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**DEPARTMENT OF ENERGY,
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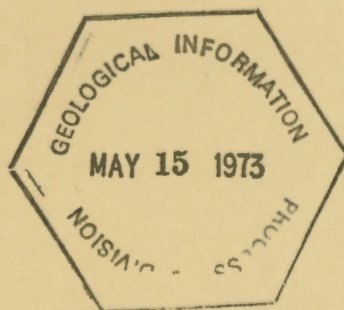
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PAPER 72-45

**DRIFT PROSPECTING; GEOCHEMISTRY OF ESKERS
AND TILL IN PERMANENTLY FROZEN TERRAIN:
DISTRICT OF KEEWATIN; NORTHWEST TERRITORIES**

W. Shilts





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(Report, 6 plates and 8 figures)

W. Shilts

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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CONTENTS

	Page
Abstract/ Résumé.....	v
Introduction.....	1
Acknowledgments.....	1
Summary of glacial geology.....	2
Esker characteristics.....	3
Sampling techniques	5
Eskers	5
Till	5
Analytical techniques	6
Effect of the permafrost environment on trace-element values.....	7
Esker transport and anomalies.....	12
Esker sedimentation	12
Results.....	13
Kaminak Esker and till: geochemical data	13
Copperneedle Esker and till: geochemical data	18
Distribution of trace elements in various fractions	19
Weight per cent of heavy and magnetic minerals	19
Conclusions.....	26
References	33
Table 1. General characteristics of Kaminak and Copperneedle Eskers	4
Table 2. Trace-element concentrations in various fractions of till	24-25

Illustrations

Figure 1: Location map showing eskers sampled and extent of marine transgression	2
2: X-ray diffractograms of -250-mesh portions of till and a nearby esker sample.....	8
3: Idealized diagrams depicting proposed mechanisms of formation of mud boils	
3a: Idealized cross-section through a till drumlin. Diagram illustrates how slopes are rapidly flattened in permanently frozen terrain (cryoplanation) and how fresh, unfrozen till is continuously produced by lowering of frost line near crest of hill.....	10
3b: Block diagram of mud boils showing components described in text.....	11
4: Trace-element concentrations in various fractions of the Kaminak Esker	in pocket
5a: Copper concentrations in various fraction of till collected from the "CT" grid, adjacent to the Kaminak Esker	14
5b: Nickel concentrations in various fraction of till collected from the "CT" grid, adjacent to the Kaminak Esker	15

	Page
Figure 5c: Zinc concentrations in various fractions of till collected from the "CT" grid, adjacent to the Kaminak Esker.....	16
5d: Lead concentrations in various fractions of till collected from the "CT" grid, adjacent to the Kaminak Esker.....	17
6: Trace-element variations in various fractions of the Copperneedle Esker.....	in pocket
7: Trace-element concentrations in -250-mesh separates from till samples collected adjacent to the Copperneedle Esker ("CN" grid).....	in pocket
8a: Copper concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake	20
8b: Nickel concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake	21
8c: Zinc concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake	22
8d: Lead concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake	23
Plates 1 to 6:	28-32

ABSTRACT

Geochemical results are reported for a program that compared samples collected from eskers and adjacent till in permanently frozen terrain. Contrasting effects of disturbance on the well- and poorly sorted sediments within the active (seasonally thawed) zone are discussed. Trace element geochemistry of several textural and mineralogical fractions of each sample is reported, compared and explained. A previously known area of copper-nickel mineralization is clearly outlined by anomalies in various fractions of both till and esker samples. Other anomalies, possibly related to unknown sources, are also described.

It is concluded that some potentially interesting ore minerals (sulphides and carbonates) are removed from the active zone of eskers and till by intense chemical weathering. Clays and secondary oxides that can scavenge cations released by this weathering are preferentially removed by surface runoff from mud boils on till, but are retained within the porous structure of the thawed zone of eskers. Thus, silt and clay (-250 mesh) is recommended for analysis in esker samples but must be used with caution when analyzing till. Heavy mineral separates from near-surface esker and till samples from permanently frozen terrain are not recommended for routine analysis.

Micas, magnetite, clay, and rock fragments can reflect economically interesting mineralization, suggesting that some mineral phases in rocks adjacent to mineralized zones may be enriched in the cations characteristic of those zones. This implies that a target for drift prospecting may be larger than the mineralized zone itself.

RÉSUMÉ

L'auteur rend compte des résultats d'analyses géochimiques dans le cadre d'un programme visant à comparer des échantillons tirés d'eskers et du till environnant dans un terrain gelé en permanence. Il étudie les divers effets des dérangements sur des sédiments bien triés et des sédiments mal triés dans la couche active (fonte saisonnière). Il rend compte, compare et explique la géochimie des éléments sous forme de traces à partir de plusieurs fractions de chacun des échantillons, au point de vue de la texture et de la minéralogie. Il établit clairement les grandes lignes d'une zone de minéralisation en cuivre et en nickel déjà connue au moyen des anomalies trouvées dans plusieurs parties des échantillons du till et des eskers. D'autres anomalies, possiblement reliées à des sources inconnues, sont aussi décrites.

L'auteur conclut que des minéraux métalliques potentiellement intéressants (sulfures et carbonates) sont enlevés de la zone active des eskers et du till par une altération chimique intense. Les argiles et les oxydes secondaires qui peuvent évacuer les cations dégagés par cette altération sont enlevés de façon préférentielle par l'écoulement de surface provenant des coulées boueuses sur le till, mais ils sont retenus à l'intérieur de la structure poreuse de la zone dégelée des eskers. Ainsi, le silt et l'argile (tamis -250) sont recommandés lorsqu'on fait l'analyse d'échantillons d'eskers mais on doit les utiliser avec précaution lorsqu'on analyse le till. Les minéraux lourds détachés de l'esker et les échantillons de till provenant du terrain gelé en permanence ne sont pas recommandés pour une analyse courante.

Les micas, la magnétite, l'argile et les fragments de roche peuvent être l'indice d'une minéralisation intéressante au point de vue économique; cela signifie que des phases minérales dans les roches adjacentes aux zones minéralisées ont peut-être été enrichies selon les caractéristiques des cations de ces zones. Cela signifie que l'objet d'une prospection morainique doit être plus étendu que la zone minéralisée elle-même.

DRIFT PROSPECTING; GEOCHEMISTRY OF ESKERS
AND TILL IN PERMANENTLY FROZEN TERRAIN;
DISTRICT OF KEEWATIN; NORTHWEST TERRITORIES

INTRODUCTION

The objective of the Kaminak Lake project was to develop techniques for drift prospecting over a glaciated shield area in the zone of deep, continuous permafrost. To this end, various glacial and postglacial sediments were collected and split into textural and mineralogical fractions for chemical analysis. This paper reports the results of one phase of the Kaminak project, namely, the comparative study of esker samples with nearby till samples.

During the summers of 1970 and 1971 samples were collected from two eskers (informally named the Copperneedle and Kaminak eskers) and from till in adjacent areas. Eskers and till were submerged under as much as 300 feet of marine water of the Tyrrell Sea, the enlarged, postglacial equivalent of Hudson Bay that inundated land isostatically depressed by the Keewatin ice sheet (Lee, 1959; see also Prest *et al.*, 1968).

Sampling and sample preparation were done by glacial sedimentologists and geologists to minimize the "sampling error" (Wennervirta, 1968, p. 19) that has plagued many geochemical studies of drift or soils developed on drift. By minimizing sampling and sample-preparation errors, and assuming the analytical errors to be tightly controlled, it has been possible to handle the chemical data with a minimum of statistical filtering. In this and future papers on the Kaminak Lake project, geochemical data will be presented, insofar as possible, as "real" data with a minimum of transformation by statistical manipulation.

It should be noted that the magnitudes of trace-element values reported in this paper are closely related to the size or mineralogical fractions analyzed and cannot easily be related to any specific type or tenor of ore deposit. Reference to the text, and particularly to Table 2, should indicate that there are many interlocking factors that influence measured trace-element values of any sample. Type of sample fraction analyzed, type of sediment and location of sample with respect to the soil profile or permafrost table are all important factors controlling measured trace-element values.

ACKNOWLEDGMENTS

Most of the samples discussed were collected by Dr. G.M. Hasleton, J.G. Warwick, L. Stevenson, and W. Podolak under less than ideal weather conditions during the summers of 1970 and 1971. Sample preparation was done in the Booth Street sedimentation laboratory, Terrain Sciences Division, Geological Survey of Canada. Chemical analyses were performed by Bondar-Clegg and Co. Ltd. Drs. R.G. Skinner, K.E. Eade and B.C. McDonald read the manuscript and offered valuable criticism. The author, however, assumes responsibility for accuracy of data and conclusions drawn.

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SUMMARY OF GLACIAL GEOLOGY

The Kaminak Lake area is situated about 75 miles southeast of the Keewatin Ice Divide (Lee *et al.*, 1957; Lee, 1959). The ice divide (Fig. 1) is the region toward which the glacial ice on the west side of Hudson Bay shrank during final dissipation of the North American continental glacier. While this centre was active, ice flow was radially outward and southeast over the Kaminak area. At one time flow originated from a point farther west than the divide, as evidenced by the abundance of Dubawnt Group erratics, apparently derived from north and west of the centre.

Drumlin orientations, ribbed- and end-moraine orientations, and striations reflect southeast flow toward a northeast-southwest-trending ice front in the Kaminak region. Ice-contact deltas associated with eskers indicate that the glacier front was probably standing in the Tyrrell Sea. Tyrrell Sea beaches are presently found at altitudes of 560 ± 3 ft. a.s.l. so that all but a few small hills were submerged beneath its waters. The oldest reliable date on Tyrrell Sea sediments in the Kaminak area is 6600 ± 230 C¹⁴ years B.P. (GSC-1434) which probably approximates the date of local deglaciation. Twigs from a delta with a present surface 210 ± 10 ft. a.s.l. have been dated at 4590 ± 220 C¹⁴ years B.P. (GSC-1484) indicating that much of the area was subjected to about 2000 years of marine submergence and portions of the region (mainly the Kaminak-Quartzite Lake basins) were submerged more than 2000 years.

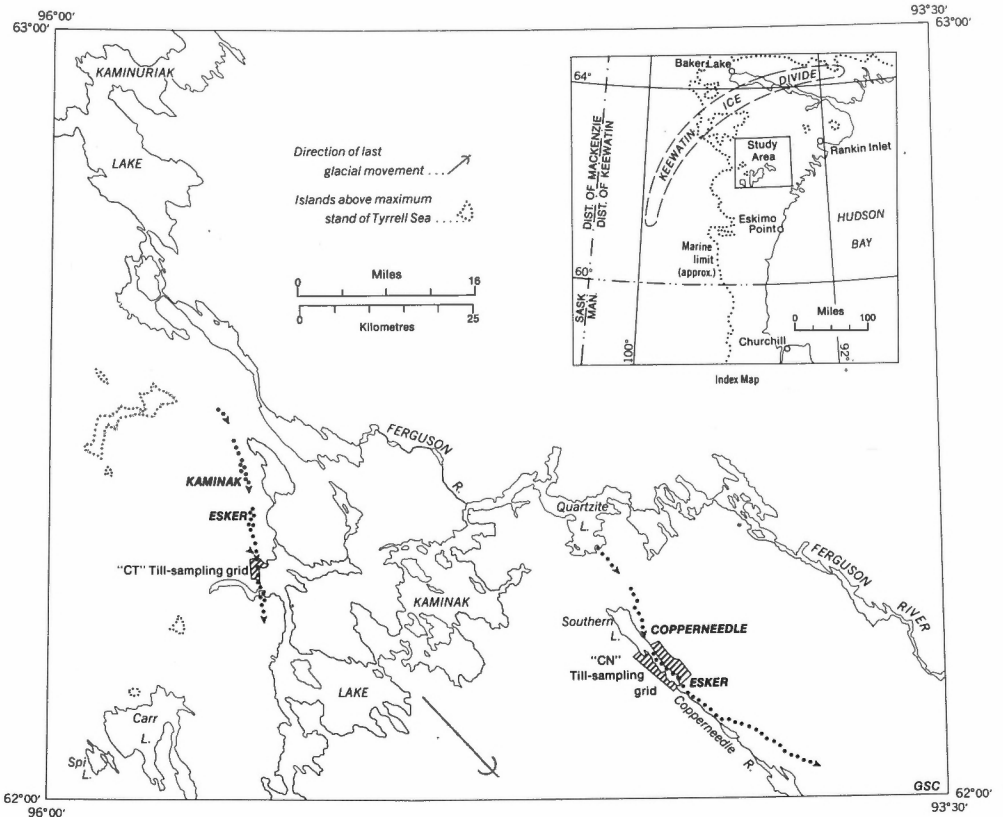


Figure 1. Location map showing eskers sampled and extent of marine transgression.

Surface till in the Kaminak area is primarily clayey and red. Where extensively modified by wave action or by frost-churning processes, it is sandy and grey to tan. The red colour results from a high content of clay- and fine-silt-sized, glacially ground specular hematite as well as from red rhyolite, slate, and sandstone fragments derived from outcrops of the Dubawnt Group, west of the area. In one section, the red surface till rests on a sandy, grey to pink till containing considerably less clay but with pebble composition similar to the red till (Shilts, 1971). Lee (1959) noted rare striations indicating that a phase of southward ice flow preceded the latest southeast phase; perhaps the lower grey, sandy till was deposited during the southward flow phase.

ESKER CHARACTERISTICS

Kaminak Esker: This esker forms the northwest shore of Kaminak Lake and extends north from the lake (Fig. 1). It can be traced discontinuously for approximately 20 miles, but only the southernmost 10-mile section was sampled. In plan, the esker is fairly straight and trends almost north-south at an angle of about 40 degrees to the last regional direction of ice flow, which was 140 degrees. It is presumed to have been built by a stream flowing south, although no current structures that could confirm the direction of flow were observed. The terrain on either side of the esker is flat, with isolated bedrock knobs protruding through drift cover consisting of till covered, in places, by marine sand and silty clay. The Kaminak Esker has two large deltaic beads in the sampled portion. They are both pockmarked by kettle-like depressions, indicating that they were built into the Tyrrell Sea, but in contact with the ice.

The wave-washed surface of the Kaminak Esker is covered by a thin boulder and cobble lag (Pl. 1) which is generally little thicker than the mean diameter of the largest clasts. Although the texture of the lag deposit varies from cobbly to bouldery, the portions underlain by granitic bedrock are strikingly bouldery compared to those underlain by other rock-types (Pl. 2). The esker can be seen in contact with bedrock only at its extreme southern end and in the beaded, discontinuous portion north of Kaminak Lake. The Kaminak Esker lies across nearly all the prominent rock types of the Kaminak map-area (Davidson, 1970).

Copperneedle Esker: The Copperneedle Esker is different from the Kaminak Esker in several respects (Fig. 6). Its length is more than 30 miles, measured from Quartzite Lake to where it disappears near Hudson Bay, but only the northernmost 20-mile segment was sampled. It lies in a broad trough formed on Archean mafic volcanics (greenstone). The esker trends parallel to the latest ice movement (southeast), has many meanders, is generally sharper-crested and two to three times higher than the Kaminak esker. Throughout its length it is flanked by patchy, sandy till with a dense cover of large surface boulders. In the vicinity of Southern Lake it is flanked by ribbed moraine (Prest, 1968). Bedrock with many small gossans is commonly exposed within the trough. Table 1 summarizes the differences and similarities of the Kaminak and Copperneedle Eskers.

Table 1. General Characteristics of Kaminak and Copperneedle Eskers

Characteristic Feature	Kaminak Esker	Copperneedle Esker
Plan view	straight	meandering
Trend	40° to regional ice movement	parallel to regional ice movement
Topographic situation	crest stands above surrounding till-marine plain	located in a trough 1 mile wide and 150 feet deep
Surrounding sediment	clayey, red till with, locally, heavy marine silty clay and sand cover; little bedrock outcrop	sandy, thin till with many boulders on surface; much bedrock outcrop
Associated glacial recessional features	two possible ice-contact marine deltas; no moraines; beaded at one point	well-developed, ribbed moraine; one possible ice-contact marine delta
Underlying bedrock	granodiorite, Archean "greenstone", Hurwitz quartzite, Hurwitz basic volcanic, Hurwitz conglomerate; two Zn - Cu showings one mile east of esker	Archean "greenstone", diabase dykes; numerous gossans and nickel showing within half a mile of esker
Permafrost structures	frost contraction cracks at right angles to trend; tundra polygons; occasional mud boils in clayey sediment near crest; rotation slumping of coherent, frozen blocks on sides (see Pl. 3)	frost contraction cracks at right angles to trend; tundra polygons; slumping of coherent blocks on sides
Marine modification	rounded and armoured with cobbles and boulders; marine fossils rare to absent; boulder lag particularly heavy where esker lies on granodiorite and Hurwitz outcrops	Erosion by wave action less severe than Kaminak Esker; cobble-boulder lag at surface, marine fossils common in upper 1 m of sediment. Relief sharp southeast of Southern Lake
Soil development	well-developed soil horizons with oxidation to > 80 cm; thin A horizon; infrequent buried profiles on flanks	thick A horizon in places; well-developed soil horizons; oxidation and carbonate leaching to > 1 m; rare multiple buried profiles on flanks

SAMPLING TECHNIQUES

Eskers

Samples were collected from the base of 40 to 80 cm-deep holes dug as near to the crests of the eskers as possible (Pl. 4). Sample holes were approximately 0.2 mile apart on the Copperneedle Esker and 0.1 mile apart on the Kaminak Esker. Supplementary samples were collected on the Southern Lake portion of the Copperneedle Esker in 1971 at 0.1 mile intervals. At each sample site, any organic material that was present at the surface or in the sides of the hole was carefully avoided. Red-orange, heavily oxidized zones and black manganese-rich zones were also avoided. The sample was chosen so as to include as few pebbles and as much sand-sized debris as possible; samples weighed three to five pounds and were easily scooped by hand from fresh sides of the sample hole.

Sample traverses were on foot from fly camps positioned and moved along the esker by Bell 47 G-2 and G-4A helicopters.

Till

In 1971 till samples were collected in some areas near each esker where 1970 samples indicated anomalous metal concentrations. Till samples were collected from pits dug in mud boils ("frost boils" in Hornbrook and Allan, 1970; "medallion patches" in Pitul'ko, 1969; "nonsorted circles" in Washburn, 1969; "tundra craters" in Jahn, 1948). These are round to oval, bare to lichen-covered depressions that are usually surrounded by turf ridges (Pl. 5). Mud boils in this area are exclusively developed on poorly-sorted, silt- or clay-rich deposits such as till or fine-grained marine sediment. Sampling pits in the mud boils were dug to depths of 20 to 50 cm and a sample of the fresh pit side was dug out with a hunting knife and placed into a heavy-gauge plastic bag. Three- to five-pound samples were taken near the base of the pit, taking care not to include the heavily oxidized or organic clasts that are commonly churned into the sediment by cryoturbation. This problem is more serious in mud boil excavations than in esker excavations where low plasticity of the gravelly sediment results in minimal cryoturbation effects.

ANALYTICAL TECHNIQUES

Four different fractions of most of the esker samples were separated and analyzed by atomic absorption techniques for Cu, Zn, Pb, Ni, Co, Ag, and Mo (Ag and Mo values are not reported here). Weight percentages of heavy minerals and of the magnetite in heavy-mineral separates were calculated to evaluate the effect of wave action on the concentration of minerals of high specific gravity in the wave-modified portions of the esker. In till samples, the same four fractions and the clay and mica fractions were analyzed for the 7 trace elements.

Fraction no. 1: silt and clay (-250 mesh): All samples were sieved dry through a stainless-steel, 250-mesh (63 μ) screen. The fine material was analyzed by atomic absorption methods after a hot, two-hour, HNO₃-HCl, mixed-acid leach. Esker samples required little preparation before sieving, but some till samples required gentle pounding with an agate mortar and pestle. Care was taken not to crush any of the original particles during disaggregation.

Fraction no. 2: methylene iodide heavy minerals (s.g. >3.3): Sand was separated from the coarse fraction by sieving through a 60-mesh (0.250 mm) stainless steel screen over a 120-mesh (0.125 mm) screen. The material on the 120-mesh screen consisted almost wholly of monomineralic sand grains. This separate was placed in methylene iodide (s.g. \approx 3.3) in a separatory funnel and the minerals > 3.3 s.g. were collected. The heavy fraction was carefully combed with a hand magnet to remove magnetic grains (mostly magnetite). Before grinding, the weights of the light minerals, heavy minerals and magnetite were determined, and simple weight percentages for total heavy minerals (of the total sand fraction) and for magnetite (of the total heavy mineral fraction) were calculated. The heavy minerals minus the magnetite were ground to -250 mesh with an agate mortar and pestle and the powder was analyzed as above.

Fraction no. 3: heavy rock fragments (s.g. >2.85; diameter + 60-mesh - 18-mesh): Coarse sand and pebbles were placed on a nested set consisting of an 18-mesh (1 mm) stainless steel screen over a 60-mesh (0.250 mm) screen. The material retained on the 60-mesh screen was largely polymineralic (rock) fragments. This separate was placed in bromoform (s.g. \approx 2.85) in separatory funnels, and the heavy rock fragments recovered. The heavy fraction was ground for 10 minutes in a two-inch alumina-ceramic container in a ballmill, to -250 mesh. The resulting powder was analyzed in the same manner as for the separates described above.

Fraction no. 4: magnetic minerals: Magnetic minerals were removed by hand magnet from the +250-60-mesh portion of the Copperneedle Esker and from selected till samples. The magnetic grains were further concentrated by passing the magnet a few millimetres over the original magnetic separate to eliminate weakly magnetic grains or non-magnetic grains trapped by magnetite clusters. The samples were ground to -250 mesh with an agate mortar and pestle and analyzed as above.

Fraction no. 5: clay minerals (< 2 μ diameter): Clay minerals were obtained by centrifuging dry-sieved, -250-mesh separates in an International Model UV centrifuge, using 100 ml tubes and an 8-place, International no. 240 head. With this apparatus, the standard centrifuge time/particle size tables in Jackson (1956) may be used to obtain a -2 μ separate. Each sample was centrifuged twice in a standardized, very weak solution of sodium hexameta-phosphate ("Calgon") in distilled water. The decantate from each sample was then centrifuged for a time sufficient to produce a sediment containing primarily phyllosilicate particles of from 0.3 μ to 2 μ in diameter. Only till samples from this particular study were centrifuged, as the -250-mesh portion of eskers is generally too small or contains too little -2 μ material for effective recovery and analysis. The clay minerals were analyzed by atomic absorption methods identical to those for other samples.

Fraction no. 6: bromoform separates (mostly micas and amphiboles): The -60 and +120-mesh sand grains from selected till samples were separated in bromoform, and methylene iodide separation was performed on the total bromoform separate. After removal of magnetic grains, the lighter part of the total bromoform separate (s.g. = 2.85 - 3.3) consisted entirely of silicate minerals. Micas and amphiboles comprise more than 90 per cent of this fraction. The 2.85 - 3.3-s.g. fraction was crushed and analyzed in the same fashion as the heavy rock fragments.

EFFECT OF THE PERMAFROST ENVIRONMENT ON TRACE-ELEMENT VALUES

Interpretation of geochemical data from surface sediments collected from permanently frozen terrain is complicated by the fact that, at the maximum depth of summer thaw, an impermeable frozen-sediment surface at a depth of 1.0 to 1.5 m bars normal downward groundwater circulation. The effect of this barrier on the weathering of eskers is not great; they appear to weather from the surface downward, developing soil profiles as well-defined as those developed on eskers in temperate regions. This is largely because 1) the eskers are very permeable, allowing water to flow readily through their thawed zones and 2) they contain little fine sediment so that, even during the short times that they are saturated, sediment plasticity is low and it does not flow, even on steep slopes. Soil-forming processes near the esker crest are rarely disturbed except near contraction cracks. Although some cations are undoubtedly carried off in the ground water, clay minerals and secondary Fe and Mn oxides, formed by the oxidation and hydrolysis of labile minerals near the surface, accumulate within the profile and scavenge cations that are released by further weathering.

The -250-mesh fraction of eskers has a much higher ratio of minerals with high exchange capacity to minerals with low exchange capacity than does the equivalent fraction of till. Figure 2 clearly illustrates that, in eskers, the ratio of phyllosilicates (001 reflections at angles less than $12.6^{\circ}2\theta$) to quartz and feldspar is visibly greater than the same ratio for nearby till. The very strong 14\AA reflection in the esker sample probably represents the first-order chlorite peak as well as vermiculitic and mixed-layer clays derived from weathering of less-stable ferro-magnesian minerals. It should be noted that several esker and till samples were X-rayed and that the

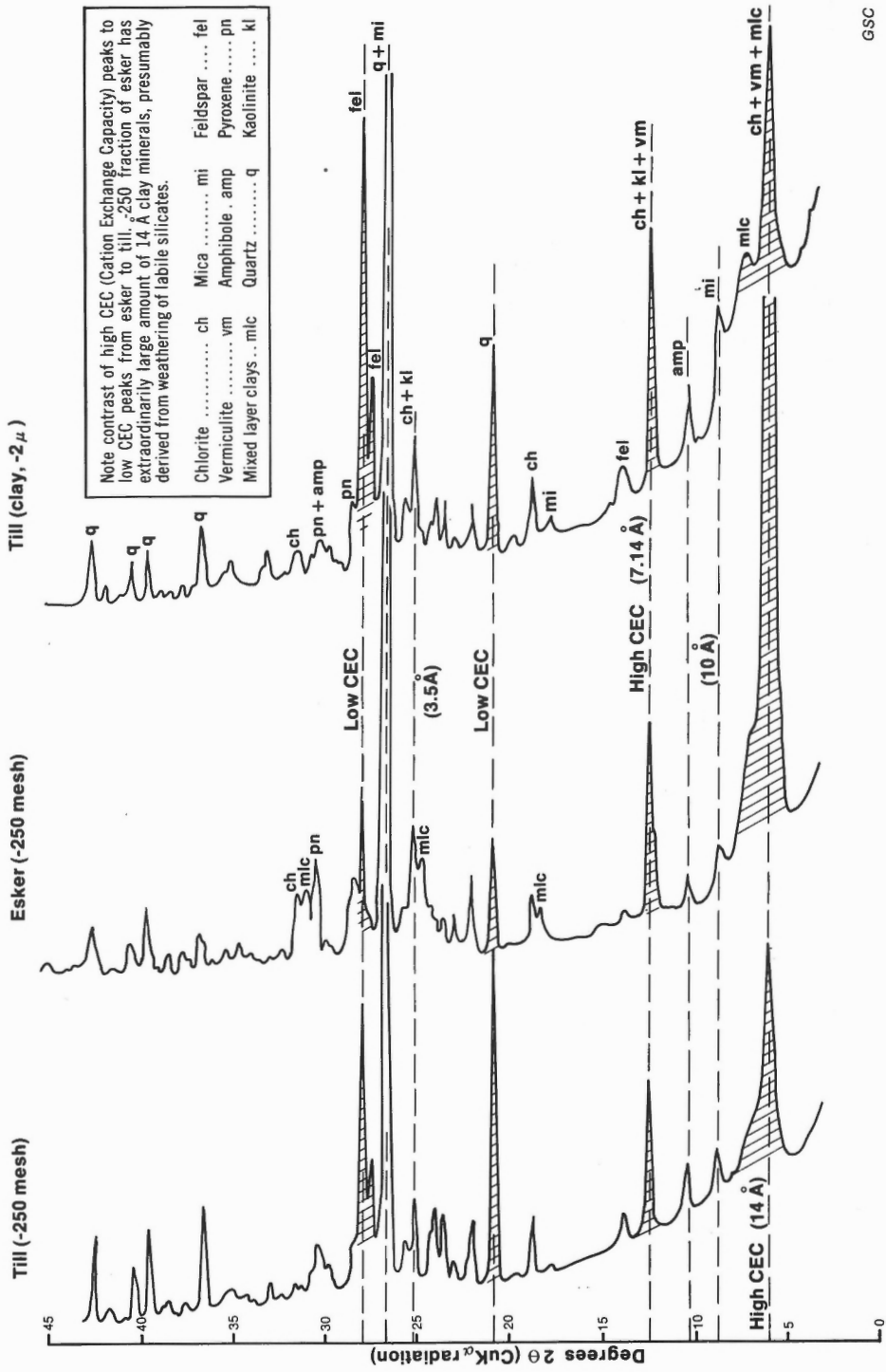


Figure 2. Smoothed x-ray diffractograms of fine fractions of typical till and esker samples from the vicinity of Southern Lake.

examples presented are typical. Glycolation failed to produce any expansion of 14Å or mixed-layer peaks and, therefore, montmorillonite and expandable vermiculite are considered to be scarce or absent.

In addition to the greater amount of high-exchange clay material, most esker samples contain visible amounts of yellow-orange, hydrated iron oxides that may add to their scavenging ability. Thus, the high background values and great contrasts among -250-mesh separates from Keewatin eskers are inferred to be largely due to the greater amount of secondary phyllosilicates and iron oxides retained within the sand-gravel matrix of esker deposits. In the high-energy, glaciofluvial environment it is unlikely that sandy, gravelly eskers would have originally contained much silt and clay (-250-mesh) making it logical to assume that any fine-grained component found in them now would be largely a product of weathering.

Till, and other poorly sorted sediments containing appreciable amounts of silt and clay, does not behave like eskers or other sand and gravel when saturated. It is very plastic and flows readily on slight slopes because groundwater does not flow through it too readily, keeping it saturated during most of the thaw season. If till in the thaw zone were saturated to the surface, it would move as mudflows down the slightest slopes. However, surface desiccation and vegetative cover form a rigid surface crust, and the saturated sediment is confined between permanently frozen sediment below and the rigid layer above. Pressures caused by the hydrostatic head built up in this "perched" hydraulic system (Fig. 3a) cause the saturated sediment to be extruded to the surface through points of weakness in the upper rigid layer (Pl. 6). Surface runoff carries away much of the silt and clay from extruded sediment leaving sand and rocks that contribute to the thickness of the desiccated layer. Points of extrusion are referred to here as mud boils (Fig. 3b). The sandy-cobbly residue left after the removal of silt and clay-sized particles is referred to here as the carapace. Its average maximum thickness in the region of the Kaminak and Copperneedle eskers is 40 cm. The maximum depth of carapace development apparently is reached when it becomes too rigid and strong to be penetrated by underlying saturated sediment under hydrostatic pressure.

Mud boils, then, are diapiric structures that are active only during the thaw season. Although not actually observed during the study, diapiric activity may increase in the autumn when the surface begins freezing downward, expelling water from the freezing sediment and causing hydrostatic pressure to increase.

Jahn (1948; as summarized in Fairbridge, 1968, p. 1099-1100) has proposed substantially the same processes for the formation of "tundra craters". It is assumed that tundra crater is another term for mud boil.

The important effects of mud boiling on the soil development and chemistry of poorly-sorted surface sediments are twofold:

- 1) Normal soil horizons are quickly disrupted or destroyed by the diapiric activity in active boils. As the carapace is loaded by extruded sediment, it sinks into the plastic sediment, and its base is reworked into the plastic material. This process creates a continual recycling of the sand and coarser portions of till; that is, virtually all the coarser material in the active zone is brought to the surface and buried many times during its transport downslope. The result of this repeated exposure to oxidation at the surface is that the labile minerals (sulphides, carbonates, etc.) are removed

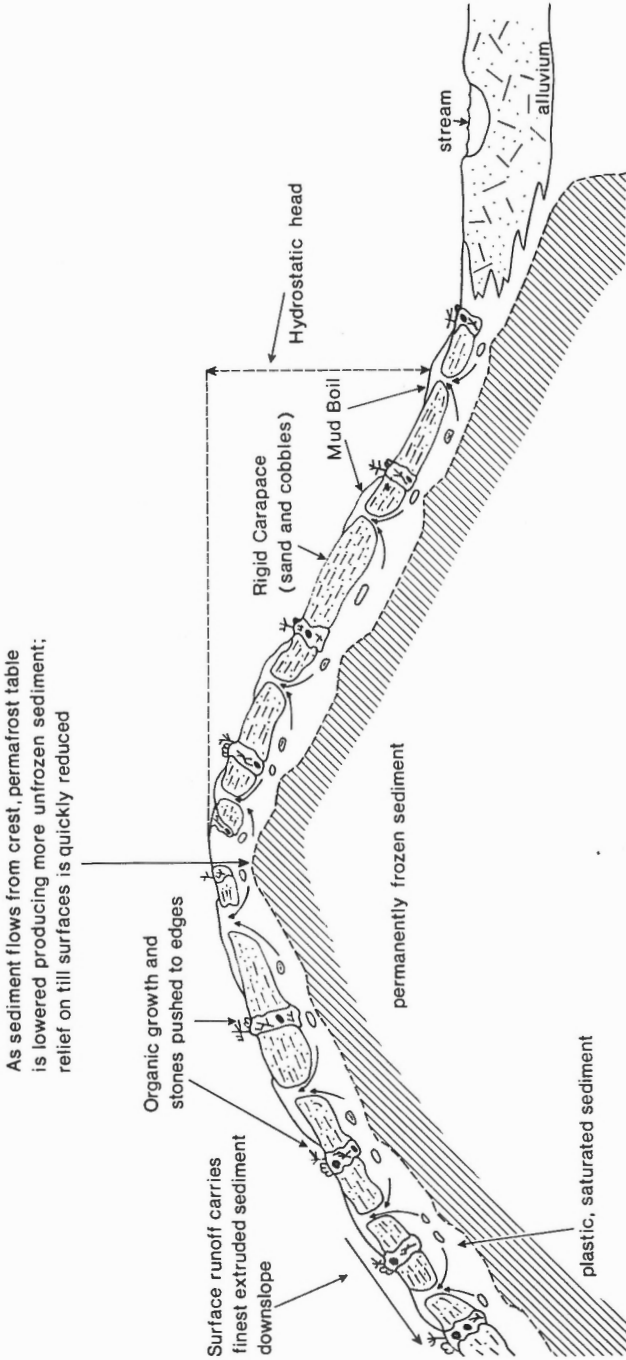


Figure 3. Idealized diagrams depicting proposed mechanisms of formation of mud boils.

3a. Idealized cross-section through a till drumlin. Diagram illustrates how slopes are rapidly flattened in permanently frozen terrain (cryoplanation) and how fresh, unfrozen till is continuously produced by lowering of frost line near crest of hill.

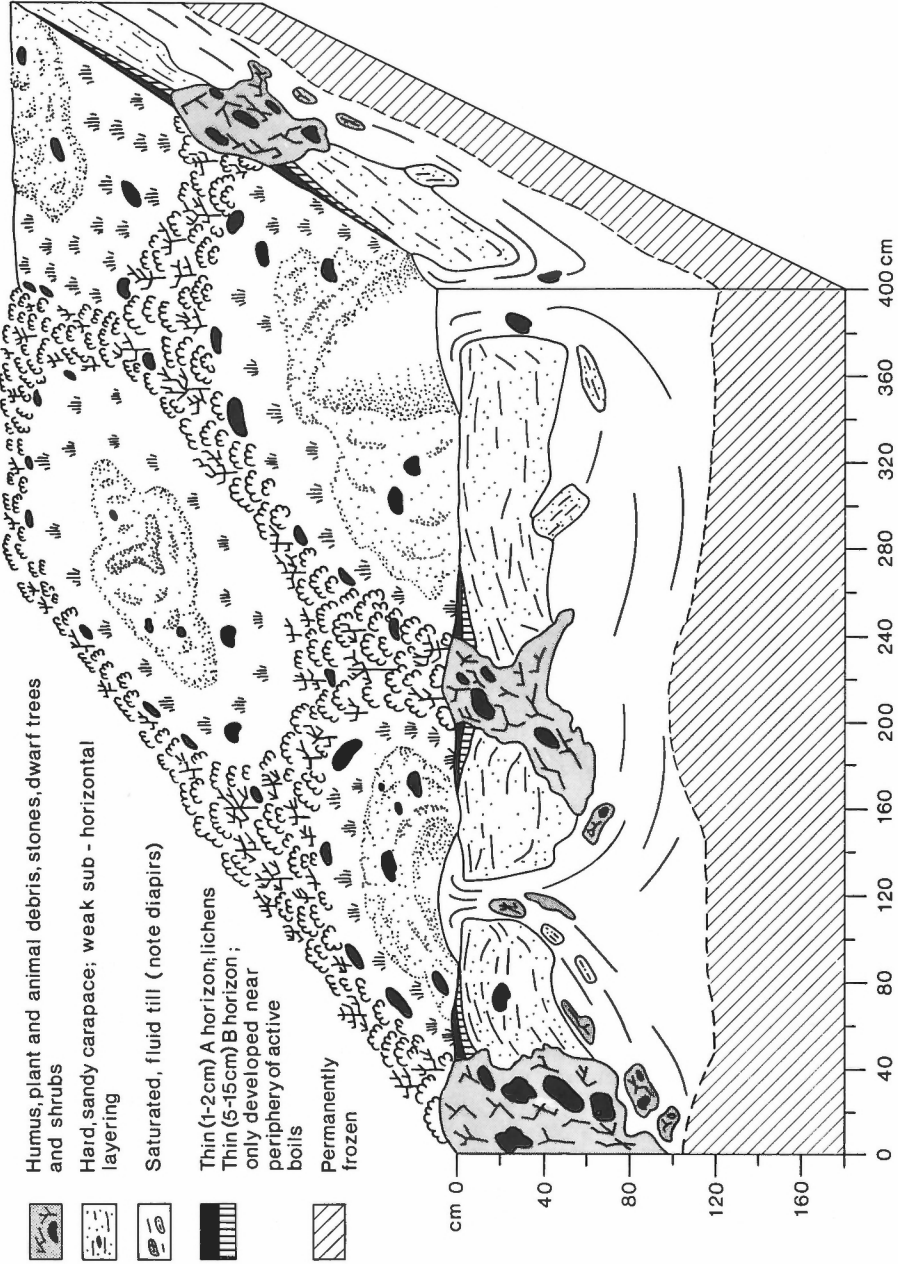


Figure 3b. Block diagram of mud boils showing components described in text.

from the active-zone sediment. Therefore, trace-element analysis of heavy-mineral suites reflects nothing more than the metal concentrations of the stable minerals, primarily silicates. Because of the poor drainage through sediment involved in mud-boiling, it is probable that humic acids and acids produced as by-products of sulphide weathering also contribute to the complete destruction of labile minerals within the active zone.

2) The secondary oxides and primary clays that would scavenge at least some of the cations released by weathering are rapidly carried away to be deposited in or transported through drainage lines and are not retained in the sediment. Thus, not only are labile minerals such as sulphides and carbonates commonly not present in otherwise "fresh" looking till, but their secondary weathering products such as iron and manganese oxides are largely absent as well, implying an intense chemical and physical "leaching" of the active zone.

By referring to data presented below one can see that, although heavy mineral trace-element values for eskers and adjacent tills are broadly comparable, the background concentrations of trace metals in -250 mesh material in eskers are roughly six to ten times those for adjacent tills, due to the predominance of secondary weathering products in the esker samples. These are largely secondary clay and iron and manganese oxides that have filtered down and become trapped in interstices of the sand and gravel in the C-horizon of the esker.

The statements regarding the basic contrast between till and esker chemistry may be applied to other sediments as well. Beaches, ice-contact stratified drift, deltas and other gravelly deposits also have high background values. Marine silty clays and till have much lower values because of the predominance of quartz and feldspar in the -250-mesh fraction caused by the selective removal of clay-sized minerals by surface runoff after extrusion of these sediments to the surface.

ESKER TRANSPORT AND ANOMALIES

Esker Sedimentation

Eskers are usually built in tunnels or open channels in a glacier (for exceptions, see Howarth, 1971). Although they often appear continuous and similar in plan to modern streams, their continuity is usually only apparent. Most eskers are probably built in short segments by streams extending a few tens of feet to a few miles back from the ice margin. As the ice margin retreats, the stream segment building the esker retreats, maintaining more or less constant length by extending itself headward.

In Keewatin, ice marginal retreat is thought to have taken place largely during the summer (B.C. McDonald, pers. comm., 1972) so that spacing of identifiable segments can be related to rate of yearly retreat.

The implication of the segmented sedimentation hypothesis of esker formation is that, unlike normal drainage systems where sediment at any point is partially derived from points upstream to the limits of the drainage basin, sediment at any point in a segmented esker can only be derived from as far as the head of the short stream segment associated with its formation. Thus, although an esker may be traceable as a continuous ridge for 100 miles,

if it is composed of sedimentation segments that average only five miles in length, five miles is the maximum distance of transport that may be expected. Therefore, a trace-element source 20 miles downstream from the esker's upstream end would be detectable only to the end of the segment that was built across it, that is, no further than a point 25 miles downstream from its upstream end.

RESULTS

Kaminak and Copperneedle esker samples have anomalously high trace-element contents that correspond either to known mineralized zones or to contact zones of one bedrock type with another. Other anomalies may be related to undiscovered sources or to extensions along strike or faults of sulphide showings a mile or more away from the eskers.

It is important to realize that, in most cases, with the sampling and analytical methods employed, there is no way of determining whether an anomaly is related to material eroded directly from the bedrock or to glacially transported debris lodged beneath or in the ice. That a significant proportion of the sand and cobble-size fractions of Kaminak Esker samples was not derived from underlying bedrock is apparent from high proportions of specular hematite and red volcanic rock fragments in the samples. These components were transported by the glacier from sources at least 60 miles from any portion of the esker. The amounts of far-travelled clasts are not so high in the Copperneedle Esker, but rock types - particularly granodiorite - that crop out beside the greenstone trough in which it lies, are common.

Figures 4 through 8 summarize the trace-element contents of various fractions of till and eskers in the Kaminak and Copperneedle Esker study areas. Trace-element concentrations recorded for the eskers in Figures 4 and 6 are rolling averages, derived at any one sample point by dividing the sum of the value for the sample point (S), the sample point immediately "upstream" (S_u), and the sample point immediately "downstream" (S_d) by 3. Thus, each value is $\frac{S_u + S + S_d}{3}$; values at upstream ends of eskers are

$\frac{S + S_d}{2}$ and downstream ends are $\frac{S_u + S}{2}$. The rolling mean technique generally

smooths out the curves, but it has the undesirable effects of involving at least three samples in every anomaly (see discussion of cobalt values near sample E173) and of sometimes reducing anomalous values to one-third of their true values. In spite of the disadvantages, the rolling mean techniques gives results that can be readily interpreted by inspection.

Kaminak Esker and Till: Geochemical Data

Trace elements in heavy minerals: Very little information can be derived from the heavy-mineral data as there are but a few small anomalies. The probable cause of the featureless curves (Fig. 4) is the almost total lack of any sulphide minerals within the seasonally thawed zone of the Kaminak Esker, a phenomenon typical of sediment from the active zone of till and eskers throughout the Kaminak Lake region. The apparent cobalt anomaly near sample

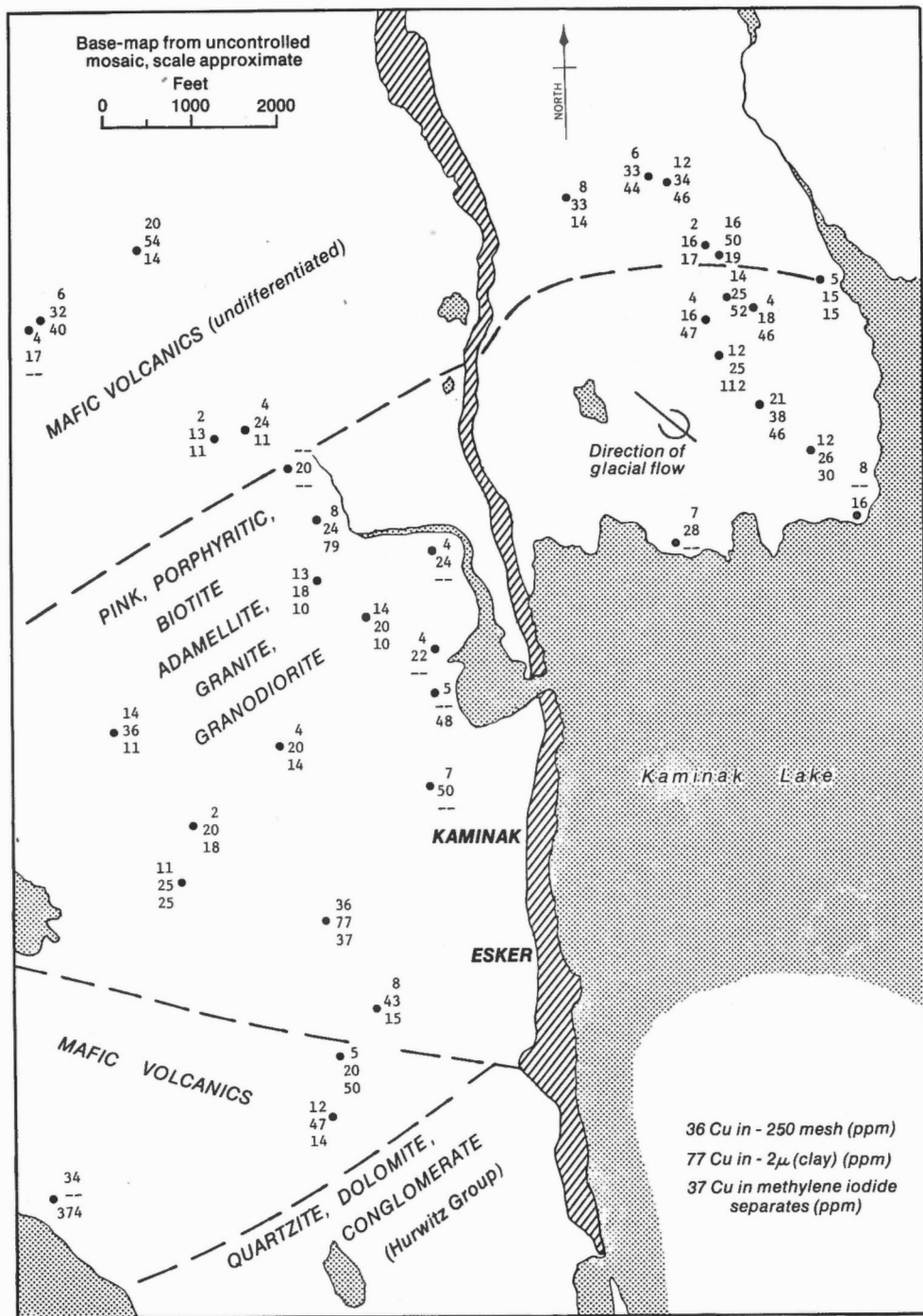


Figure 5a. Copper concentrations in various fraction of till collected from the "CT" grid, adjacent to the Kaminak Esker.

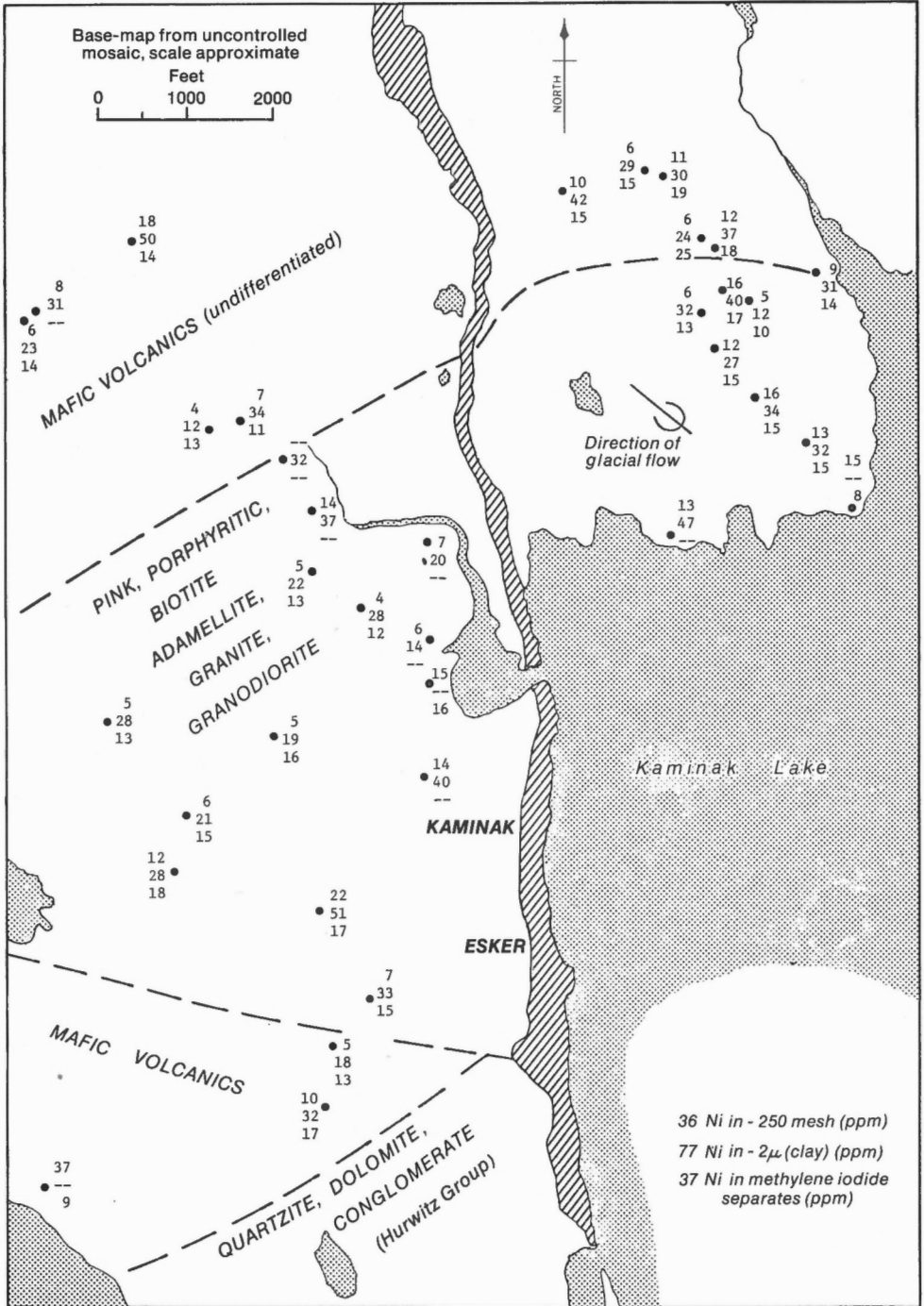


Figure 5b. Nickel concentrations in various fraction of till collected from the "CT" grid, adjacent to the Kaminak Esker.

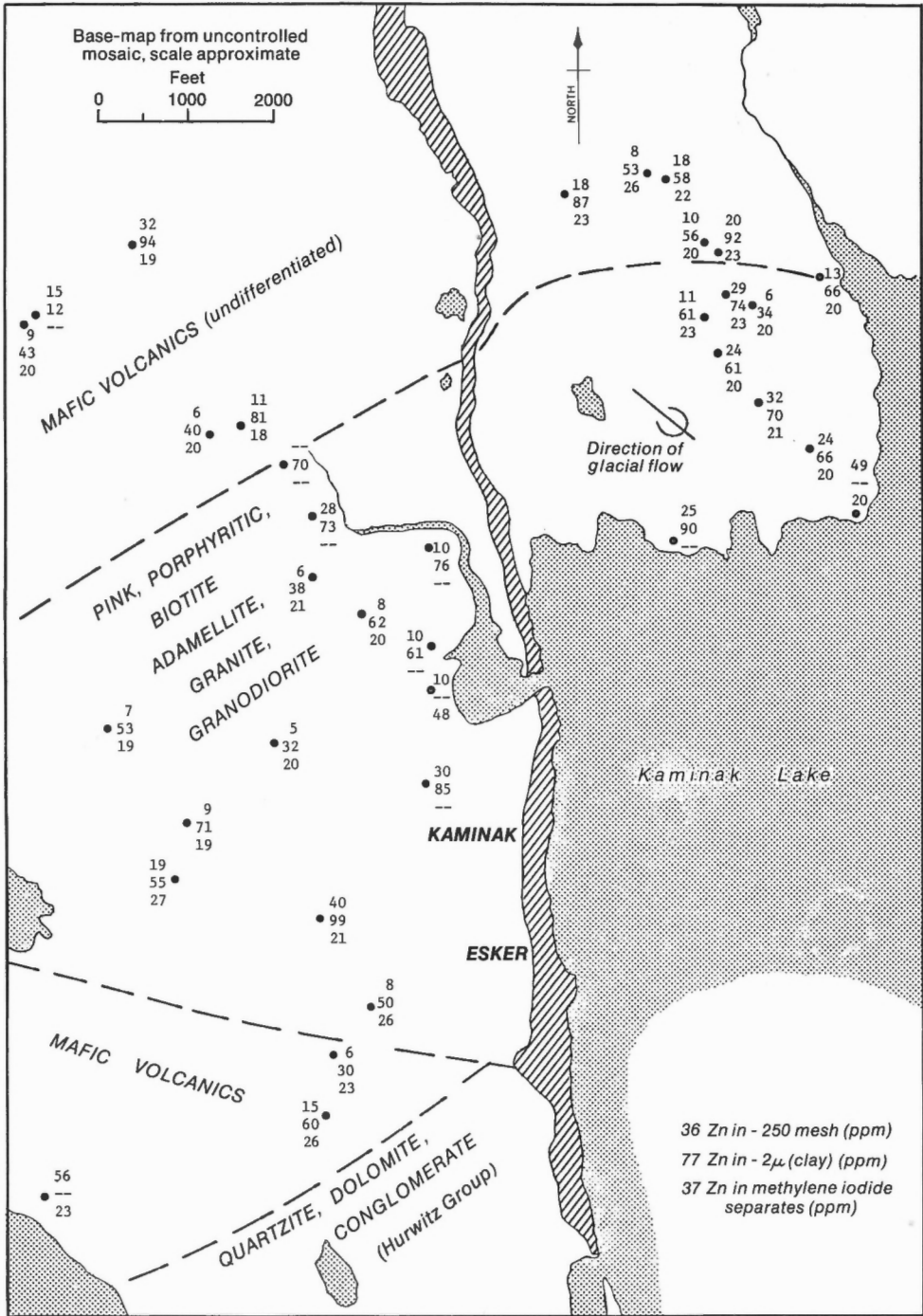


Figure 5c. Zinc concentrations in various fraction of till collected from the "CT" grid, adjacent to the Kaminak Esker.

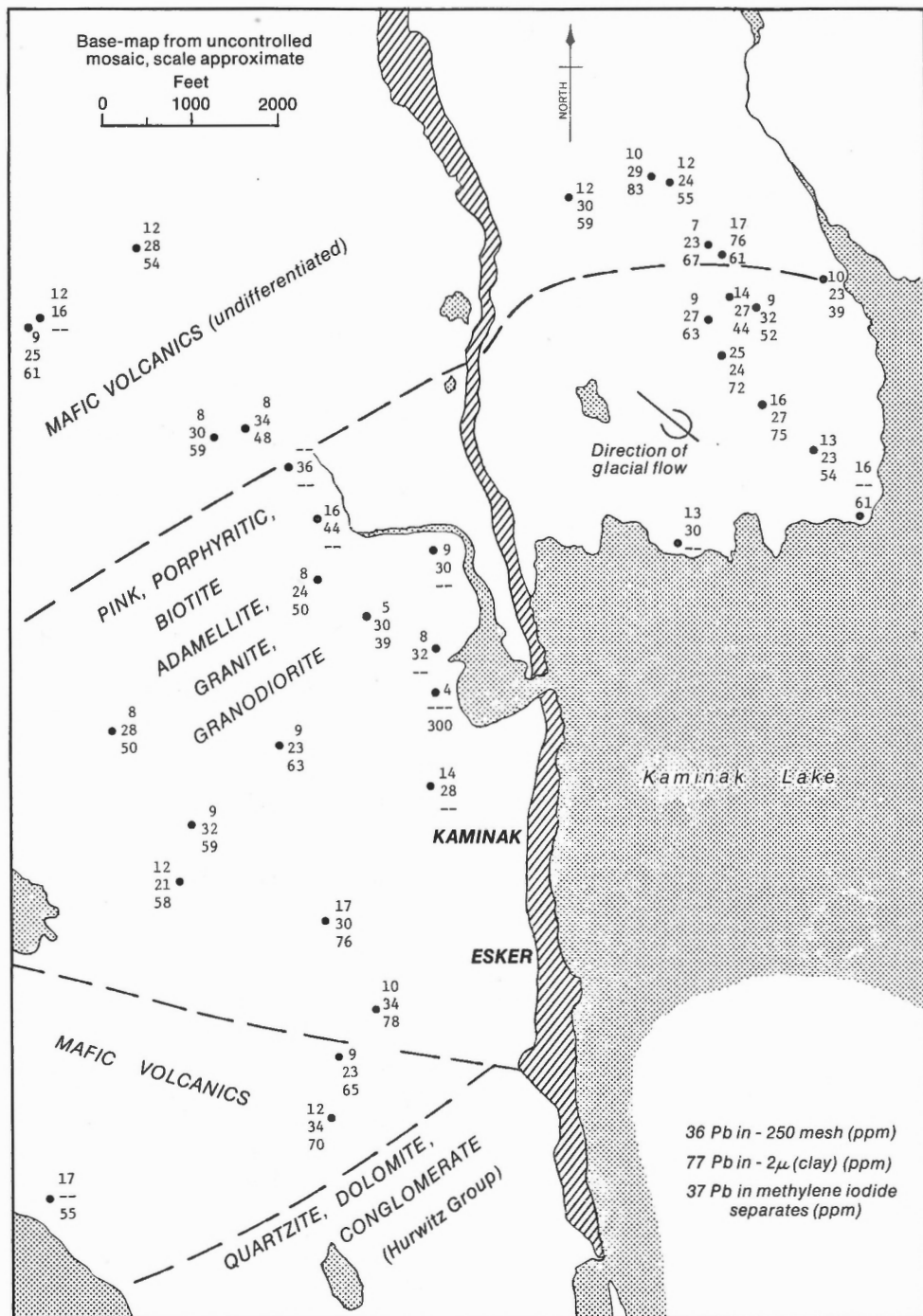


Figure 5d. Lead concentrations in various fractions of till collected from the "CT" grid, adjacent to the Kaminak Esker.

E173 is caused by a single high cobalt value of 130 ppm with values of 20 ppm and 8 ppm on the upstream and downstream sides, respectively. The subdued peak in the copper curve includes three very low copper values (20 to 30 ppm) and probably does not reflect significant mineralization. A high lead value occurs where the esker passes over the volcanic member of the Hurwitz Group.

-250 mesh, trace elements: Except for lead, trace-element concentrations of -250-mesh material are significantly higher than those for heavy minerals (Fig. 4). This is thought to be a result of the scavenging of cations by secondary oxides and clays which comprise the bulk of -250-mesh material in eskers (see discussion above). The scavenged cations were presumably released by oxidation of sulphides which, in unweathered samples, would have occurred in the heavy mineral fraction.

Copper and lead and, to a lesser extent, zinc show small but sharp increases over the "upstream" and "downstream" margins of a small granodioritic body which is in contact with mafic volcanics and with Hurwitz Group sediments, respectively. The "upstream" point of increase in these elements is coincident with a strong concentration of granodioritic boulders on the surface of the esker (Pl. 2). A sharp zinc anomaly and smaller nickel and copper anomalies also occur in the esker over greenstone about one mile west, along strike, from a previously known chalcopyrite-sphalerite mineralized zone.

Several samples of the till and marine sediments that form the surface on either side of the esker in the vicinity of the granodiorite-greenstone contact were collected (Fig. 5). Marine sediments are so common in this region that samples of till were difficult to collect (compare Pl. 3 and Fig. 5). No obvious correspondence was found between high trace-element values for till and peaks in the esker curves. Methylene iodide separates from till, however, have lead values that are in the 65 ppm to 80 ppm range - the highest in the Kaminak Lake area.

Trace elements in rock fragments: Trace elements derived from heavy rock fragments show very little variation from one end of the sampled portion to the other.

Copperneedle Esker and Till: Geochemical Data

Trace elements in heavy minerals (s.g. > 3.3): Both copper and cobalt show considerable variation in the vicinity of Southern Lake and south along the Copperneedle River (Fig. 6). Lead, zinc, and nickel (and copper-cobalt north of Southern Lake) show little variation from sample to sample. The origin of high copper values near the southern end of the sampled portion is unknown. There are several chalcopyrite occurrences one to two miles northeast of the esker in that vicinity (Davidson, 1970). Although the rolling mean makes these peaks appear as significant anomalies, they are, in reality, single-sample anomalies, and the concentrations were determined on very small samples. The high values are possibly a result of sample-preparation or analytical error.

The copper and cobalt anomalies that occur in the segment of the esker that lies in Southern Lake are supported by -250-mesh anomalies, and it is assumed that they relate to presently unknown mineralization.

-250-mesh; trace elements: The fine fraction of the Copperneedle Esker has provided some well-defined and important anomalies. Copper, nickel, zinc and cobalt all have similar patterns from the esker segment in Southern Lake southeastward to the final sample point. The source of the high metal contents in the island segment is unknown but may tie in with numerous gossans and relatively high values that were measured in till on the northeast side of Southern Lake.

The next anomaly to the south, near the southeast end of Southern Lake, is closely linked with copper-nickel mineralization which occurs 200 to 300 feet southwest of the esker and has been drilled extensively. Till anomalies (Fig. 7) are also strong near this mineralized zone. Many highly oxidized, formerly sulphide-bearing boulders were noted on the surface of the esker where trace-element values are high.

Trace elements in magnetic fraction: Copper, nickel and cobalt concentrations are high in the island segment of the Copperneedle esker. These high values correspond to anomalies noted for the -250-mesh and heavy mineral fractions. The rest of the magnetite curves, however, are relatively featureless except for high zinc values near the start of the esker.

Trace elements in rock fragments: The rock-fragment curves are largely featureless and, except for copper in the island segment show no peaks that could be considered anomalous in the Copperneedle Esker.

The strong anomalies in the Copperneedle Esker and the good correlation between till and esker anomalies in the vicinity of a known showing of copper-nickel mineralization are encouraging indications of the effectiveness of these sediments as sampling media capable of reflecting "transported" anomalies. The fact that anomalies drop off within a short distance downstream is probably not so much a function of the dilution of ore-bearing minerals downstream as it is of segmented sedimentation in eskers.

Distribution of Trace Elements in Various Fractions

Figures 8a through 8d show how trace elements are distributed in various fractions of till in the vicinity of the Southern Lake nickel showing. It is readily apparent from these diagrams that trace-element values are derived not only from ore minerals such as sulphides, but from silicate minerals and rock fragments as well. This might indicate that, in this region, an ore occurrence may be surrounded by country rocks whose silicate minerals are rich in the principal cations of the ore. If this proves to be the general case (it has been tested successfully in other areas of sulphide mineralization in the Kaminak Lake area) it will considerably increase the effectiveness of drift prospecting using either eskers or till because target areas will be much larger than the relatively small sulphide bodies. Table 2 summarizes corroborating data from another test site near Carr Lake.

Weight Per Cent of Heavy and Magnetic Minerals

Figures 4 and 6 show the variation of heavy mineral weight percentages expressed as proportions of the total sand-size mineral grains and weight percentages of magnetite expressed as proportions of the total heavy

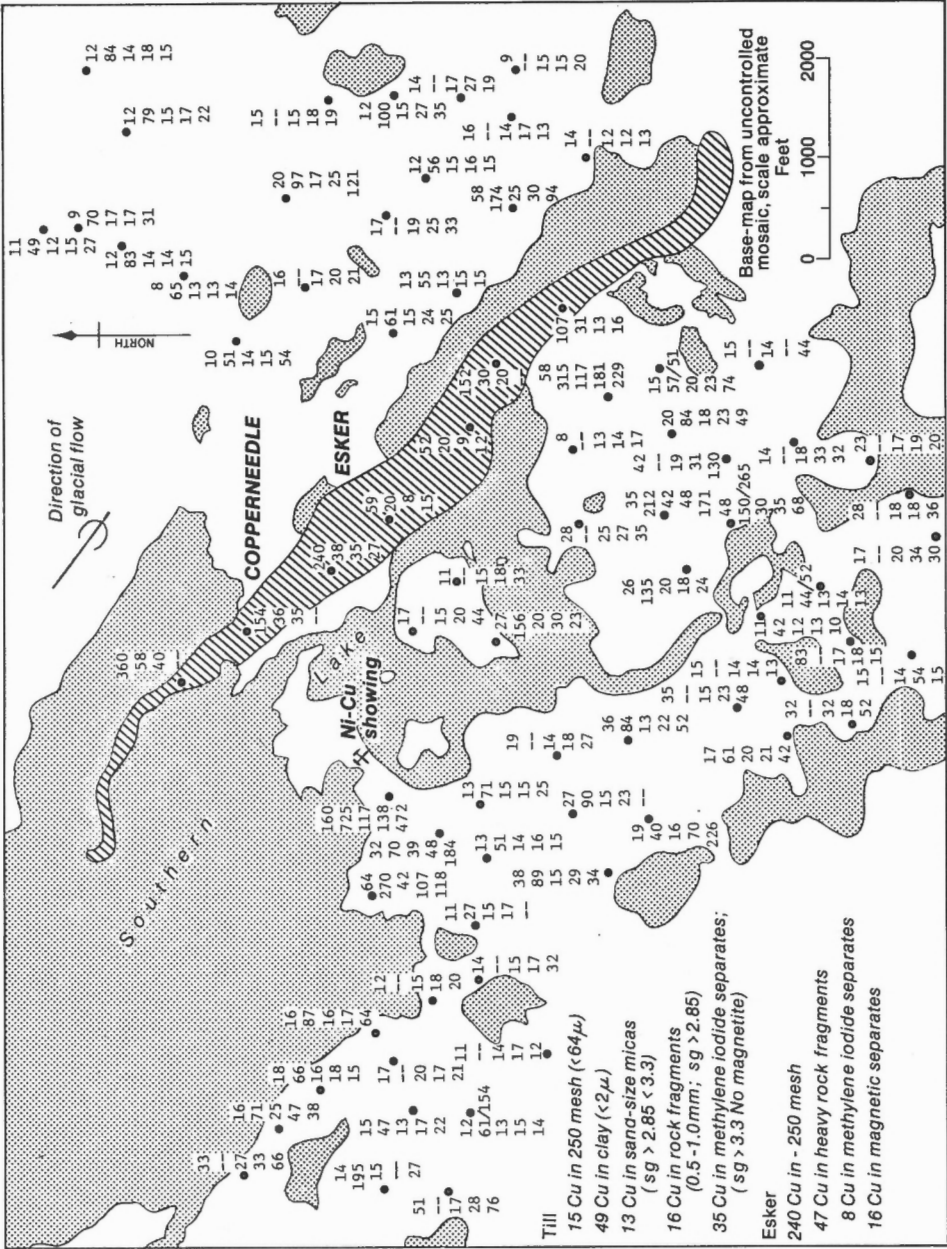


Figure 8a. Copper concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake.

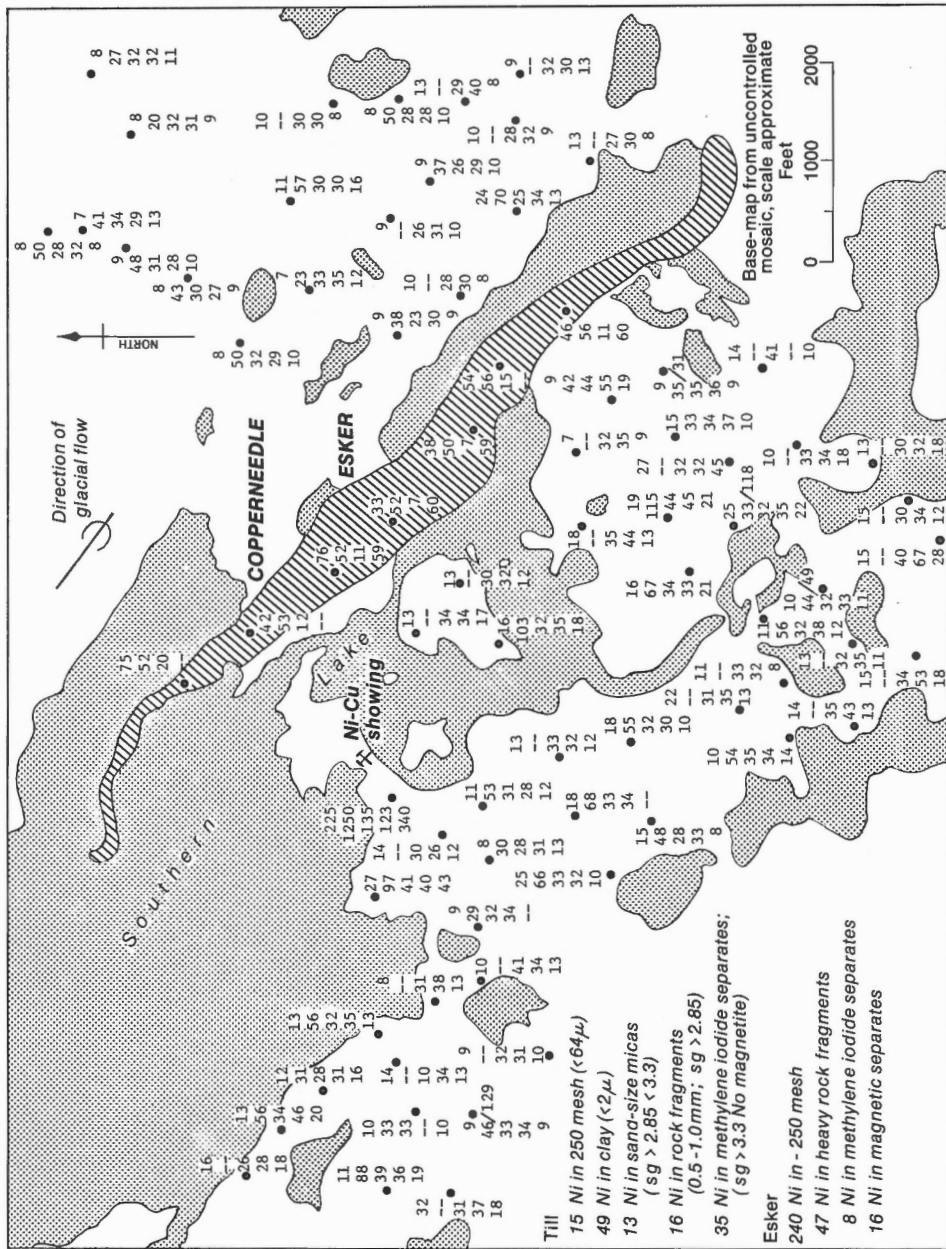


Figure 8b. Nickel concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake.

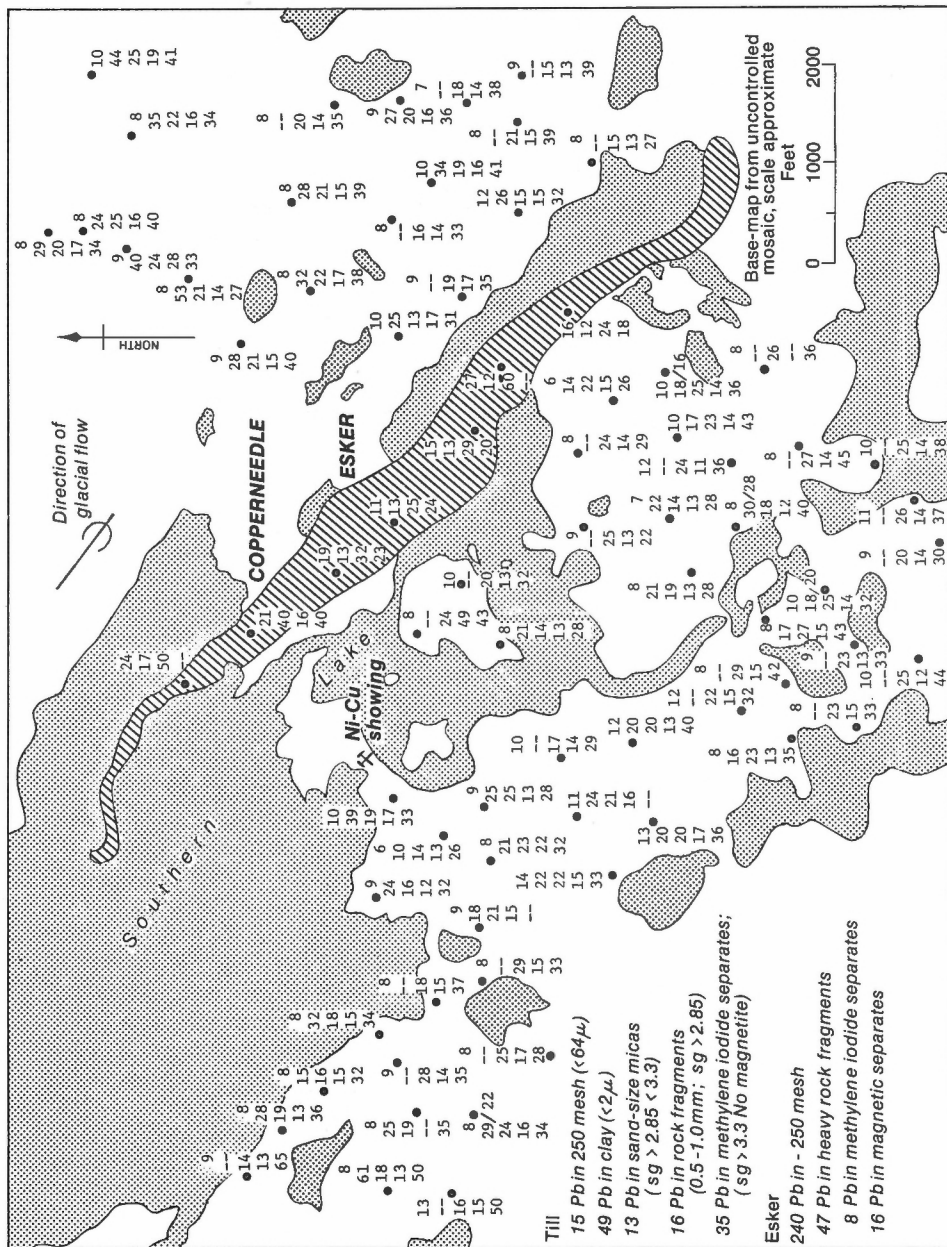


Figure 8d. Lead concentrations in various fractions of till and esker samples in the vicinity of Cu-Ni mineralization on Southern Lake.

Table 2
Trace-element concentrations in various fractions of till

Sample Fraction no.	Copper (Cu)						Zinc (Zn)						Lead (Pb)					
	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
CN 246	160	725	138	117/74	485	25	35	149	37	48/65	32	62	10	39	17	17/21	33	27
CN 146	58	174	30	25	94	19	49	150	55	47	16	50	12	26	15	15	32	23
CN 271	58	181	181	117	229	36	20	20	80	65	23	56	6	6	15	22	26	22
CN 282	48	150	35	30	68	33	29	127	46	50	19	58	8	16	12	18	40	22
C 25A	12	49	20	14	32	12	13	86	48	48	28	76	9	20	24	22	44	48
C 25B	8	70	24	15	14	7	11	120	69	68	130	95	9	40	28	25	50	37
C 25C	23	62	17	12	50	13	40	130	57	48	33	76	14	30	23	33	52	23
C 25D	44	100	12	12	37	24	56	132	47	47	31	78	16	26	26	27	51	51
C 25E	80	382	90	77	56	22	185	1050	224	170	150	115	12	40	25	35	50	36
C 25F	15	97	33	16	37	20	14	120	72	40	88	86	11	39	24	33	63	23
C 25G	10	70	20	2	16	8	10	97	44	41	31	68	9	39	19	24	53	32
Sp Lake	24	133	52	28	26	8	32	220	152	63	175	62	100	700	192	135	230	76

Table 2 (continued)

Sample no.	Fraction	Nickel (Ni)						Cobalt (Co)						Silver (Ag)					
		A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
CN 246	225	1250	123	141/130	340	84	23	87	26	29/29	77	47	0.7	2.4	1.1	1.9/1.0	1.3	1.4	
CN 146	24	70	35	25	13	60	16	24	17	18	22	40	0.8	1.4	1.0	1.4	1.6	2.0	
CN 271	9	-	55	44	19	75	7	-	31	31	29	24	0.5	-	1.4	1.4	1.2	2.0	
CN 282	25	33	35	32	22	74	14	16	20	22	26	68	0.6	0.7	1.1	0.8	1.2	2.1	
C 25A	12	36	33	31	14	58	4	15	20	16	18	64	0.3	0.8	1.4	0.9	0.8	1.6	
C 25B	8	42	34	33	14	67	4	23	23	16	14	48	0.3	1.0	1.4	1.0	0.7	1.8	
C 25C	20	51	35	36	15	82	8	18	21	15	19	33	0.5	1.1	1.3	1.1	0.7	23.3	
C 25D	26	62	-	36	15	111	8	22	-	17	15	87	0.5	1.2	-	1.1	0.7	2.5	
C 25E	9	38	30	29	12	56	5	14	19	13	13	41	0.4	1.2	0.9	1.0	0.7	1.6	
C 25F	9	40	30	27	14	100	4	20	17	12	14	88	0.3	1.0	0.9	0.9	0.7	3.5	
C 25G	9	44	32	31	13	46	3	20	19	14	16	35	0.3	0.7	1.0	0.9	0.7	1.3	
C 25I	6	37	30	29	12	43	5	19	19	14	12	32	0.6	3.6	3.0	1.8	3.0	1.11	

Explanation: CN samples; Till samples near Copperneedle Esker anomalies near south end of Southern Lake;

C samples; Till samples in vicinity of Cu-Zn-Pb showing on Spi Lake (Lat. 62°04' Long. 95°47.5');

A, -250-mesh separate;

B, -2u separate (clay);

C, 18-60-mesh rock fragments - bromoform separate; F, magnetic grains from 60-250-mesh separate.

D, 60-250-mesh grains, bromoform separate, (particles from 2.85-3.3 s.g.);

E, 60-250-mesh grains, methylene iodide separate (particles > 3.3 s.g.);

mineral fractions for the two eskers. Because of their high specific gravities, heavy minerals and magnetite may be concentrated in place by wave or current action or may be left behind by the winnowing action of wind or water. In areas that have been submerged under post-glacial lakes or seas, this can give rise to reworked deposits (Pl. 1) with irregularly distributed pockets that are either rich in heavy minerals or poor in heavy minerals in redeposited, winnowed material. Cachau-Herreillat and LaSalle (1969) have described the effects of such reworking on apparent trace-element contents of -80-mesh (largely sand), unfractionated samples from dunes formed on eskers and from esker sediment collected from the Mattagami Esker of northwestern Quebec. In that esker, formerly submerged beneath Lake Barlow-Ojibway, -80-mesh fractions of dune sands were poor in heavy minerals and gave trace-element values considerably lower than those of underlying esker sands.

Figures 4 and 6 show that heavy mineral percentages (s.g. > 3.3) vary rapidly and rather randomly in the wave-washed upper portions of both eskers. The less variable and lower heavy-mineral concentrations in the portion of the Kaminak Esker lying on granodiorite and Hurwitz rocks are difficult to explain. The smaller amounts of heavies are probably due to fewer heavy species in the Hurwitz and granodioritic rocks than in the surrounding mafic volcanics. The contrast in sample to sample per cent variation may be due to either or both of the following: 1) the presence of members with variable heavy mineral content within Davidson's (1970) mafic volcanic map-unit, or 2) the presence of a coarse boulder lag (Pl. 2a), peculiar to this portion of the esker, which may have protected the finer esker sediments from winnowing.

Magnetite shows an even greater, apparently random, variation than heavy minerals. It is because of the wide variation of magnetite percentages in these modified eskers that this component is eliminated before chemical analysis of heavy minerals. Magnetite fluctuations are capable of adding a high degree of random variation to the results. It is probably good practice to remove magnetite from any fine sand - heavy mineral separate collected in an area that has undergone postglacial submergence.

CONCLUSIONS

This study has successfully outlined an anomaly that is closely tied to known mineralization of some economic interest. High copper and nickel values are common in esker and till samples from the anomalous area at the south end of Southern Lake. Other anomalies of equal magnitude appear along other portions of the Copperneedle and Kaminak Eskers and may reflect economically interesting mineralization. Further till and bedrock sampling in the vicinity of these anomalies is required to evaluate them. Where anomalous values occur in the Kaminak Esker, however, widespread marine and alluvial cover on the terrain near the esker may make sampling difficult without drilling. The anomalies in the Kaminak Esker correspond roughly to one of the mercury anomalies that Hornbrook and Jonasson (1971) found in lake water from Kaminak Lake. Relatively high lead contents in heavy mineral separates from till and the esker also correspond to their mercury anomaly.

Other technical conclusions are:

1) The -250-mesh fraction is superior to heavy-mineral fractions for geochemical evaluation of near-surface samples of eskers in

permanently-frozen terrain. This is a result of the predominance of secondary weathering products with presumed high cation exchange capacity in the -250-mesh fraction. Cations scavenged in the -250-mesh fraction have probably been derived from the sulphides that are nearly totally leached from coarser fractions. Sulphides are apparently also leached from +60-mesh rock fragments so that the -250 mesh is superior to this fraction as well.

2) The -250-mesh fraction of tills can also reflect anomalous areas but background values and contrasts are much lower than for eskers. This is because the -2_{μ} (clay-mineral) fraction is the only significant scavenging component of till, and this component, as well as fine secondary weathering products, is depleted by surface runoff as it is brought to the surface by mud boiling. The relative stability of the seasonally thawed zone on eskers, as compared to the widespread diapirism characteristic of till surfaces, accounts for the strong contrast in background values and of trace element concentrations in the fine fractions of both sediment types.

3) For eskers, methylene iodide heavy-mineral separates failed to yield anomalous values near mineralized zones or in zones where -250-mesh fractions showed anomalies. Magnetic and heavy rock fragment fractions do not seem suitable for detecting trace-element anomalies in eskers. In only one case a particularly strong copper-nickel-cobalt anomaly that was detected in -250-mesh fractions and methylene iodide separates was also detected in the magnetic fraction and, to a small degree, in the heavy rock fragments.

4) In till samples, all fractions analyzed usually gave anomalous values for trace elements common to the anomalous zone. Accessory minerals such as mica and magnetite are apparently enriched in trace metals in bedrock surrounding a mineralized zone.

5) Wave and current winnowing during marine submergence can cause radical differences in heavy-mineral and magnetite content from one closely-spaced sample to the next. Thus, -80-mesh fractions (which largely include sand-size particles) may give values that reflect only the concentration of heavy minerals by winnowing, if heavy-liquid fractionation (preferably methylene iodide) is not used. If magnetite is not removed from heavy-mineral separates, magnetite per cent variations (6 to 50 per cent in these eskers) can contribute to erroneous interpretations of the trace-element concentrations in powdered heavy-mineral separates.

6) A conclusion which is not obvious from this text but which is evident from a glance at maps in Lee (1959) is that, although eskers have been successful prospecting media in this area and have several advantages over till for sampling (ease of sampling on foot, always sampling same facies, easier sample preparations, more contrast between background and anomalous values, etc.), they only occur at intervals of several miles and sampled only small areas adjacent to their central and tributary ridges. Except for the broadest reconnaissance or in areas where till is not available, till is the more useful prospecting medium in that it is present over wide areas. Thus, using till, a whole mineralized belt can be covered with a random grid, rather than just those narrow portions that an esker may traverse.

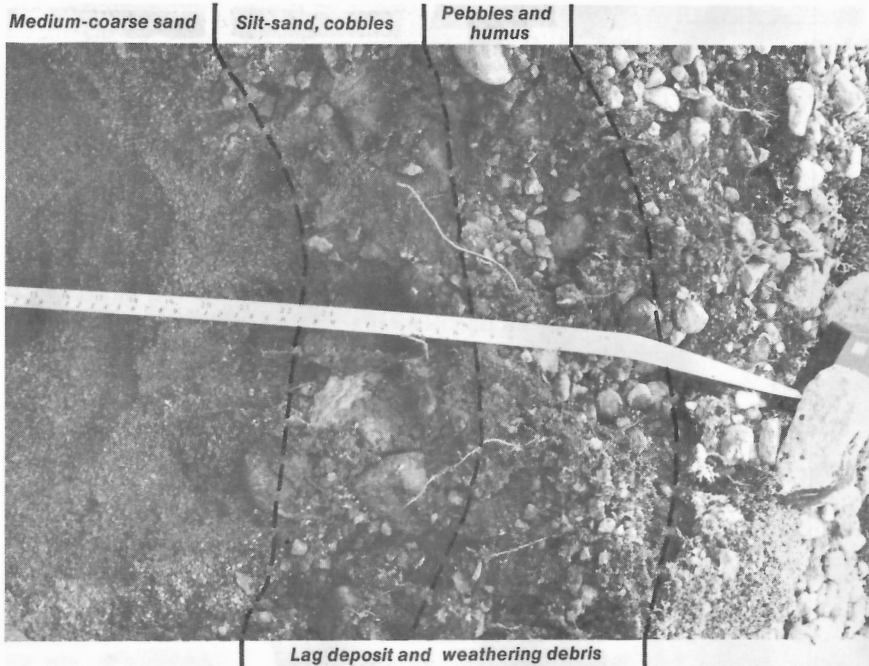


Plate 1. Profile of sample hole E159 showing typical effects of winnowing by wave action. Lower sand was sampled. Silt and clay of middle band may be largely weathering debris. (GSC photo 202090-D)

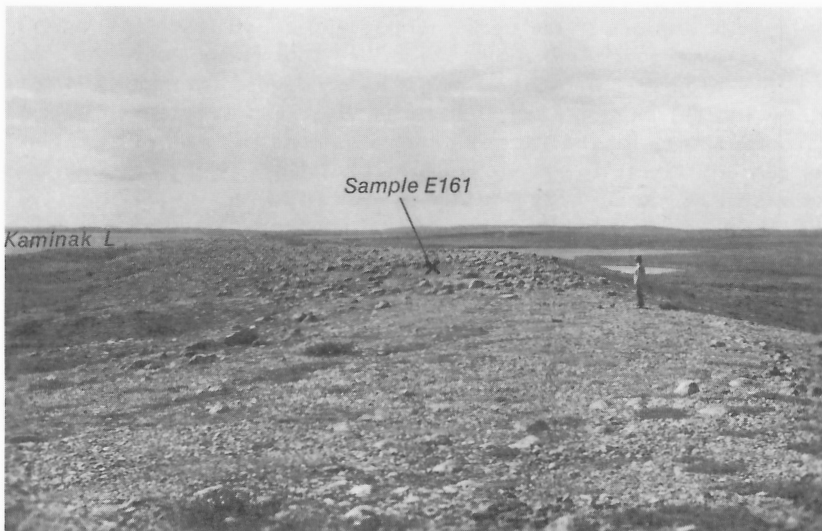


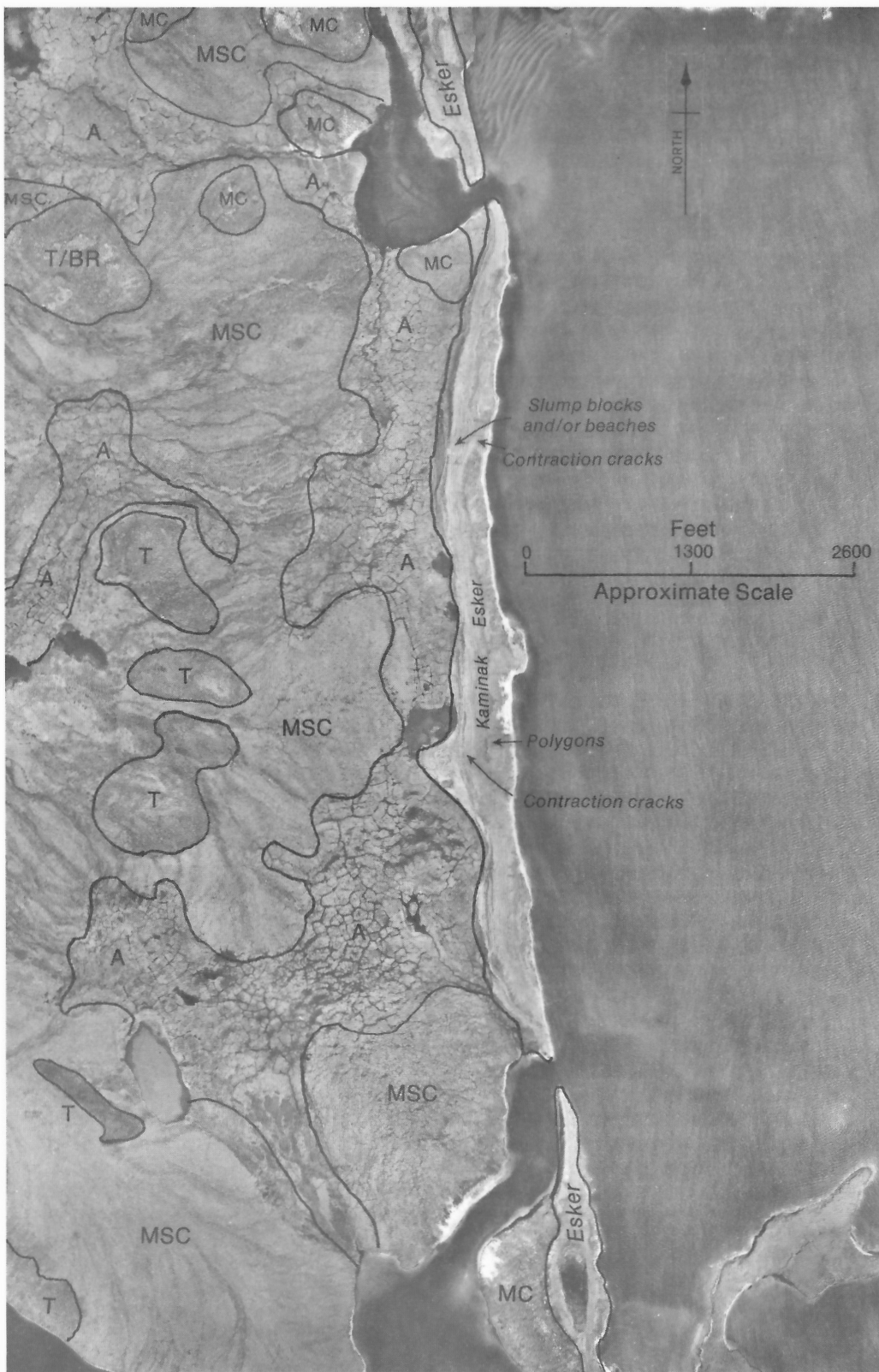
Plate 2. View of Kaminak Esker south from sample E160. Note sharp increase of granodiorite boulders where esker crosses inferred mafic volcanic-granodiorite contact. (GSC photo 201696-Q)



Plate 2a. View downstream (south) from sample location E161
(GSC photo 202090-A)



Plate 2b. View north from sample location E161; note sharp contrast with
Plate 2a in texture of surface lag. (GSC photo 202090-B)



LEGEND FOR PLATE 3 (opposite)

- A - Sandy, gravelly Alluvium and Marine sand, undifferentiated
- MSC - Marine sandy silty clay (mud boils)
- MC - Marine silty clay with very active Mud boils
- T - Till and marine silty clay, undifferentiated (mud boils)
- BR - Bedrock

Plate 3. Vertical air photograph of a portion of the Kaminak Esker and adjacent terrain. Note tension cracks and tundra polygons on esker. Lineations parallel to esker trend are small slump scarps and traces of small beaches. Note kettle-like depression in esker at bottom of photo. (EMR A19655-60)



Plate 4. Sampling Kaminak Esker with folding "G.I." entrenching shovel. Coarse surface lag is easily penetrated. View east from sample location E160. (GSC photo 202090-C)

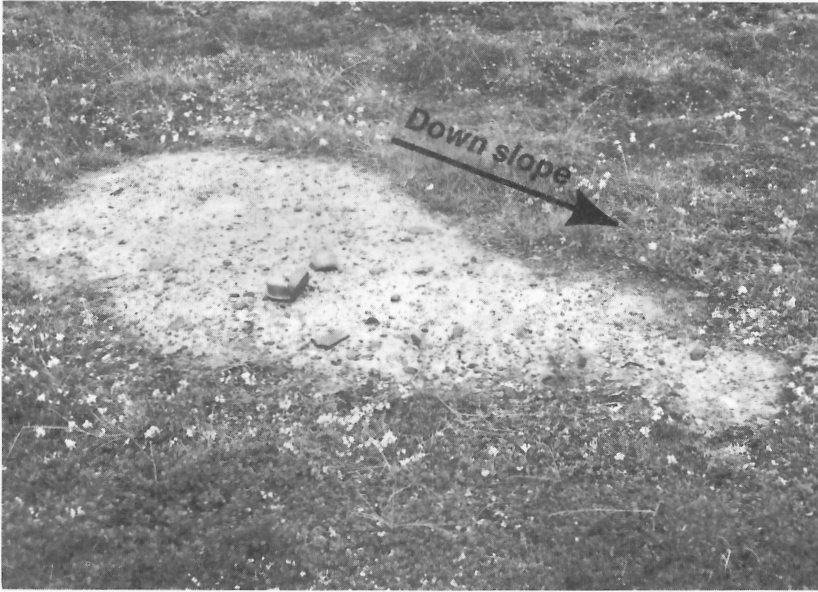


Plate 5. Typical active mud boil; note lack of vegetation and elongate form. Elongate form caused by down slope flow of mud from diapiric "vent". (GSC photo 202090)



Plate 6. Diapir of red clayey till penetrating grey, sandy, rigid carapace. This diapir is actually along a crack-like fissure and is marked at the surface by a line of white encrustation of secondary salts on the red till. (GSC photo 201696-P)

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