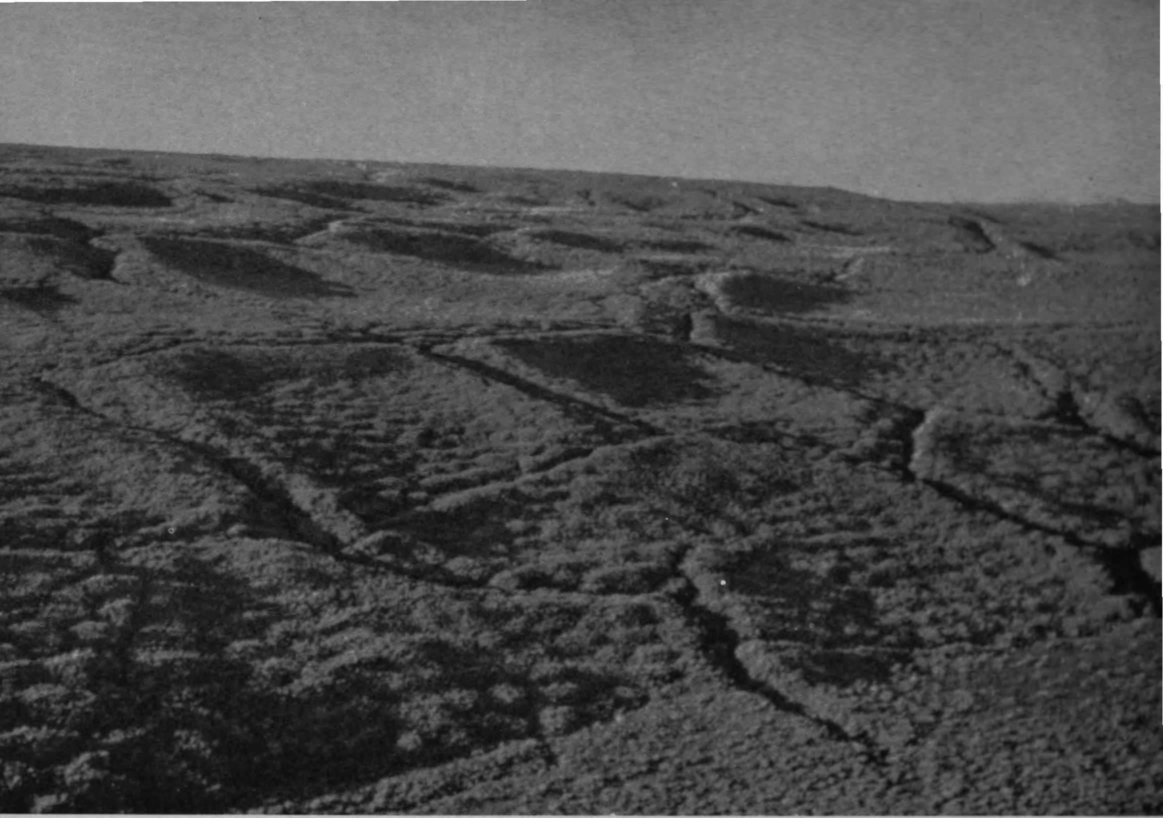
Sorted net, Coral Harbour, Southampton Island, N.W.T., 1956. Scale given by shovel. The individual forms vary from circular to polygonal in form.

Réseau de pierres avec triage, à Coral Harbour, île Southampton (T.N.-O.), 1956. La pelle donne l'échelle. La forme est tantôt circulaire, tantôt polygonale.

Sorted net, Resolute Bay, Cornwallis Island, N.W.T., 1954. Individual polygonal forms, varying from 0.5 to 1 meter in diameter, are outlined by vegetation.

Réseau de pierres avec triage, à la baie Resolute, île Cornwallis (T.N.-O.), 1954. La végétation encadre chaque polygone, dont le diamètre varie de 50 cm à 1 m.





Non-sorted polygons on 7-degree slope, Fosheim Peninsula, Ellesmere Island, N.W.T., 1955. These are depressed-centre, ice-wedge or 'tundra' polygons. They are widespread along the Arctic coast, and often have diameters of 50 meters or more. They probably are formed by contraction of the ground during the cold winters.

Polygones de pierres sans triage, sur une pente de 7 degrés, dans la péninsule Fosheim, île Ellesmere (T.N.-O.), 1955. Les dimensions de ces polygones de toundra, à centre concave et contenant des coins de glace, atteignent souvent 50 m. ou plus. Ils sont fréquents le long du littoral de l'océan Arctique et résultent probablement de la contraction du sol au cours des froids hivers.

Non-sorted stripe on southeast side of plateau, near southeast nose of Mount Pelly, Victoria Island, N.W.T (From "Reconnaissance Geology of Portions of Victoria Island and Adjacent Regions of Arctic Canada", *Geol. Soc. Amer.*, Mem. 22 Plate 27, Figure 2, 1947). (Photo by A. L. Washburn).

Bandes de pierres sans triage, côté nord-est du plateau localisé près de la pointe sud-est du mont Pelly, île Victoria (T.N.-O.), 1952. (Photo tirée de *"Reconnaissance Geology of Portions of Victoria Island and Adjacent Regions of Arctic Canada"*. Geol. Soc. Amer., mém. 22, planche 27, figure 2, 1947.) (Photo A. L. Washburn).

Non-sorted net in the vicinity of Alert, northern Ellesmere Island, N.W.T., 1952. This wide area of earth hummocks probably results from uplift of soil caused by ground-water pressure and frost action.

Réseau sans triage près d'Alert, partie septentrionale de l'île Ellesmere (T. N.-O.), 1952. Cette large étendue de buttes de terre a probablement été causée par l'action de la poussée hydrostatique et par l'action du gel.

Non-sorted net, arctic shore west of Cape Belknap, northern Ellesmere Island, N.W.T., 1952. A close-up of earth hummocks.

Réseau sans triage, rive de l'océan Arctique à l'ouest du cap Belknap, nord de l'île Ellesmere (T.N.-O.), 1952. Vue en gros plan de buttes de terre.

Solifluction overriding beach lines, Signal Mountain, Resolute Bay, Cornwallis Island, N.W.T., 1955. Solifluction, the progressive downslope movement, mainly by viscous flow, of saturated waste is probably the most widespread and obvious process of mass-wasting in periglacial regions. It is most frequent in regions of permafrost where summer thawing is limited to a depth of 1 meter or less.

Matériaux soliflués chevauchant les lignes d'anciens rivages, mont Signal, baie Resolute, île Cornwallis (T.N.-O.), 1955. Par solifluxion, on entend le glissement lent le long des pentes, surtout par écoulement visqueux, de matériaux fins saturés d'eau; c'est là probablement le mouvement de masse le plus répandu et le plus apparent des régions périglaciaires. Ce phénomène est fréquent surtout dans les zones de pergélisol où le sol ne dégèle en été que jusqu'à un mètre ou moins de profondeur.

Non-sorted net, Grenier Lake Cambridge Bay area, Victoria Island, 1955. Patterns are formed in fine, marine silty till, submerged, rewashed and redeposited on underlying ground moraine about 20 to 25 meters above present sea level.

Réseau sans triage, lac Grenier, près de Cambridge Bay, île Victoria, 1955. Dessins constitué par du till fin surtout limoneux, puis remanié par les eaux marines lors de la submersion et déposé sur la moraine de fond sous-jacente, à environ 20 ou 25 mètres au-dessus du niveau actuel de la mer.

Fissures on gravel slope on drumlinoid south of Lady Pelly, Cambridge Bay area, Victoria Island, N.W.T. 1955. Fissures are common features on raised beaches throughout the Canadian Arctic. They occur in both longitudinal and transverse positions, usually meeting at right angles. They are probably formed by contraction of the ground during the cold winter, and may outline large "tundra" polygons.

Fentes en coin de gravier sur la pente d'un kame situé au sud de la colline Lady Pelly, région de Cambridge Bay, île Victoria (T.N.-O.), 1955. Dans tout l'archipel arctique, les fentes en coin sont des phénomènes qu'on rencontre souvent sur les plages soulevées. Elles se présentent soit parallèlement soit perpendiculairement aux lignes de plage; d'ordinaire elles se recoupent à angle droit. Les fentes en coin se développent au cours des froids hivers par suite des phénomènes de contraction du sol. Les fentes en coin délimitent souvent des polygones de toundra.

QUELQUES TYPES DE SOLS À FIGURE GÉOMÉTRIQUE AU CANADA

Frank A. Cook

Parmi les phénomènes cryogéniques les plus répandus dans le Nord du Canada, on peut mentionner les sols à figure géométrique, nom collectif dû à Washburn* et qui, dans les ouvrages scientifiques publiés en Amérique du Nord, désigne les dessins plus ou moins symétriques qui caractérisent certains matériaux superficiels cryoturbés. Ce qui distingue principalement ces sols, ce sont leurs dessins et le triage ou le non-triage des éléments.

D'après la classification de Washburn, généralement utilisée en Amérique du Nord, les sols à figure géométrique avec ou sans triage se présentent sous forme de cercles, de réseaux de polygones, de gradins et de bandes; les trois premières formes se présentent surtout sur un terrain plat, les deux dernières, sur les pentes. En certains cas, il y a transition graduelle dans le dessin et dans le degré du triage. De plus, pour mieux décrire ces phénomènes, on parle parfois de grandes et petites figures, de sols argileux, limoneux ou pierreux.

Nous laissons de côté ici les questions, toujours controversées parmi les géomorphologues, de la genèse des sols à figure géométrique. Remarquons toutefois que dans un milieu périglaciaire, comme aujourd'hui dans le Nord canadien et dans les hautes montagnes situées plus au sud où règne le même climat, c'est la cryoturbation qui leur donne naissance. Dans d'autres régions, soumises temporairement à un climat périglaciaire depuis la dernière glaciation, il subsiste parfois des sols à figure géométrique fossiles ou non fonctionnels.

C'est lors de la mémorable excursion au Spitzberg du Congrès de géologie de Stockholm, en 1910, que l'on a "découvert" ces sols. Depuis lors, on leur a consacré de nombreux ouvrages en Europe. Cependant, les Canadiens ne se sont intéressés aux sols à figure géométrique qu'à partir de 1950, date de la fondamentale étude de Washburn. Jusqu'à 1950, le Nord canadien était resté peu accessible. Les travaux en étaient encore au stade d'exploration ou de la reconnaissance et on ne songeait guère, faute de temps, à étudier ce que certains chercheurs considéraient d'ailleurs comme

*Washburn, A. L.: Patterned Ground, *Rev. Can. Géog.*, vol. IV, nos 3-4, 1950. Classification of Patterned Ground and Review of Suggested Origins, *Bull. Geol. Soc. Amer.*, vol. 67, 1956.

des phénomènes géomorphologiques peu importants. Depuis lors, cependant, à la suite de la pénétration récente du Nord, des recherches sur les sols à figure géométrique ont pu être effectuées dans certaines régions.

C'est ainsi que les géographes de la Direction de la géographie ont fait de nombreuses observations sur ces questions dans le Nord du pays. C'est à partir de leurs collections de photographies qu'on a rédigé la présente étude illustrée. Sauf indication contraire, les photos ont été prises par l'auteur.

BOOK NOTES

VARIABILITY OF PHYSICAL CHARACTERISTICS OF SNOW COVER ACROSS CANADA. By Gaynor P. Williams. Canada, National Research Council, Div. of Building Research, Research Paper No. 62, Ottawa, 1958. 5 p., table, graphs, map. Price 10 cents.

For a number of years the National Research Council has conducted a program of study on the physical characteristics of snow cover across Canada. This report presents a brief summary of the results. Regional variations of snow density, snow hardness, and snow grain-size are shown graphically, as well as the probability values of extremes from these snow characteristics.

[F.A.C.]

A FOREST CLASSIFICATION FOR CANADA (1958). Canada Dept. of Northern Affairs and National Resources, Forestry Br., Forest Research Divn. Revision of Forestry Br. Bull. 89. 27 p., mimeo., map.

The *Forest Classification for Canada* (Halliday, 1937) has been widely used since its publication.

This revised edition is published in preliminary form to accompany the new forest classification map issued in 1957. A final revised edition of the bulletin will be published during the current year. Like its predecessor it will prove to be a standard reference on Canada's forest regions.

[F.A.C.]

INDUSTRIAL WATER RESOURCES OF CANADA. Mackenzie River and Yukon River Drainage Basins in Canada, 1952–53. By J. F. J. Thomas. Canada, Dept. of Mines and Tech. Surv., Mines Br., Water Surv. Report No. 8, Ottawa 1957; 78 p., tables, maps, graphs. Price $1.00.

This report is the eighth in a series on the chemical and physical properties of surface waters and municipal water supplies in Canada. It presents analyses of samples taken at 66 localities in the Mackenzie River basin and 5 in the Yukon River basin. It includes descriptions of municipal water systems and chemical analyses of their water supplies.

[W.E.H.]

CROPS VARIETY GUIDE FOR THE ATLANTIC PROVINCES. Canada Dept. of Agriculture, Experimental Farms Services, Ottawa 1958, 39 p., map.

A revision of a similar publication issued in 1955, this bulletin lists the recommended varieties in all crops for the Atlantic Provinces. Cereal crops, forage crops, small fruits, tree fruits, and vegetables are listed in that order. The information results from testing undertaken at the five Dominion experimental farms located in the area: Fredericton, N.B.; Charlottetown, P.E.I.; Nappan and Kentville, N.S.; and St. John's West, Newfoundland. All recommendations are made according to eight agricultural zones whose boundaries are shown on a map in the centre of the publication.

[C.W.R.]

A ZOOGEOGRAPHICAL STUDY OF THE AMPHIBIANS AND REPTILES OF EASTERN CANADA. By. J. Sherman Bleakney. Canada, Dept. of Northern Affairs and National Resources, National Museum of Canada, Bull. No. 155, Ottawa, Queen's Printer, 1958, 199 p., tables, maps. Price $2.00.

This book is a notable contribution to the limited geographical knowledge of the ranges and distributions of herpetofaunal species in eastern Canada. As the author points out, "this existing situation of varying densities and varying species composition within the herpetofauna of Eastern Canada has not previously been recognized or analyzed."

The forest cover pattern and environmental temperatures are shown to be major determinants in limiting the ranges of amphibians and reptiles. Other notable limiting factors are wide water bodies, salt water (in the case of amphibians), cold salt water (explaining the almost complete lack of herpetofaunal species on Newfoundland and Anticosti), habitat preference, and interspecific competition.

From eastern Ontario to Newfoundland the author has established 16 herpetofaunal sections. The accompanying maps clearly indicate these, and the distributional records of the 43 species studied. The author's own field research is supported by 105 distributional reports and 110 references.

A section of the book is devoted to the postglacial period. Using zoogeographical evidence he illustrates how Prince Edward Island and Cape Breton must have been joined to the mainland while Newfoundland and Anticosti must not have been. Many species are traced back to their origin of dispersal.

[J.A.R.]

INDUSTRIAL DEVELOPMENT IN NOVA SCOTIA. Report to the Department of Trade and Industry, Province of Nova Scotia. Arthur D. Little Inc., Cambridge, Massachusetts, March 1955. 77 p., tables.

During 1954 Arthur D. Little Inc., acting as consultant to the Nova Scotia government, prepared a series of memoranda for the provincial Department of Trade and Industry. The more important of these are brought together in this report. "They include: an audit of the policy and organization of the Department of Trade and Industry; a broad outline of Nova Scotia's present economic position and industrial composition; and a preliminary list of industrial opportunities, together with an exposition of the bases on which these opportunities were developed". A suggested programme for further progress in the industrial development of the province is also presented.

The report gives valuable insight into the condition and prospect of Nova Scotian industry, and the fourteen simplified tables provide a concise compendium of information on the subject.

[C.W.R.]

AN INDUSTRIAL SURVEY OF AMHERST, NOVA SCOTIA. Canadian National Railways, Research and Development Dept., Development Br., Montreal, 1958. 46 p., maps, tables.

AN INDUSTRIAL SURVEY OF SACKVILLE, NEW BRUNSWICK. Canadian National Railways, Research and Development Dept., Development Br., Montreal, 1959. 43 p., maps, tables.

AN INDUSTRIAL SURVEY OF GREATER SAINT JOHN, NEW BRUNSWICK. Canadian National Railways, Research and Development Dept., Development Br., Montreal, 1958. 67 p., maps, tables.

An Industrial Survey of Springhill, Nova Scotia. Canadian National Railways, Research and Development Dept., Development Br., Montreal, 1958. 39 p., maps, tables.

These four surveys are the most recent of a series that have been prepared by the C.N.R. for those interested in locating industrial establishments in centres in the Maritime Provinces. Each report contains general information on site, situation and history. This is followed by the factors which are considered valuable for industrial plant location: climatic conditions, municipal government, services, transportation, communications, power, population, housing, labour, industry, commerce, education, and recreation. In the Amherst report there is a survey of several of these factors in Cumberland county, with additional notes on agriculture, forestry, mineral deposits and fisheries. Studies of the agricultural land utilization by the Geographical Branch have been included in the Sackville, the Amherst and the Springhill reports.

[J.A.R.]

Sept-Îles: Canada's Newest Seaport. By George H. Michie. McGill Sub-Arctic Research Laboratory, Research Paper No. 2, McGill Univ., Montreal, 1957. 123 p., maps, Illus.

This booklet, presented originally as a master's thesis, has been published as a research paper on the industrial and commercial potential of Sept-Îles and the Quebec North Shore region.

For nearly three centuries the economic function of Sept-Îles was that of a trading post and fishing station. Within the past decade Sept-Îles has changed from a community of minor significance to a town with a commanding regional importance. Its function as a trans-shipment point for Quebec-Labrador iron ore has been complemented by local industries, diversified commercial activities and airport facilities. The location of Sept-Îles as a possible wheat trans-shipment port and a likely site for an aluminum smelter should undoubtedly make it the dominant centre of the North Shore.

The nearby pulp and paper town of Clarke City is also discussed, with additional notes on Moisie and the Indian village, Maliotenam.

[C.W.R.]

Flood Control and Hydro-Electric Power in the Fraser River Basin. Preliminary Report of the Fraser River Board, Victoria, British Columbia, 1958. 171 p., maps, graphs, and statistics.

The Fraser River Board has presented a comprehensive review of the water resources of the Fraser River basin with the object of laying the foundation of plans to lead to the most advantageous development of the basin for flood control and hydro-electric power. Topics included in the review are the hydrology of the basin, flood control, hydro-electric power, and the effects of river regulation upon navigation, silting, erosion, irrigation and the fisheries. Conclusions and recommendations as well as estimates for future investigations are included.

The text is well illustrated with maps and graphs and well documented with statistics, gathered by the Board or other agencies.

[J K.]

Gazetteer of Canada, Alberta. Canada, Canadian Board on Geographical Names, Ottawa, 1958. 96 p., map. Price $1.25.

Gazetteer of Canada, Northwest Territories and Yukon. Canada, Canadian Board on Geographical Names, provisional edition, Ottawa, 1958. 89 p., Price $1.00.

These are the sixth and seventh volumes in the series of the Gazetteer of Canada. The Alberta volume, for each entry, provides as complete a description as space allows. This includes type of feature, location in relation to some other feature, section, township and range in subdivided territory and latitude and longitude. In addition, places formerly populated are indicated.

The Northwest Territories and Yukon volume contains an alphabetical history of populated places and physical features with the location by latitude and longitude.

[B.C.]

THE ARCTIC CIRCULATION. By Hare, F. Kenneth and Svenn Orvig. Arctic Meteorology Research Group Publication in Meteorology No. 12. McGill University, Montreal, 1958. 211 p., maps, graphs, charts, table.

This important report is a preliminary review of the climatology of the northern atmospheric circulation from sea-level to 30 km. The treatment is mainly descriptive, and the report makes no attempt to be a study bearing on the general circulation problems at large. The approach is climatological, and while it is, of necessity, technical in nature, the geographer and others interested in northern climatology will find this report of great use.

[F.A.C.]

MAXIMUM WINTER ICE THICKNESS IN RIVERS AND LAKES IN CANADA. Canada, Department of Transport, Meteorological Branch. Cir. —3195, Ice-4, 1959. 20 p.

This circular is a companion work to Cir.—3156, Ice-2, 30 Jan., 1959, which contains the dates of break-up and freeze-up of rivers and lakes in the immediate vicinity of meteorological stations in Canada.

Maximum winter ice thicknesses are given for 78 lakes and 42 rivers at 125 locations. For most locations there is data for only 1957 and 1958, but six stations have data for periods exceeding 15 years.

The data are presented in tabular form, in two sections: Maximum Winter Ice Thickness in Rivers; and Maximum Ice Thicknesses in Lakes, Bays, Harbours etc. Indices to bodies of water, and to places facilitate the location of data.

[M.E.G.]

BREAK-UP AND FREEZE-UP DATES OF RIVERS AND LAKES IN CANADA. Canada, Department of Transport, Meteorological Branch. Cir. —3156, Ice-2, 1959. 92 p., mimeo.

This circular contains the dates of break-up and freeze-up of 87 rivers, and 113 lakes, bays and harbours in the immediate vicinity of meteorological stations. Individual records vary from one year to 130 years.

The dates are presented in tabular form, in four sections: Dates of Break-up of Rivers in Canada; Dates of Break-up of Lakes, Bays, Harbours etc.; Dates of Freeze-up of Rivers in Canada; and Dates of Freeze-up of Lakes, Bays, Harbours etc. For most stations two dates are given for each break-up and freeze-up. In break-up, the first date indicates when the ice first moved or showed signs of breaking, and the second date indicates when the water body was clear of ice. Similarly for freeze-up, the date when the ice first formed, and the date when the water body was completely frozen over, are listed. Where the length of record is ten years or more, mean dates are given, and extreme dates are underlined. An index to the bodies of water facilitates the location of data.

[M.E.G.]

CHURCHILL RIVER AND MISSISSIPPI RIVER DRAINAGE BASINS IN CANADA. 1952–4. By J. F. J. Thomas. Canada, Department of Mines and Tech. Surv. Mines Branch, Industrial Minerals Division. Industrial Water Resources of Canada, Water Survey Report No. 9, Ottawa, 1958. 53 p.

This is the ninth report in the series of Water Survey Report on the chemical quality of surface and municipal water supplies available for industrial and domestic use in Canada. Report No. 1 outlines the aim, scope and procedures of the country-wide survey begun in 1947, and discusses the interpretation and analytical results which have been recorded in subsequent reports of the series.

The report is divided into two parts, each discussing one river basin. Descriptions are given of the basins and of the municipal water systems; statistical information is presented in graphic or tabular form.

[M.E.G.]

THE MAMMALS OF BANKS ISLAND. By T. H. Manning and A. H. Macpherson. Arctic Institute of North America. Tech. Paper No. 2, 1958. 74 p., tables, map, diagr. Price $2.00.

A record of field observations made in 1951, 1952 and 1953 is supplemented by observations of previous authors. The bulk of the paper consists of a systematic list of the 13 species of mammals which are or have been regular inhabitants of the island or the surrounding seas.

[J.K.F.]

MAP NOTES

ATLAS OF CANADA. Canada, Dept. of Mines and Technical Surveys, Geographical Branch, Queen's Printer, Ottawa, 1957. 110 plates. Price $25.00.

PLATE NO

1. ROUTES OF EXPLORERS, 1534-1870
1534-1670; 1670-1763; 1768-1795; 1800-1870. (1 : 20,000,000).

2. MAPPING THE COASTS, 1492-1874
Stephanius 1590; Behaim 1492; Ruysch 1508; Walsemüller 1507; Agnese 1540; Ptolemy 1548 Edition; Zaltieri 1566; La Cosa 1500; Canerio 1502-04; Desceliers 1550; Ribero 1529; Velasco 1610; Mercator 1595; Foxe 1635; Franklin 1823; British Admiralty 1835; British Admiralty 1874; De Laet 1630; Anonymous 1758; Cook 1784; Arrowsmith 1822.

3. MAPPING THE INTERIOR, 1630-1870
Champlain 1632; Dollier and Galinée 1680; Franquelin 1699; Delisle 1750 and Buache 1754 combined; Pond 1787; Thompson 1814; Arrowsmith 1857 and Russell 1868 combined; Delabat 1710; Duberger 1808.

4. EXTENT OF MAPPING SURVEYS — 1955
Legal Surveys; Geodetic Surveys; Air Photographic Surveys. (1:20,000,000).

5. EXTENT OF TOPOGRAPHICAL MAPPING — 1955
Areas covered by maps of the scales of 1:50,000 and 1:63,360; 1:126,720; 1:190,080; 1:250,000 and 1:253,440. (1:20,000,000)

6. COMPARISON OF SCALES
Part of Ottawa, Ontario (1:14,400); Ottawa and vicinity (1:50,000); Ottawa to Kemptville (1:250,000); Ottawa to Brockville (1:506,880); Ottawa to Trenton (1:1,000,000); Ottawa to Windsor (1:4,055,040).

7. AERONAUTICAL CHARTS
Aeronautical Chart (8 miles to 1 inch); Aeronautical Chart (16 miles to 1 inch); Instrument Approach Chart; Landing Chart; Aeronautical Chart (1:506,880); Mercator Plotting Chart (1:1,000,000); Navigational Plotting Chart (1:3,000,000); Radio Facility Chart (1:2,534,400); Trans Atlantic Plotting Chart (1:4,000,000); Aeronautical Planning Chart (1:5,000,000).

8. HYDROGRAPHIC CHARTS
Areas covered by Canadian hydrographic charts (1:20,000,000); Inland Waters (1:72,968); Harbour Chart (1:9,122); Coastal Chart (1:145,000).

9. BATHY-OROGRAPHY – CANADA (1:10,000,000)

10. BATHY-OROGRAPHY – EASTERN CANADA (1:5,000,000)

11. BATHY-OROGRAPHY – WESTERN CANADA (1:5,000,000)

12. BATHY-OROGRAPHY – NORTHERN CANADA (1:5,000,000)

13. PHYSIOGRAPHIC REGIONS
Physiographic Regions of Canada (1:20,000,000); Physiographic Divisions of the Canadian Cordillera (1:5,000,000); Physiographic Divisions of Canadian Appalachia (1:5,000,000).

14. PHYSIOGRAPHY OF SOUTHERN ONTARIO (1:1,000,000)

15. GLACIAL GEOLOGY (1:10,000,000)

16. BEDROCK GEOLOGY (1:10,000,000)

17. PRINCIPAL MINERALS (1:20,000,000)

18. EARTHQUAKES, MAGNETISM AND TIDES
Lines of Equal Magnetic Variation (1:20,000,000); Lines of Equal Annual Change in Magnetic Variation (1:20,000,000); Semi-diurnal co-tidal and co-range lines (1:5,000,000); Diurnal co-tidal and co-range lines (1:10,000,000); Earthquake probability (1:50,000,000).

19. ATMOSPHERIC PRESSURE
January mean sea-level pressure; April mean sea-level pressure; July mean sea-level pressure; October mean sea-level pressure (1:20,000,000).

20. WIND AND SUNSHINE
Direction frequencies of winter winds; Direction frequencies of summer winds; Mean annual total hours of bright sunshine; Mean annual percentage of total daylight hours with bright sunshine (1:20,000,000).

21. SEASONAL TEMPERATURES
January mean daily temperature; April mean daily temperature; July mean daily temperature; October mean daily temperature (1:20,000,000).

22. TEMPERATURE RANGES
Mean annual minimum temperature; Extreme lowest recorded temperature; Mean annual maximum temperature; Extreme highest recorded temperature (1:20,000,000). Mean annual number of days with a minimum temperature of 0°F. or lower; Mean annual number of days with a maximum temperature of 90°F. or higher (1:50,000,000).

23. FROST
Mean annual frost-free period (1:10,000,000); Mean date of the first occurrence of a temperature of 32°F. in fall; Mean date of the last occurrence of a temperature of 32°F. in spring (1:20,000,000).

24. GROWING SEASONS
Mean annual length of growing season; Mean annual number of degree days above 42°F.; Mean growing season precipitation; Variability of growing season precipitation (1:20,000,000).

25. ANNUAL PRECIPITATION
Mean annual total precipitation (1:10,000,000); Mean annual total snowfall (1:20,000,000).

26. PRECIPITATION DAYS AND PRECIPITATION VARIABILITY
Variability of annual precipitation (1:10,000,000); Mean annual number of days with measurable precipitation (1:20,000,000); Mean annual number of days with measurable snowfall (1:20,000,000).

27. SEASONAL PRECIPITATION
Mean spring precipitation; Mean summer precipitation; Mean fall precipitation; Mean winter precipitation (1:20,000,000).

28. SNOW COVER
Mean date of first snow cover; Mean date of last snow cover; Mean annual number of days with snow cover; Mean annual maximum depth of snow (1:20,000,000).

29. HUMIDITY AND FOG
January mean mixing ratio; July mean mixing ratio; Mean number of days with fog – winter; Mean number of days with fog – spring; Mean number of days with fog – summer; Mean number of days with fog – fall (1:20,000,000).

30. CLIMATIC REGIONS (1:10,000,000)

31. TYPICAL WEATHER SITUATIONS
Surface Weather Maps for February 18th, 1954; April 19th, 1955; July 3rd, 1955; October 12th, 1954 (1:30,000,000).

32. WEATHER STATIONS AND FORECAST REGIONS (1:10,000,000)
Inset: Public Weather Forecast Districts and areas (1:22,000,000 and 1:10,500,000).

PLATE NO

93. EDUCATION
Institutions of Higher Education (1:5,000,000); Proportion of the population of 5 to 24 years of age attending school; Median years of schooling. (1:20,000,000).

94. PUBLIC LIBRARIES, MUSEUMS AND ART GALLERIES (1:5,000,000)

95. POPULATED PLACES - GULF OF ST. LAWRENCE AREA (1:2,500,000)

96. POPULATED PLACES - GREAT LAKES AREA (1:2,500,000)

97. POPULATED PLACES - PRAIRIES (1:2,500,000)

98. POPULATED PLACES - THE FAR WEST (1:2,500,000)

99. POPULATED PLACES - NORTHERN CANADA (1:10,000,000)

100. QUEBEC CITY AND MONTREAL
Quebec City Urban Growth 1608-1955; Montreal Urban Growth 1642-1955; Quebec City Land Use - 1955; Montreal Land Use - 1955. (1:100,000).

101 OTTAWA AND TORONTO
Ottawa Urban Growth 1826-1955; Toronto Urban Growth 1793-1955; Ottawa Land Use 1955; Toronto Land Use 1955. (1:100,000).

102. WINNIPEG AND EDMONTON
Winnipeg Urban Growth 1835-1955; Edmonton Urban Growth 1802-1956; Winnipeg Land Use 1955; Edmonton Land Use 1956. (1:100,000).

103. VANCOUVER AND VICTORIA
Vancouver Urban Growth 1886-1956; Victoria Urban Growth 1851-1955; Vancouver Land Use 1955; Victoria Land Use 1955. (1:100,000).

104. RURAL MUNICIPALITIES - EASTERN CANADA (1:5,000,000)

105. RURAL MUNICIPALITIES - GREAT LAKES - ST. LAWRENCE AREA (1:2,500,000)

106. RURAL MUNICIPALITIES - WESTERN CANADA (1:5,000,000)

107. CENSUS DIVISIONS - 1951 (1:10,000,000)

108. FEDERAL ELECTORAL DISTRICTS - 1952 (1:10,000,000)

109. POLITICAL EVOLUTION (1:20,000,000)

110. CANADA AND THE WORLD
The Commonwealth; The North Atlantic Treaty Organization; Organization for European Economic Corporation; The Colombo Plan; The United Nations Organization.

Bound copies of the Atlas of Canada may be obtained from the Queen's Printer, Department of Public Printing and Stationery, Ottawa, Canada. Price $25.00.

Separate plates from the Atlas of Canada may be obtained from the Geographical Branch, price 50 cents each.

FICHES CARTOGRAPHIQUES

ATLAS DU CANADA. Canada, Ministère des Mines et des Relevés techniques, Direction de la géographie, Imprimeur de la Reine, Ottawa 1957. 110 planches. Prix $25.00.

PLANCHE NO

1. ROUTES DES EXPLORATEURS, 1534-1870
   1534-1670; 1670-1763; 1768-1795; 1800-1870 (1:20,000,000).
2. CARTES CÔTIÈRES (1492-1874)
   Stephanius 1590; Behaim 1492; Ruysch 1508; Waldseemüller 1507; Agnese 1540; Ptolémée, édition de 1548; Zaltieri 1566; La Cosa 1500; Canerio 1502-04; Desceliers 1550; Ribero 1529; Velasco 1610; Mercator 1595; Foxe 1635; Franklin 1823; Amirauté Britannique 1835; Amirauté Britannique 1874; De Laet 1630; Anonyme 1758; Cook 1784; Arrowsmith 1822.
3. CARTES DE L'ARRIÈRE-PAYS (1630-1870)
   Champlain 1632; Dollier et Galinée 1680; Franquelin 1699; Delisle 1750 et Buache 1754, cartes combinées; Pond 1787; Thompson 1814; Arrowsmith 1857 et Russell 1868, cartes combinées; Delabat 1710; Duberger 1808.
4. ÉTAT DES LEVÉS CARTOGRAPHIQUES — 1955
   Levés officiels; Levés géodésiques; Levés aéro-photographiques (1:20,000,000).
5. ÉTAT DE LA CARTOGRAPHIE TOPOGRAPHIQUE — 1955
   Superficies cartographiées aux échelles de 1:50,000 et 1:63,360; 1:126,720; 1:190,080; 1:250,000 et 1:253,440 (1:20,000,000).
6. ÉCHELLES COMPARÉES
   Une partie d'Ottawa, Ontario (1:14,400); Ottawa et ses alentours (1:50,000); d'Ottawa à Kemptville (1:250,000); d'Ottawa à Brockville (1:506,880); d'Ottawa à Trenton (1:1,000,000); d'Ottawa à Windsor (1:4,055,040).
7. CARTES AÉRONAUTIQUES
   Carte aéronautique (8 milles au pouce); carte aéronautique (16 milles au pouce); carte d'approche aux instruments; carte d'atterrissage; carte aéronautique (1:506,880); carte de tracés de mercator; (1:1,000,000); carte de tracés de navigation (1:3,000,000); carte d'installations radio (1:2,534,400); carte de tracés transatlantiques (1:4,000,000); carte aéronautique générale (1:5,000,000).
8. CARTES HYDROGRAPHIQUES
   Superficies couvertes par les cartes hydrographiques publiées à date (1:20,000,000); eaux intérieures (1:72,968); carte des ports (1:9,122); carte côtière (1:145,000).
9. BATHYMÉTRIE ET OROGRAPHIE — CANADA (1:10,000,000)
10. BATHYMÉTRIE ET OROGRAPHIE — EST DU CANADA (1:5,000,000)
11. BATHYMÉTRIE ET OROGRAPHIE — OUEST DU CANADA (1:5,000,000)
12. BATHYMÉTRIE ET OROGRAPHIE — NORD DU CANADA (1:5,000,000)
13. RÉGIONS PHYSIOGRAPHIQUES
    Régions physiographiques du Canada (1:20,000,000); divisions physiographiques de la Cordillère canadienne (1:5,000,000); divisions physiographiques des Appalaches canadiennes (1:5,000,000).
14. PHYSIOGRAPHIE DU SUD DE L'ONTARIO (1:1,000,000)
15. GÉOLOGIE GLACIAIRE (1:10,000,000)
16. GÉOLOGIE (1:10,000,000)
17. PRINCIPAUX MINÉRAUX (1:50,000,000)
18. SÉISMES, MAGNÉTISME ET MARÉES
    Lignes de même variation magnétique (1:20,000,000); lignes de même changement annuel dans la variation magnétique (1:20,000,000); lignes semi-diurnes cotidales et de co-amplitude (1:5,000,000); lignes diurne cotidales et de co-amplitude (1:10,000.000); probabilités séismiques (1:50,000,000).
19. PRESSION ATMOSPHÉRIQUE
    Pression moyenne au niveau de la mer: janvier; avril; juillet; octobre (1:20,000,000).
20. VENTS ET ENSOLEILLEMENT
    Fréquence de la direction des vents d'hiver; d'été; total moyen annuel des heures d'ensoleillement; pourcentage moyen annuel de l'ensoleillement par rapport au total des heures de clarté (1:20,000,000).
21. TEMPÉRATURES SAISONNIÈRES
    Température moyenne diurne: janvier; avril; juillet; octobre (1:20,000,000).
22. TEMPÉRATURES EXTRÊMES
    Température minimum annuelle moyenne; température minimum extrême enregistrée; température maximum annuelle moyenne; température maximum extrême enregistrée (1:20,000,000). Nombre annuel moyen de jours à la température minimum de 0°F et moins; nombre annuel moyen de jours à la température maximum de 90°F et plus (1:50,000,000).
23. GELÉE
    Période moyenne annuelle sans gelée (1:10,000,000); date moyenne de la première observation de la température de 32°F en automne; date moyenne de la dernière observation de la température de 32°F au printemps (1:20,000,000).
24. SAISON DE VÉGÉTATION
    Longueur annuelle moyenne de la saison de végétation; nombre annuel moyen de degrés-jours au-dessus de 42°F; précipitations moyennes de la saison de végétation; variabilité des précipitations de la saison de végétation (1:20,000,000).
25. PRÉCIPITATIONS ANNUELLES
    Moyenne annuelle des précipitations totales (1:10,000,000); moyenne annuelle des précipitations en neige (1:20,000,000).
26. JOURS DE PRÉCIPITATIONS ET VARIABILITÉ DES PRÉCIPITATIONS
    Variabilité des précipitations annuelles (1:10,000,000); nombre annuel moyen de jours de précipitations mesurables (1:20,000,000); nombre annuel moyen de jours de chutes de neige mesurables (1:20,000,000).
27. PRÉCIPITATIONS SAISONNIÈRES
    Précipitation moyenne au printemps; en été; en automne; en hiver (1:20,000,000).
28. ENNEIGEMENT
    Date moyenne de la première couche de neige; date moyenne de la dernière couche de neige; moyenne annuelle du nombre de jours où l'on a observé une couche de neige; moyenne annuelle de la hauteur maximum de neige (1:20,000,000).
29. HUMIDITÉ ET BROUILLARD
    Richesse hygrométrique moyenne de janvier; de juillet; moyenne des jours de brouillard en hiver; au printemps; en été; à l'automne (1:20,000,000).
30. RÉGIONS CLIMATIQUES (1:10,000,000)
31. SITUATIONS MÉTÉOROLOGIQUES CARACTÉRISTIQUES
    Situation météorologique à la surface du sol le 18 février 1954; le 19 avril 1955; le 3 juillet 1955; le 12 octobre 1954 (1:30,000,000).
32. STATIONS MÉTÉOROLOGIQUES ET RÉGIONS DE PRÉVISION DU TEMPS (1:10,000,000)
    Encart: Districts et zones de prévisions météorologiques publiques (1:22,000,000 et 1:10,500,000).
33. BASSINS HYDROGRAPHIQUES ET DÉBIT DES COURS D'EAU (1:10,000,000)
34. PROFILS DES PRINCIPAUX COURS D'EAU
    Encart: Emplacement des cours d'eau profilés.

PLANCHE NO

35. RÉGIONS PÉDOLOGIQUES (1:10,000,000)

36. CARTES DES SOLS
Fragments des cartes des sols suivantes: îles Montréal-Jésus et Bizard, Québec (1:63,360); York County, Ontario (1:63,360); extrait de la feuille Red Deer, Alberta (1:190,080); région de Winnipeg, Manitoba (1:126,720).

37. HABITATS DE CERTAINS INSECTES, ACARIDES ET ARAIGNÉES TYPES (1:50,000,000)

38. VÉGÉTATION NATURELLE ET FLORE (1:20,000,000-1:50,000,000)

39. RÉGIONS FORESTIÈRES (1:10,000,000)

40. CARTES DE L'INVENTAIRE FORESTIER
Forêts subalpines du versant est des Rocheuses; forêts mixtes de la région boréale; forêts mixtes de la région acadienne; terrains boisés d'une zone agricole (1:63,360).

41. PEUPLEMENT DES PRINCIPAUX ARBRES À VALEUR COMMERCIALE (1:50,000,000)

42. HABITATS DES PRINCIPAUX MAMMIFÈRES (1:50,000,000)

43. AIRES DES PRINCIPAUX OISEAUX (1:50,000,000)

44. HABITATS DES PRINCIPAUX POISSONS DE COMMERCE DES EAUX INTÉRIEURES (1:50,000,000)

45. PARCS ET RÉSERVES DE FAUNE (1:10,000,000)

46. RÉPARTITION DE LA POPULATION (1851-1941)
Amérique du Nord Britannique, 1851; Canada, Ile-du-Prince-Édouard et Terre-Neuve, 1871; Canada et Terre-Neuve, 1901; Canada et Terre-Neuve, 1921; Canada et Terre-Neuve, 1941 (1:20,000,000).

47. RÉPARTITION DE LA POPULATION EN 1951 (1:10,000,000)

48. DENSITÉ DE LA POPULATION — 1951 (1:5,000,000)

49. VARIATIONS DÉMOGRAPHIQUES, 1851-1951
Mouvements de la population, 1851-1901; mouvements de la population, 1901-1951 (1:10,000,000).

50. NAISSANCES, MARIAGES ET DÉCÈS, ETC.
Natalité; mortalité; accroissement naturel; mariages; mortalité infantile; enfants au foyer par famille (1:20,000,000).

51. RÉPARTITION DES ÂGES ET DES SEXES
Pourcentage de la population de moins de 20 ans; 20 et 64 ans; plus de 64 ans; nombre d'hommes pour 100 femmes (population rurale); nombre d'hommes pour 100 femmes (population urbaine) (1:20,000,000).

52. POPULATION INDIGÈNE (1:10,000,000)
Encart: Répartition des Indiens et des Esquimaux, 1951.

53. ORIGINES FRANÇAISE ET BRITANNIQUE
Répartition de la population d'origine française; répartition de la population d'origine britannique (1:10,000,000).

54. AUTRES ORIGINES ET CITOYENNETÉ
Origines allemande et néerlandaise; origines polonaise et ukrainienne; origines scandinave et juive; pourcentage des Canadiens de naissance par rapport à l'ensemble de la population; pourcentage des immigrés par rapport à l'ensemble de la population; pourcentage des citoyens canadiens par rapport à l'ensemble de la population (1:20,000,000).

55. RELIGIONS PRINCIPALES
Catholiques; adhérents à l'Église Unie du Canada; adhérents à l'Église Anglicane du Canada; Presbytériens; Baptistes; Luthériens (1:20,000,000).

56. POPULATION URBAINE
Répartition de la population urbaine (1:10,000,000); répartition nocturne de la population de la région métropolitaine de Toronto; répartition nocturne de la population d'une partie de l'île de Montréal (1:126,720); régions où les agglomérations urbaines d'au moins 1,000 habitants sont distantes de 15 milles au plus les unes des autres (1:20,000,000).

57. POPULATION RURALE
Population rurale non agricole; population rurale agricole (1:10,000,000).

58. FOURRURES, PÊCHE À LA BALEINE ET CONDITIONNEMENT DU POISSON
Fermes à fourrure et établissements du commerce des fourrures (1:20,000,000); personnes vivant de la pêche et du piégeage (1:20,000,000); usines de conditionnement du poisson (1:10,000,000); baleines (1:10,000,000); peaux d'animaux à fourrure levées pendant la saison 1950-51 (1:50,000,000).

59. PÊCHERIES DES CÔTES DE L'EST (1:10,000,000)

60. PÊCHERIES DES CÔTES DE L'OUEST (1:10,000,000)

61. SYLVICULTURE ET INDUSTRIE DU BOIS
Portes et châssis et bois corroyé; meubles (1:20,000,000); main-d'oeuvre de la sylviculture et de l'exploitation forestière (1:10,000,000).

62. SCIERIES (1:5,000,000)

63. FABRIQUES DE PÂTE ET DE PAPIER (1:5,000,000)

64. ANIMAUX DE FERME
Vaches laitières; bovins d'abattage; porcs; moutons; poules et poulets; chevaux (1:20,000,000).

65. BLÉ ET ORGE
Blé; orge (1:10,000,000).

66. AUTRES CÉRÉALES ET GRAINES OLÉAGINEUSES
Avoine; céréales mélangées; seigle; lin à graine (1:20,000,000); maïs à grain (1:10,000,000); soya (1:5,000,000).

67. CÉRÉALES FOURRAGÈRES ET CULTURES INTENSIVES
Foin; maïs d'ensilage; betteraves à sucre; pommes de terre; culture maraîchère (1:20,000,000); vergers (1:10,000,000 et 1:5,000,000); tabac (1:10,000,000 et 30 milles au pouce).

68. FERMES
Fermes à exploitation saisonnière; fermes occupées; pourcentage des terres agricoles occupées par les propriétaires; pourcentage des fermes occupées ayant l'électricité; pourcentage des fermes occupées ayant des tracteurs; valeur des produits agricoles vendus par ferme (1:20,000,000).

69. RÉGIONS AGRICOLES (1:5,000,000)

70. MAIN-D'OEUVRE ET SERVICES AGRICOLES
Main-d'oeuvre agricole; écoles d'agriculture et stations expérimentales (1:10,000,000).

71. INDUSTRIES ALIMENTAIRES
Abattage et conserves des viandes; élévateurs à grains et minoteries; industrie laitière; boulangeries et pâtisseries; conserveries des fruits et des légumes; boissons alcooliques (1:20,000,000).

72. FER ET ACIER BRUTS (1:10,000,000)

73. MÉTAUX NON FERREUX — EST DU CANADA (1:5,000,000)
Encart: Main-d'oeuvre des mines et des carrières (1:20,000,000); carte géologique du Bassin de Sudbury.

74. MÉTAUX NON FERREUX — OUEST DU CANADA (1:5,000,000)

75. MINÉRAUX INDUSTRIELS (1:5,000,000)

76. COMBUSTIBLES MINÉRAUX, PIPE-LINES ET RAFFINERIES
Pipe-lines de pétrole et de gaz et raffineries de pétrole (1:10,000,000); gisements de houille, de pétrole et de gaz (1:5,000,000).

77. ÉNERGIE HYDRO-ÉLECTRIQUE ET THERMO-ÉLECTRIQUE — EST DU CANADA (1:5,000,000)

78. ÉNERGIE HYDRO-ÉLECTRIQUE ET THERMO-ÉLECTRIQUE — OUEST DU CANADA (1:5,000,000)

79. INDUSTRIE MÉTALLIQUE
Matériel roulant de chemin de fer; avions et pièces; véhicules automobiles et machines agricoles; pièces de véhicules automobiles; appareils et accessoires électriques; autres machines (1:20,000,000).

80. TEXTILES, VÊTEMENTS ET PRODUITS DE CAOUTCHOUC
Chaussures de cuir; vêtements de fabrication industrielle pour femmes et enfants; pour hommes; textiles et soies artificiels; textiles de coton; produits de caoutchouc (1:20,000,000).

81. CENTRES INDUSTRIELS (1:5,000,000)

82. EAUX NAVIGABLES
Eaux navigables (1:20,000,000); canaux actuels (1:2,500,000); voie maritime du Saint-Laurent (1:375,000).

83. CHEMINS DE FER (1:5,000,000)

84. TRAFIC-MARCHANDISES DES CHEMINS DE FER (1:5,000,000)

85. ROUTES PRINCIPALES (1:5,000,000)

86. AÉROPORTS ET AÉRODROMES CIVILS, FUSEAUX HORAIRES
Aéroports et fuseaux horaires (1:10,000,000); aérodromes (1:20,000,000).

87. LIGNES AÉRIENNES (1:10,000,000)

88. TRAFIC-VOYAGEURS AÉRIEN (1:10,000,000)
Encart: Personnes employées dans les transports et communications (1:20,000,000).

89. COMMERCE INTÉRIEUR, FINANCE ET CONSTRUCTION
Travailleurs employés dans le commerce de gros; le commerce de détail; la construction; la finance, l'assurance et l'immeuble; valeur nette en pourcentage des ventes du commerce de gros; du commerce de détail (1:20,000,000).

90. NAVIGATION
Navires étrangers; caboteurs canadiens (1:10,000,000).

91. RADIO ET TÉLÉVISION
Postes et réseaux de télévision; postes et réseaux de radiodiffusion (1:10,000,000).

PLANCHE NO

92. HÔPITAUX
Hôpitaux généraux (1:10,000,000); hôpitaux pour maladies mentales (1:20,000,000); hôpitaux spécialisés (1:20,000,000).
93. ENSEIGNEMENT
Institutions d'enseignement supérieur (1:5,000,000); proportion de la population étudiante dont l'âge varie entre 5 et 24 ans; moyenne des années de scolarité (1:20,000,000).
94. BIBLIOTHÈQUES, MUSÉES ET GALERIES D'ART (1:5,000,000)
95. CENTRES HABITÉS — RÉGION DU GOLFE ST-LAURENT (1:2,500,000)
96. CENTRES HABITÉS — RÉGION DES GRANDS LACS (1:2,500,000)
97. CENTRES HABITÉS — PRAIRIES (1:2,500,000)
98. CENTRES HABITÉS — EXTRÊME OUEST (1:2,500,000)
99. CENTRES HABITÉS — NORD DU CANADA (1:10,000,000)
100. QUÉBEC ET MONTRÉAL
Expansion urbaine: Québec 1608-1955; Montréal 1642-1955; aménagement du terrain: Québec 1955; Montréal 1955 (1:100,000).
101. OTTAWA ET TORONTO
Expansion urbaine: Ottawa 1826-1955; Toronto 1793-1955; aménagement du terrain: Ottawa 1955; Toronto 1955 (1:100.000).
102. WINNIPEG ET EDMONTON
Expansion urbaine: Winnipeg 1835-1955; Edmonton 1802-1956; aménagement du terrain: Winnipeg 1955; Edmonton 1956 (1:100,000).
103. VANCOUVER ET VICTORIA
Expansion urbaine: Vancouver 1886-1956; Victoria 1851-1955; aménagement du terrain. Vancouver 1955; Victoria 1955 (1:100,000).
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