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QUATERNARY GEOLOGY AND DRIFT PROSPECTING, BEARDMORE-GERALDTON AREA, ONTARIO

L.H. Thorleifson and F.J. Kristjansson

1993

Energy, Mines and Resources Canada
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Ministry of Northern Development and Mines
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Cover description

Air photo of an area (approx. 3 km x 4 km) southeast of Wildgoose Lake, showing a lineated till plain on which glacial meltwater erosional features have been superimposed. In the northwest portion of the view is an esker. Crossing the area are Highway 11 and a gas pipeline. Photo courtesy of Ontario Ministry of Natural Resources 74-4929-18-156.

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Preface

The mineral industry is an essential part of the economy of Ontario. To ensure the future prosperity of the industry, the governments of Canada and Ontario agreed to fund jointly a five year, $30 million development plan, the Canada-Ontario Mineral Development Agreement (COMDA) to be implemented from 1984 to 1989. Federal programs under the agreement were carried out by Energy, Mines and Resources Canada and provincial programs by the Ontario Ministry of Northern Development and Mines.

The Beardmore-Geraldton area has a well developed infrastructure and an excellent potential for further discoveries of gold as well as a wide range of metallic minerals. The area was therefore chosen for studies in Precambrian geology, Quaternary geology, geophysics, and geochemistry. The surveys were designed to stimulate exploration by the private sector.

This report summarizes surficial geological surveys carried out in the Beardmore-Geraldton area under COMDA. The work was carried out as a co-operative project of the Geological Survey of Canada (GSC) and the Ontario Geological Survey (OGS). Resulting data were interpreted jointly and are now being published as a co-authored report under the sponsorship of both surveys.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

L'industrie des minéraux est un élément essentiel de l'économie de l'Ontario. Pour assurer la prospérité future de l'industrie, les gouvernements du Canada et de l'Ontario ont convenu de financer conjointement un plan quinquennal de développement de 30 millions $, l'Entente Canada-Ontario d'exploitation minérale (ECOEM) s'échelonnant de 1984 à 1989. Les programmes fédéraux dans le cadre de l'entente ont été réalisés par Énergie, Mines et Ressources Canada, et les programmes provinciaux, par le ministère ontarien du Développement du Nord et des Mines.

La région de Beardmore-Geraldton possède une infrastructure bien établie et un excellent potentiel de découvertes d'or futures, ainsi qu'une vaste gamme de minéraux métalliques. La région a donc été choisie pour des études en géologie précambrienne, en géologie du Quaternaire, en géophysique et en géochimie. Les levés visent à favoriser l'exploration par le secteur privé.

Le présent rapport résume les levés géologiques effectués dans la région de Beardmore-Geraldton en vertu de l'ECOEM. Le travail a été réalisé dans le cadre d'un projet de nature collaborative entre la Commission géologique du Canada (CGC) et l'Ontario Geological Survey (OGS). Les résultats ont été interprétés conjointement et ont paru dans un rapport co-rédigé dont la publication a été parrainée par les deux commissions.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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QUATERNARY GEOLOGY AND DRIFT PROSPECTING, BEARDMORE-GERALDTON AREA, ONTARIO

Abstract

A project consisting of glacial geological mapping and drift sampling was carried out in the Beardmore-Geraldton area by the Geological Survey of Canada and the Ontario Geological Survey. An area extending from Lake Nipigon to the town of Longlac was chosen for the study on the basis of gold and base metal potential. Till and sand samples were obtained from excavations and drill holes at roughly 1 km spacing where appropriate material was available.

Till is the most common surficial sediment in the area. Thick fluted drift in the central part of the study area consists largely of exotic debris derived from the Paleozoic and Proterozoic rocks of the Hudson Bay Lowland. At depth in this area and at the surface near Beardmore, locally derived debris is present. Glacial meltwater deposited sand and gravel as esker and kame deposits trending southwestward across the area, as braided outwash in the central portion of the area, and as sandy subaqueous outwash near Lake Nipigon and in the Geraldton-Longlac area. Glaciolacustrine silt and clay occurs as rare deposits near Lake Nipigon and Kenogamisis Lake as well as minor deposits near Long Lake.

In the vicinity of and northeast of Beardmore, till samples from the uppermost metre of thin discontinuous till contain visible gold typically 75 µm and ranging from 25 to 450 µm in size and show geochemical patterns indicative of nearby mineralization. Sampling of soil or oxidized till is therefore likely to be an effective mineral exploration tool where till is exposed at surface in this area. In the Wildgoose Lake-Geraldton area, exotic calcareous debris dilutes and/or buries locally derived debris. Consequently, drilling is required in much of this area in order to test for nearby mineralization.

Résumé

Un projet de cartographie géologique glaciaire et d'échantillonnage des dépôts glaciaires a été réalisé dans la région de Beardmore-Geraldton par la Commission géologique du Canada et l'Ontario Geological Survey. Une région allant du lac Nipigon à la ville de Longlac a été choisie pour l'étude à cause de son potentiel d'or et de métaux communs. Des échantillons de till et de sable ont été prélevés dans des excavations et des trous de sonde espacés d'environ 1 km, là où les matériaux étaient idoines.

Le till est le sédiment le plus abondant dans la région. Les épais dépôts glaciaires cannelés dans le centre de la région contiennent surtout des débris allochtones provenant de roches du Paléozoique et du Protérozoïque des basses terres de la baie d'Hudson. En profondeur dans cette région et en surface près de Beardmore, on trouve des débris dérivés par endroits. L'eau de fonte des glaciers a déposé du sable et du gravier, formant des eskers et des kames de direction sud-ouest en travers de la région, des apports fluvio-glaciaires anastomosés dans le centre de la région, et des épendages fluvio-glaciaires sableux près du lac Nipigon et dans la région de Geraldton-Longlac. De rares dépôts de limon et d'argile glacio-lacustres sont dispersés près du lac Nipigon et du lac Kenogamisis, avec quelques dépôts près du lac Long.

Au voisinage et au nord-est de Beardmore, des échantillons provenant des premiers mètre de till mince discontinu renferment des particules visibles d'or dont le diamètre, de 75 µm en moyenne, varie entre 25 et 450 µm, ainsi que des indices géochimiques de minéralisation locale. L'échantillonnage du sol ou du till oxydé semble donc un moyen efficace d'explorer les minéraux, là où le till affleure dans la région. Dans la région de Geraldton-lac Wildgoose, des débris calcaires allochtones diluent ou recouvrent des débris d'origine locale. Par conséquent, il faudra faire des sondages dans presque toute la région pour localiser les emplacements de minéralisation locaux.

SUMMARY

The Beardmore-Geraldton area is one of several areas in which geological surveys designed to stimulate further growth in Ontario's mining industry were initiated as part of the Canada-Ontario Mineral Development Agreement 1984-1989. A glacial geological research project was carried out in this area, as a joint effort of the Geological Survey of Canada and the Ontario Geological Survey, to facilitate the use of till sampling in mineral exploration and to obtain information required for engineering and environmental management. Field data were obtained from excavations, existing exposures, and overburden drilling. Surficial geology was interpreted using aerial photography at a scale of 1:15 840. Drift provenance was assessed using 15 kg till and sand samples collected at surface and from backhoe pits and drill holes.

Within the study area, the Wabigoon Subprovince of the Canadian Shield is subdivided into two greenstone belts. The Onaman-Tashota Greenstone Belt, in the northwest, consists predominantly of intermediate to felsic volcanic rocks intruded by felsic plutonic bodies. The Beardmore-Geraldton Greenstone Belt, which parallels and flanks Highway 11, is a predominantly metasedimentary sequence intercalated with mafic to intermediate metavolcanic rocks. Granitic rocks lie between the greenstone belts and the Paleozoic carbonate rocks of the Hudson Bay Lowland, located 100 km to the northeast. South of the greenstone belts lies the Quetico Subprovince, dominated in this area by metasedimentary rocks. Late Precambrian diabase dykes and, in the western portion of the study area, large tabular sills intrude the older rocks. Nineteen past-producing mines in the area yielded over 4 000 000 ounces (125 000 kg) of gold and 300 000 ounces (9000 kg) of silver. Copper, nickel, zinc, lead, molybdenum, and tungsten mineralization, as well as iron ore, are also present.

The area was glaciated during the Late Wisconsinan which ended about 10 000 BP (before present). The youngest set of glacial striations form a radiating pattern ranging from about 250° at Beardmore, 230° at Geraldton, to 210° at Longlac. Rare occurrences of preserved older striations indicate a former ice flow direction of 210° at Beardmore and 190° at Geraldton. Veillette (1986) has reviewed evidence for an older west-southwestward ice flow which also may have influenced the Beardmore-Geraldton area.

Till is the most common surficial sediment in the area. The most distinctive feature of much of this debris is its calcareous matrix below the 0.5 m thick upper soil horizons and the abundance, particularly in areas of thick drift, of gravel-sized clasts of Paleozoic carbonate and Proterozoic metasedimentary rocks derived from the Hudson Bay Lowland, 100 km to the northeast. The presence of this far-travelled material and the lack, in many cases, of much dilution by more locally derived debris are attributed to: 1) a zone of vigorous ice flow, an ice stream, emanating from Paleozoic terrane; 2) the high susceptibility to erosion of

SOMMAIRE

La région de Beardmore-Geraldton est une de plusieurs régions où des levés géologiques destinés à favoriser le développement de l'industrie des minéraux de l'Ontario ont été entrepris dans le cadre de l'Entente Canada-Ontario d'exploitation minérale 1984-1989. Un projet de recherche en géologie glaciaire a été réalisé dans la région, dans un effort de collaboration entre la Commission géologique du Canada et l'Ontario Geological Survey, en vue de faciliter l'utilisation de l'échantillonnage des tills dans le domaine de l'exploration minérale et d'obtenir l'information recherchée sur les plans technique et de la gestion de l'environnement. Des données ont été recueillies sur le terrain dans des excavations, des affleurements naturels et des sondages des morts-terrains. La géologie des formations en surface a été interprétée à l'aide de photographies aériennes à l'échelle de 1/15 840. L'origine des dépôts glaciaires a été établie à l'aide d'échantillons de till et de sable de 15 kg, prélevés en surface et dans des excavations pratiquées à l'aide d'une rétrocaveuse et dans des trous de sonde.

Dans la région à l'étude, la sous-province de Wabigoon du Bouclier canadien est subdivisée en deux zones de roches vertes. La zone d'Onaman-Tashota, dans le nord-ouest, est essentiellement constituée de roches volcaniques intermédiaires à felsiques pénétrées par des corps plutoniques. La zone de Beardmore-Geraldton, qui longe et flanque la route 11, est une séquence surtout métasédimentaire intercalée de roches métavolcaniques de nature mafique à intermédiaire. Il y a des roches granitiques entre les zones de roches vertes et les roches carbonatées du Paléozoïque des basses terres de la baie d'Hudson, situées à 100 km au nord-est. Au sud des zones de roches vertes se trouve la sous-province de Quetico, dominée dans la région par des roches métasédimentaires. Des dykes diabasiques précambriens et, dans la partie occidentale de la région à l'étude, d'importants filons-couches tabulaires pénètrent les roches plus anciennes. Dix-neuf anciennes mines de la région ont produit 4 000 000 onces (125 000 kg) d'or et 300 000 onces (9 000 kg) d'argent. On trouve aussi des minéralisations de cuivre, de nickel, de zinc, de plomb, de molybdène et de tungstène, ainsi que du minerai de fer.

La région a été englacée pendant le Wisconsinien tardif qui a pris fin il y a environ 10 000 ans. L'ensemble de striations glaciaires le plus récent est disposé en éventail allant d'environ 250° à Beardmore, à 230° à Geraldton et à 210° à Longlac. Quelques striations plus anciennes, qui se sont conservées, révèlent une direction antérieure de l'écoulement glaciaire de 210° à Beardmore et de 190° à Geraldton. Veillette (1986) a examiné des indices d'un écoulement glaciaire ouest-sud-ouest encore plus ancien qui aurait aussi pu avoir un effet sur la région de Beardmore-Geraldton.

Le till est le sédiment de surface le plus abondant dans la région. La caractéristique la plus distinctive de la majorité de ces débris est sa matrice calcaire sous les horizons supérieurs de sol de 0,5 m d'épaisseur et l'abondance, notamment dans les régions de dépôts glaciaires épais, de fragments de la taille du gravier de roches carbonatées du Paléozoïque et de roches métasédimentaires du Protérozoïque dérivées des basses terres de la baie d'Hudson, à 100 km au nord-est. La présence de ce matériau d'origine si éloignée et le manque fréquent de dilution prononcée par des débris d'origine plus locale sont attribuables à: (1) une zone d'écoulement glaciaire vigoureux, une langue glaciaire, émanant d'un terrane paléozoïque;

Paleozoic carbonate rocks; 3) the low erodibility of Archean granites which occur between the greenstone belt and Paleozoic terrane; and 4) the short distance over which glacial ice flowed over greenstones prior to the deposition of till in the study area. The exotic composition of thick till grades into that of more locally derived thin till at surface in the area around and northeast of Beardmore and in the subsurface in areas of thick sediments. The fluted surface of these deposits, their massive and compact structure, and the presence of faceted and striated clasts as well as boulder pavements indicate that these tills were deposited by actively sliding ice. Graded sediment flow diamicts derived from the ice surface overlie till in places.

Glacial meltwater deposited esker, kame, and outwash deposits as belts of sand and gravel crossing the area. Subaqueous outwash was deposited by continuously flowing, sediment-laden turbidity currents or underflows derived from the ice. These currents were driven by their density to the deeper parts of the shallow, short-lived proglacial lakes which covered part of the area. Whereas higher ground in the southern and north-central parts of the area was not inundated, the lower areas between Jellicoe and Lake Nipigon as well as low areas near Geraldton and Longlac were inundated. The upper limit of inundation, which rises to the northeast due to postglacial isostatic rebound, varies from 320 m (1050 ft.) at Beardmore to 350 m (1150 ft.) at Longlac. Most of the area within these limits consisted of islands. Currents in these shallow, restricted glacial lakes were probably responsible for the lack of varved silt and clay, considered typical of glaciolacustrine deposits elsewhere.

Postglacial sedimentation is limited to eolian reworking of subaqueous outwash sand, deposition of alluvium on the floodplains of rivers, and accumulation of peat in poorly drained depressions.

Mineral exploration programs must take into account the several environments of glacial sedimentation, variable distances and directions of glacial transport, and the effects of postglacial weathering. Till derived from within the greenstone belt, which is a desirable sampling medium for mineral tracing and exploration geochemistry, may be sampled at the surface in areas of thin drift. Lack of preserved sulphides in all near-surface till samples indicates that this material is oxidized to a depth of typically 3 or 4 m to as much as 7 m in well drained sites. Metals formerly hosted by sulphides have been redistributed in oxidized till, possibly into the fine grained fractions. The geochemical characteristics of surface till samples therefore differ from unoxidized sulphide-bearing till which can be obtained by drilling below a depth of several metres. Calcareous till rich in Paleozoic carbonate clasts should be examined for a local component before analysis. A local component is most readily recognized by the presence of angular, foliated metasedimentary and metavolcanic clasts in the pebble fraction.

The most favorable aggregate sources are located in areas of glaciofluvial ice contact sediment and outwash deposits.

(2) la forte susceptibilité à l'érosion des roches carbonatées du Paléozoïque; (3) la faible susceptibilité à l'érosion des granites archéens situés entre la zone de roches vertes et le terrane paléozoïque; et (4) la faible distance parcourue par l'écoulement glaciaire sur les roches vertes avant l'accumulation du till dans la région à l'étude. La composition allochtone du till épais se fond avec celle du till mince d'origine plus locale, en surface dans les environs et au nord-est de Beardmore, et sous la surface dans les zones de couches épaisses de sédiments. La surface cannelée de ces dépôts, leur structure massive et compacte, et la présence de fragments détritiques facettés et striés ainsi que de dallages de pierres indiquent que ces tills ont été mis en place par la glace en cours de glissement. Des diamictes de sédiments classés provenant de la surface de la glace recouvrent le till par endroits.

L'eau de fonte de la glace a déposé des eskers, des kames et des épandages fluvio-glaciaires sous forme de zones de sable et de gravier traversant la région. Les matériaux fluvio-glaciaires subaquatiques ont été déposés par des courants ou des sous-écoulements de turbidité ininterrompus et chargés de sédiments, d'origine glaciaire. En raison de leur densité, ces courants ont été entraînés dans les parties les plus profondes des lacs proglaciaires éphémères et peu profonds qui recouvraient en partie la région. Tandis que les terrains élevés du sud et du centre-nord de la région restaient à sec, les terres basses entre Jellicoe et le lac Nipigon, comme celles des environs de Geraldton et de Longlac étaient inondées. La limite supérieure d'inondation, qui s'élève en direction du nord-est à cause du rajustement isostatique postglaciaire, varie de 320 m à Beardmore à 350 m à Longlac. La région était essentiellement constituée d'îles à l'intérieur de ces limites. Les courants dans ces lacs glaciaires peu étendus et peu profonds expliquent probablement pourquoi on y trouve peu de limon et d'argile varvés, constituants caractéristiques des dépôts glacio-lacustres.

La sédimentation postglaciaire est limitée au remaniement éolien du sable fluvio-glaciaire subaquatique, au dépôt d'alluvions sur les plaines d'inondation des cours d'eau et à l'accumulation de tourbe dans les dépressions mal drainées.

Les programmes d'exploration minérale doivent tenir compte des différents milieux de sédimentation glaciaire, des diverses distances et directions de transport glaciaire, et des effets de l'altération postglaciaire. Le till, provenant par endroits de l'intérieur de la zone de roches vertes, est un bon milieu d'échantillonnage pour la recherche de minéraux et l'exploration géochimique, et peut être échantillonné en surface dans les régions de dépôts glaciaires minces. L'absence de sulfures non altérés dans tous les échantillons de till proches de la surface indique que cette substance est oxydée jusqu'à une profondeur de 3 ou 4 m, et même jusqu'à 7 m en général dans les endroits bien drainés. Les métaux anciennement logés dans des sulfures ont été redistribués dans du till oxydé, peut-être dans les fractions à grains fins. Les caractéristiques géochimiques des échantillons de till de surface diffèrent donc de celles du till contenant des sulfures non oxydés qui peut être obtenu en forant à une profondeur de plusieurs mètres. Il faudrait établir la présence d'un constituant local dans les fragments détritiques carbonatés du Paléozoïque, riches en till, avant de procéder à leur analyse. Un constituant local se reconnaît facilement par la présence de fragments détritiques métavolcaniques et métasédimentaires feuilletés et anguleux dans la fraction caillouteuse.

Les meilleures sources d'agrégats sont situées dans les régions de sédiments de contact glaciaires et d'épendage fluvio-glaciaires.

INTRODUCTION

Rationale and scope

The Canada-Ontario Mineral Development Agreement, a subsidiary agreement of the Economic and Regional Development Agreement, was signed by the governments of Canada and Ontario in November of 1984. The Beardmore-Geraldton area (Fig. 1) was one of several areas in which geological surveys designed to stimulate further growth in the Ontario mining industry were initiated. Past mineral production from this area has been concentrated in areas of abundant bedrock outcrop. Excellent potential for further discoveries exists where glacial sediments conceal the bedrock. Increased recognition of the usefulness of till sampling as an exploration tool (Shilts, 1982a, 1984a; Coker and DiLabio, 1989; Saarnisto, 1990) has necessitated the acquisition of a more thorough knowledge of glacial sediments. Glacial geological research in the Beardmore-Geraldton area therefore dealt with the distribution, stratigraphy, sedimentology, composition, and source of glacial sediments, particularly till, in the vicinity of known and potential mineralization.

Till may be conceived of as crushed and transported bedrock (Shilts, 1982a). Due to its wide distribution, ease of identification, ease of relating to known ice transport directions, direct derivation from bedrock, and straight line transport, till has become a commonly used surficial sampling medium for prospecting in areas of glaciated terrain. The glacial erosion of a point bedrock source results in its dispersion, in the form of an indicator train, in a down-glacier direction. The dispersion train, due to its greater surface area, is easier to detect than the source and therefore comprises the target during the initial phase of till sampling. It is the detection of the dispersal train by mapping mineralized clasts or by geochemical analysis of the till (DiLabio, 1981, 1990b) which provides the means of tracing back to source.

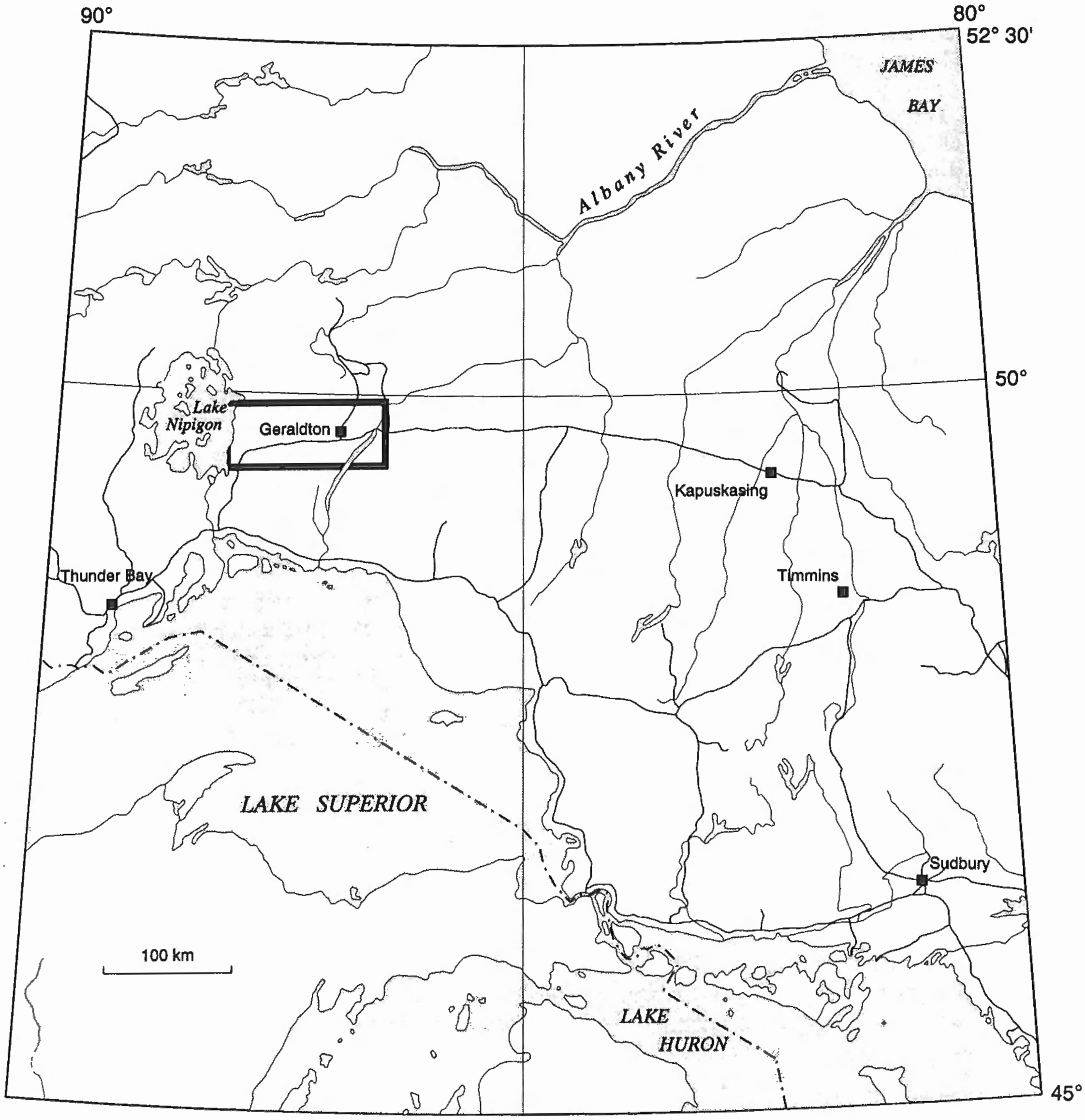


Figure 1. Location of the Beardmore-Geraldton study area.

Study area

Location and access

The Beardmore-Geraldton area, part of the District of Thunder Bay, is located immediately east of Lake Nipigon, 100 km north of Lake Superior. The study area is traversed by Highway 11, the northern route of the Trans-Canada Highway, highways 580, 584, and 801, and numerous secondary and tertiary forest access roads. The Beardmore-Geraldton area is also serviced by the Canadian National Railway.

The study area is bounded by latitudes 49°30' and 49°52'30"N and longitudes 86°30' and 88°12'W. The area is covered by the following 1:50 000 National Topographic Series map areas: Geraldton (42E/10), Wildgoose Lake (42E/11), Beardmore (42E/12), and parts of North Wind Lake (42E/13), Treptow Lake (42E/14), Longlac (42E/15), Shakespeare Island (52H/9), and Livingstone Point (52H/16).

Communities within the study area (Fig. 2) include Beardmore (1988 population: 638), Jellicoe (1988 population: 175), Geraldton (1988 population: 2821) and Longlac (1988 population: 2258). The area includes at least portions of 32 named townships (Fig. 2). The principal economic activities in the area are forestry, tourism, and mineral exploration.

Precambrian geology

The Precambrian geology of the Beardmore-Geraldton area (Fig. 3) has been described by Pye et al. (1966), Mason and McConnell (1983), Mason et al. (1985), and Mason and White (1986).

Rocks of the Wabigoon Subprovince of the Canadian Shield in the area consist of two greenstone belts of Archean age: 1) the Onaman-Tashota Belt in the northwest part of the study area and 2) the Beardmore-Geraldton Belt which parallels and flanks Highway 11. The two greenstone belts were distinguished on the basis of lithology, structure, and geochronology. The Paint Lake Fault, a regional transcurrent fault, separates the two belts.

The Onaman-Tashota Belt, the older of the two belts, consists predominantly of calc-alkaline and tholeiitic felsic to intermediate as well as mafic metavolcanic rocks intruded by felsic plutonic rocks. Metavolcanic rocks of this terrane were deformed into arcuate shapes by the emplacement of intervening granitic intrusions (Mason and White, 1986). Regional lineaments or faults within the area trend north and northeasterly. Mafic metavolcanic rocks consist of massive to foliated, pillowed, porphyritic and amygdaloidal flows, chlorite schist, tuff, lapillistone, tuff breccia, and agglomerate. These rocks are intercalated with felsic pyroclastic rocks with minor quartz porphyry and rhyolitic flows. Felsic metavolcanic rocks consist of rhyolite to rhyodacite, rhyolite porphyry, crystal tuff, lapilli-tuff, tuff breccia, rhyolitic quartz feldspar porphyry, and pyroclastic breccia. Metasedimentary rocks are also present as argillite, arkose, wacke, sandstone, conglomerate, and minor chemical metasediments (Mason and White, 1986).

The Beardmore-Geraldton Belt is an east-trending, isoclinally folded sequence in which lithologic units have been tectonically transposed into a series of alternating slices of metavolcanic and metasedimentary rocks within a wrench or megashear zone (Mason and White, 1986). Along the southern boundary of the belt are mafic volcanic rocks consisting of massive, pillowed, amygdaloidal, and rarely variolitic flows of magnesium to iron tholeiites. Iron tholeiite flows are 15 to 25 m thick and consist of a massive, medium grained basal part, crudely fining upward, becoming aphanitic and commonly pillowed. Intermediate to mafic tuffs are medium- to fine-grained light green rocks which display a weak foliation. Adjacent to these mafic volcanic rocks within the Beardmore-Geraldton Belt are metasedimentary rocks consisting of wacke, conglomerate, siltstone, and iron-formation.

Gabbro, diorite, granodiorite, quartz diorite, monzonite, feldspar porphyry, and quartz-feldspar porphyry have intruded rocks of both belts. Late felsic intrusions include pegmatite and felsite. Late Precambrian diabase dykes and, in the western portion of the study area, large tabular sills intrude the older rocks. Metamorphic grade is commonly greenschist but ranges to amphibolite grade (Mason and White, 1986).

Granitic rocks lie between the metasedimentary-metavolcanic greenstone belts and the Paleozoic carbonate rocks of the Hudson Bay Lowland, located 150 km to the northeast. To the south lie metasedimentary rocks of the Quetico Subprovince.

Mineralization and mining history

Gold, silver, copper, nickel, zinc, lead, molybdenum, and tungsten mineralization, as well as iron ore, are present in the Beardmore-Geraldton area (Fig. 3; Pye et al., 1966). Gold and silver mineralization in the study area was subdivided by Mason and McConnell (1983) on the basis of stratigraphic location and host rock lithology: 1) southern mafic volcanic rocks of the Beardmore-Geraldton Belt, 2) southern sedimentary rocks of the Beardmore-Geraldton Belt, and 3) northern felsic volcanic rocks of the Onaman-Tashota Belt. These authors reported that over 94% of past Au and Ag production in the area was from the southern sedimentary belt and that the bulk of the known mineralization appears to be structurally controlled. The Bankfield-Tombill Fault (strike 100-110°, dip 60-70° south) and the east-trending Little Long Lac Fault appear to have been important in the formation of most of the Geraldton area gold deposits. Whereas most known mineralization in the area occurs in narrow, high grade veins, attention has recently turned to occurrences in large fault-shear zones with much greater tonnage potential (Mason and White, 1986). The precious metal mineralization in the area is commonly associated with quartz-carbonate veins variously associated with other minerals. Arsenopyrite, pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, scheelite, and tourmaline are associated with free gold mineralization in varying combinations. Micro-inclusions of gold in sulphide minerals, and more rarely gold within sulphide crystal lattices, have also been

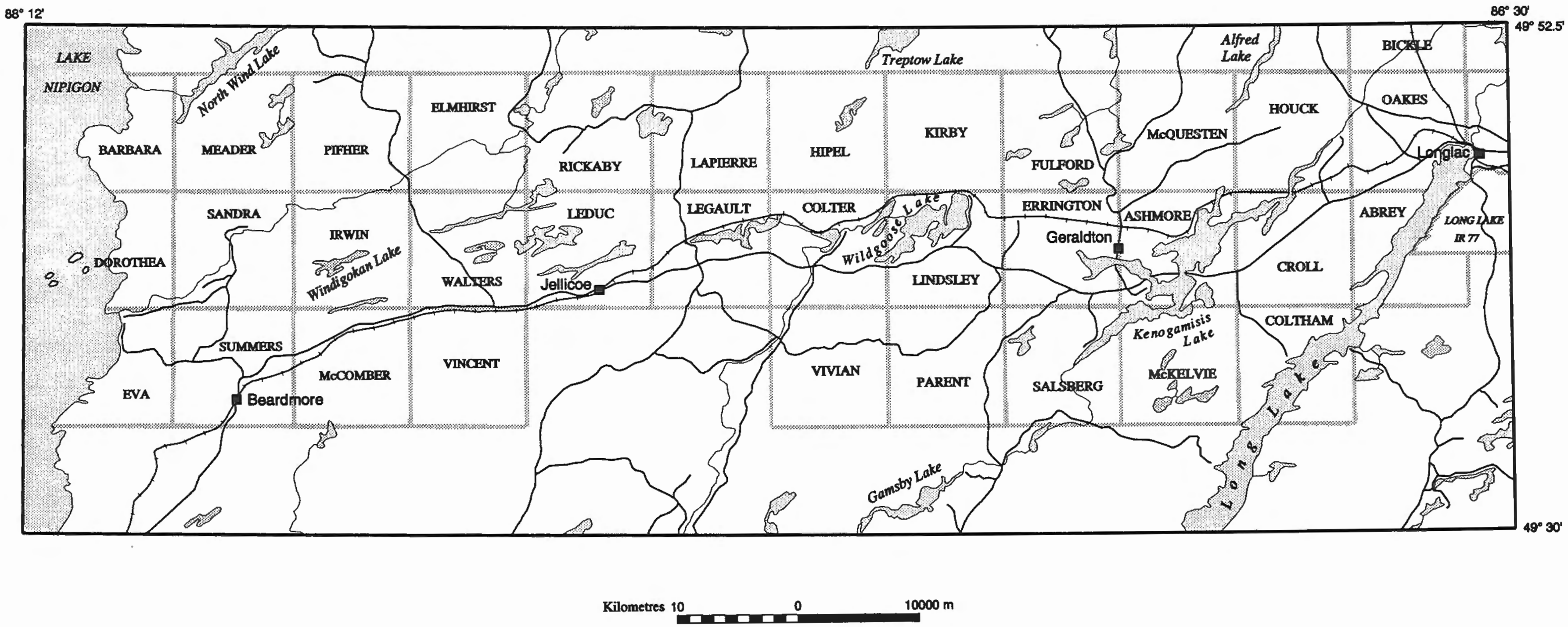


Figure 2. Location of geographic features and townships in the study area.

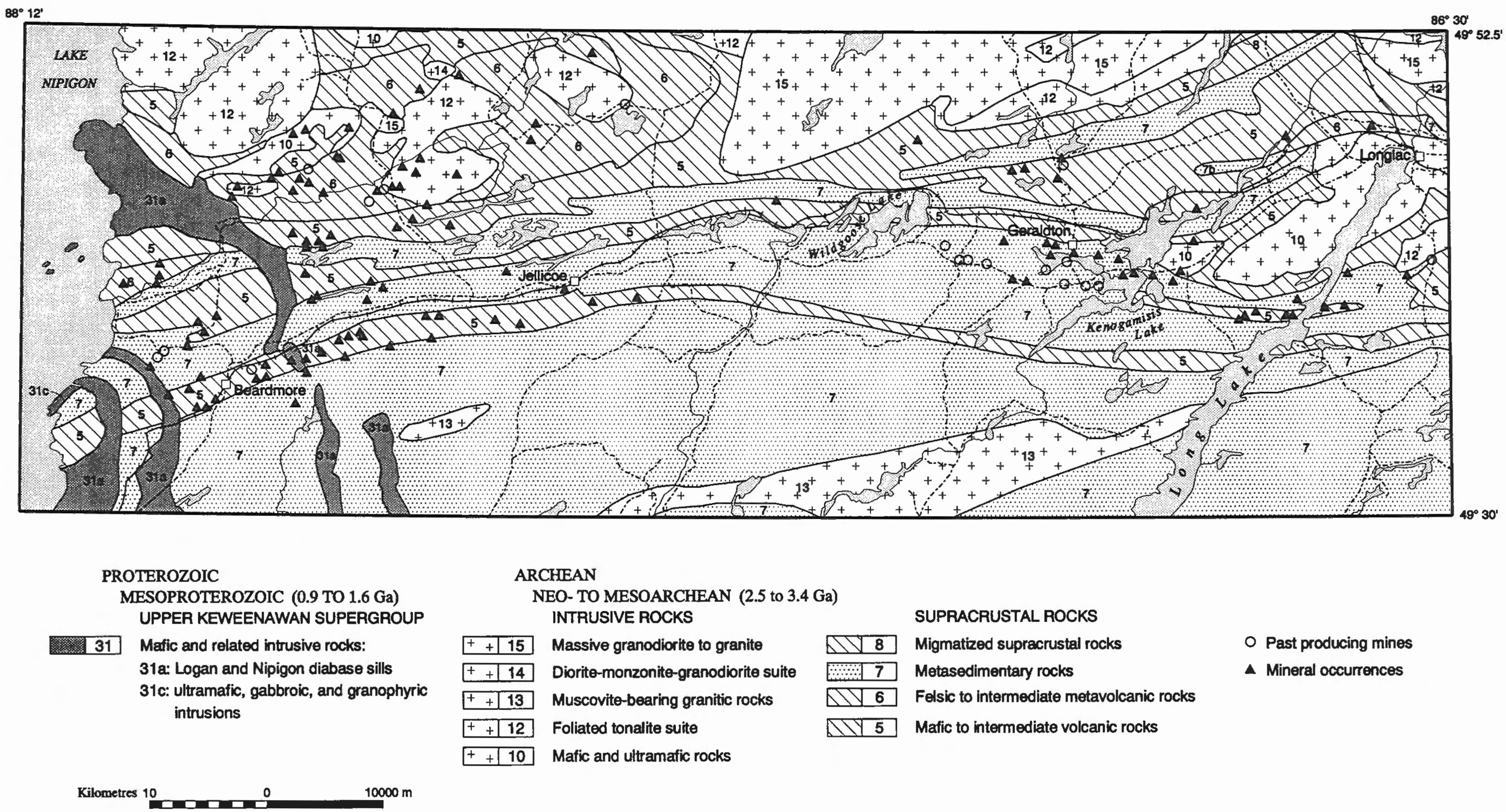


Figure 3. Bedrock geology, after Ontario Geological Survey (1991). Locations of past producing mines and mineral occurrences are from Pye et al. (1966).

recognized (Mason and White, 1986). Base metal deposits are known within the Onaman-Tashota Belt. In Elmhirst township, drilling has indicated reserves of nickel and copper (Mason and White, 1986).

Early in this century, exploration focused on iron ore. Subsequently, however, nineteen mines (Fig. 3) yielded over four million ounces of gold and 300 000 ounces of silver (Mason and White, 1986). The area therefore rates among the top five gold camps in the Canadian Shield. In 1925, gold was discovered in the Beardmore area (Mason and McConnell, 1983). The former Orphan (Dik-Dik) and Northern Empire mines commenced production in 1934. Over one million ounces of gold were eventually produced at the Leitch, Northern Empire, and Sand River mines, all located within an 8 km radius of Beardmore (Mason and White, 1986). The Leitch mine generated 847 690 ounces of gold and 31 802 ounces of silver during the period from its opening in 1936 to shutdown in 1968. The mean grade for gold at this mine was 0.92 ounce per ton. Gold was first reported at Geraldton during World War I, but it was not until 1931 that a discovery which led to a mine was made. This occurred at the site of the Hard Rock mine near Geraldton. In 1932, gold in quartz veins was encountered on Barton Bay. This property became the former Little Long Lac mine in 1934. The largest producer in the Geraldton camp was the McLeod-Cockshutt mine (Mason and White, 1986), which operated from 1938 to 1968. A total of 1 475 728 ounces of gold, at a mean grade of 0.14 ounces gold per ton, along with 101 338 ounces of silver were produced at this mine.

Topography and drainage

The Beardmore-Geraldton area includes two broad topographic highs. A highland situated north and northwest of the town of Geraldton is thinly drift-covered and is underlain by granitic rocks of the Onaman-Tashota Belt. In this area, elevations exceed 1450 ft. (442 m). A second highland located in the southern part of the study area is also thinly drift-covered and is underlain by metasedimentary, migmatitic, and felsic intrusive rocks of the Quetico Subprovince. The elevation of much of this highland area is above 1300 ft. (396 m), with elevations in some parts approaching 1400 ft. (457 m). The morphology of the ground surface in these highlands is rolling and undulating to knobby and cliffed, with low to moderate local relief respectively.

With the exception of glacially streamlined, thick drift in the central part of the study area (Fig. 4), the intervening lowland to a large extent is a low to moderate relief bedrock plain with elevations generally below 1150 ft. (350 m). This lowland is underlain by the Onaman-Tashota volcanic-plutonic belt, in the northwestern part of the study area, and the Beardmore-Geraldton metavolcanic- metasedimentary belt. Felsic plutonic rocks of the Onaman-Tashota belt and mafic metavolcanic of the Beardmore-Geraldton belt tend to underlie areas of higher elevation within this broadly defined lowland. The form of the ground surface varies from mildly rolling and undulating to knobby and ridged. A prominent aspect of the topography consists of bedrock ridges oriented east-west (Fig. 4). The lower elevation areas are commonly associated with drift cover. Consequently, the ground surface in these areas is more subdued, with a mildly rolling and undulating to planar form. Large tabular diabase sills, in the western part of the study area, form major local topographic highs around Beardmore. At opposite ends of this east-west lowland along the central axis of the study area are Lake Nipigon in the west, whose surface rests at 852 ft. (260 m) above sea level, and Long Lake in the east at 1025 ft. (312 m) a.s.l.

The Beardmore-Geraldton map area straddles the Hudson Bay-Great Lakes drainage divide. Drainage in the Beardmore-Jellicoe area is dominated by the Namewaminikan (Sturgeon) and Blackwater rivers. Runoff from this area enters Lake Nipigon which in turn empties into Lake Superior. To the east is the drainage basin of the Kenogami River, which includes the Kenogamisis River basin of the Geraldton area. The Kenogami River, which drains Long Lake, ultimately joins the Albany River before entering James Bay. A portion of the runoff from Long Lake has been artificially diverted southward to Lake Superior.

Climate

The study area has been included in the moist mid-boreal ecoclimatic region by Environment Canada (1989). Summers are warm and rainy (60-90 mm per month). Winters are cold and snowy, but receive less precipitation than summer months. Total annual precipitation is approximately 800 mm. Mean daily temperatures greater than 0° last up to seven months (Environment Canada, 1989).

Soils and vegetation

Within the Beardmore-Geraldton area, soils representing five of the nine soil orders defined by Agriculture Canada (1987) are present. Organic soils have been approximately mapped in the present study as these soils are generally regarded as geological deposits by surficial geologists. Associated with these poorly drained soils, gleysols presumably occur. At well drained sites where bedrock is not exposed, soils of the podzolic, brunisolic, and luvisolic orders occur (Clayton et al., 1977). The most common soil subgroups of these orders occurring in the area are orthic humo-ferric podzol (common horizon sequence: LFH, Ae, Bf, BC, C), orthic eutric brunisol (common horizon sequence: LFH, Bm, C or Ck), and orthic grey luvisol (common horizon sequence: LFH, Ae, AB, Bt, C or Ck) (Clayton et al., 1977; Fig. 5). These soils are assigned to the boreal cool to moderately cool temperature class and the perhumid to humid moisture subclass, hence the soils in the area are normally moist throughout the year.

Podzolic soils are those which 1) do not meet the criteria of cryosolic or organic soils, 2) have a podzolic B horizon, 3) do not have a Bt horizon (an illuvial horizon enriched with silicate clay) within 50 cm of the mineral surface (Agriculture Canada, 1987). A podzolic B horizon is at least 10 cm thick and meets morphological and chemical criteria regarding colour and accumulation of amorphous material composed mainly of humified organic matter combined in varying degrees with aluminum and iron. These soils are typical of coarse- to medium-textured (sandy to loamy) acid parent materials under forest or heath vegetation in cool to very cold humid to perhumid climates. They can, however, form in materials that were once calcareous. Humo-ferric podzols have a Bf horizon, characterized by enrichment primarily by aluminum and iron, in contrast with other podzols with Bh or Bhf horizons, in which enrichment of the B horizon by organic matter is more prominent.

Luvisolic soils lack the development of a chernozemic A horizon or a solonetzic B horizon, both of which are typical of grassland, or the features of reducing conditions seen in gleysols, but have a clay-rich Bt horizon within 50 cm of the mineral surface (Agriculture Canada, 1987). These soils develop characteristically in well- to imperfectly-drained sites, in sandy loam to clay base-saturated parent materials under forest vegetation in subhumid to humid, mild to very cold climates.

Other soils which have a Bm horizon or a weakly developed luvisolic Bt or podzolic Bf horizon are referred to as brunisols (Agriculture Canada, 1987). Hence a brunisol is an immature soil, but is more developed than the very immature regosols. A Bm horizon is slightly altered by hydrolysis, oxidation, or solution, or all three to give a change in colour or structure, or both. It has evidence of alteration as colour, partial or complete removal of carbonates, or structure. Eutric brunisols have a relatively high degree of base saturation as indicated by their pH and lack of a well developed mineral-organic surface horizon. They occur mainly on parent material of high base status under forest or shrub vegetation in a wide range of climates. Orthic eutric brunisols have an organic surface horizon overlying a brownish, base-saturated B horizon. The C horizon is commonly calcareous.

The area, with the exception of organic terrain and areas of human disturbance, is forested. According to Environment Canada (1989), most sites in the area are characterized by stands of white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Dry sites are dominated by jack pine (*Pinus banksiana*), with secondary quantities of black spruce (*Picea mariana*). On locally warmer locations, some red pine (*Pinus resinosa*) and eastern white pine (*Pinus strobus)* occur. Stands of tamarack (*Larix laricina*) with black spruce (*Picea mariana*), moss and lichen occur on cold sites with moisture regimes that range from dry to wet.

Previous research

Previous published surficial geological research in and surrounding the study area has been associated with a series of phases of government and academic activity. The first phase of research was carried out in the late nineteenth century by the Geological Survey of Canada (e.g., Bell, 1870). This work was part of an effort by the Government of Canada to assess the mineral potential of Canada and promote economic development in vast areas of sparsely populated territory. Subsequent research on the surficial geology of the region was carried out in the 1960s in order to better understand the controls on soil nutrients and resultant forest productivity (e.g., Zoltai, 1967a). Stratigraphic research which complemented the geomorphic work by Zoltai was carried out by coring of bottom sediments in Lake Superior (e.g., Dell, 1974) and analysis of riverbank exposures in the Hudson Bay Lowland (e.g., Skinner, 1973). Regional geochemical surveys initiated in the 1970s and designed to support mineral exploration and environmental management led to recognition of the importance of glacial transport trends and resultant drift composition. Specifically, the great significance of calcareous debris transported from the Paleozoic rocks of the Hudson Bay Lowland was recognized (e.g., Coker and Shilts, 1979). Maps and accompanying reports issued under the Northern Ontario Engineering Geology Terrain Study program (NOEGTS) included coverage of the study area (e.g., Gartner, 1979a). A series of efforts were carried out in the area during the 1970s in order to facilitate the local application of exploration geochemical methods (e.g., Closs and Sado, 1981). Research on the eastward drainage of Lake Agassiz, an immense proglacial lake centred on the Red River valley of Manitoba, through the Lake Nipigon basin during deglaciation of the region included additional stratigraphic work involving analysis of glaciolacustrine sediments in the Lake Nipigon basin (e.g., Lemoine, 1989). Surficial geological surveys carried out by the Ontario Geological Survey in the Hemlo-Manitouwadge area (e.g., Geddes, 1984a) were stimulated by the immense Hemlo gold discoveries. These activities later influenced research at Beardmore-Geraldton, located 100 km to the northwest. Projects carried out in the Beardmore-Geraldton area under the Canada-Ontario Mineral Development Agreement, in addition to the surficial geological work reported here, were carried out from 1986 to 1989 and included research on till sedimentology (e.g., Hicock, 1988a), bedrock mapping, lake sediment geochemistry, and geophysical surveys.

Early exploration

The westernmost part of the study area, along Lake Nipigon, was examined by Robert Bell of the Geological Survey of Canada in 1869 (Bell, 1870). Bell reported two orientations of striations near Poplar Lodge, 185-190° and 235-265°. A generally westward trend of erratic transport was also reported. Bell discussed Paleozoic limestone erratics occurring in the area, including their similarity to unpublished observations made in 1846 by Sir William Logan along the north shore of Lake Superior. Long Lake was traversed by Bell as part of an expedition to the Hudson Bay Lowland in 1870 (Bell, 1872a). Bell noted the abundance of what he described as boulders of very dark granular quartzite along Hudson Bay Lowland rivers. Later, Bell (1872b) reported striations oriented 180-205° in the Long Lake area and 210-220° in the area to the northwest. Bell commented that the drift, having come from the northeast, is rich in fine grained carbonate, as well as pebbles and boulders of Paleozoic limestones which he had observed in situ northeast of the area. Bell (1887) drew attention to erratics which clearly demonstrated the generally southwestward trend of long distance glacial transport across northern Ontario. This

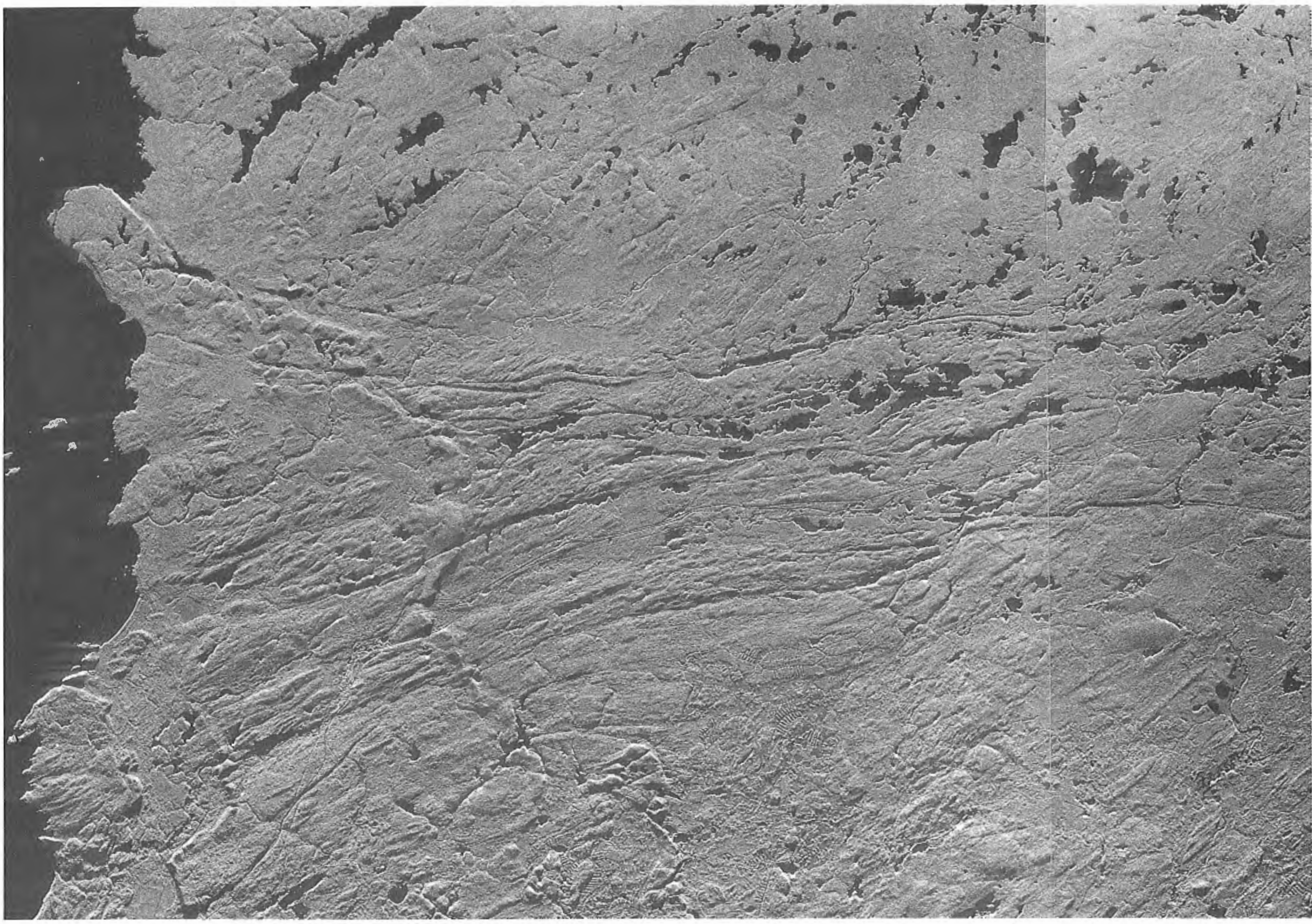


Figure 4. Synthetic aperture radar image, produced using data collected during a single pass (26 May 1988) along a flight line parallel to the study area (Canada Centre for Remote Sensing Airborne C-Band SAR, Project 88-23, National Air Photo Library Roll HS880155, Frames 51-54.).

erratic was described as a dark grey granular felsite or greywacke "with round spots, from the size of a pea to that of a cricket ball or larger, of a lighter colour than the rest of the rock, which weather out into pits of the same form". Bell correlated these erratics to Proterozoic rocks he had observed along eastern Hudson Bay. The erratics have recently been correlated to the Omarolluk Formation, which outcrops on the Belcher Islands in Hudson Bay (Prest and Nielsen, 1987; Prest, 1990). The distinctive spherical calcareous concretions of these rocks at their outcrop were examined by McEwen (1978).

A discussion of soils in Ontario by Hills (1959) included description of calcareous material over much of northern Ontario southwest of the Paleozoic rocks of the Hudson Bay Lowland. Further detail was provided by Dell (1963), who mapped a high lime area over most of northern Ontario, extending to a limit located between the Beardmore-Geraldton area and Lake Superior. Dell (1963) referred to a till sample from the study area as "the Bankfield till from the Geraldton drumlin fields". This sample contained 35% carbonate in the fine sand fraction, the highest value encountered in the study. Dell drew attention to abnormally high distances of glacial transport from bedrock sources to the northeast. Till samples from the shield south of the high lime area were found to be more representative of nearby bedrock and hence were much more variable than calcareous sediments to the north. For example, Dell (1963) found high magnetite content, as much as 9%, in the fine sand of sediments derived from diabase of the Lake Nipigon basin.

Surficial mapping

Zoltai (1965a, 1967a) carried out an extensive surficial geological survey in the region including the study area in support of soil productivity research. His work included description of the nature and extent of surficial materials and glacial features in the area and an outline of ice marginal positions and proglacial lakes.

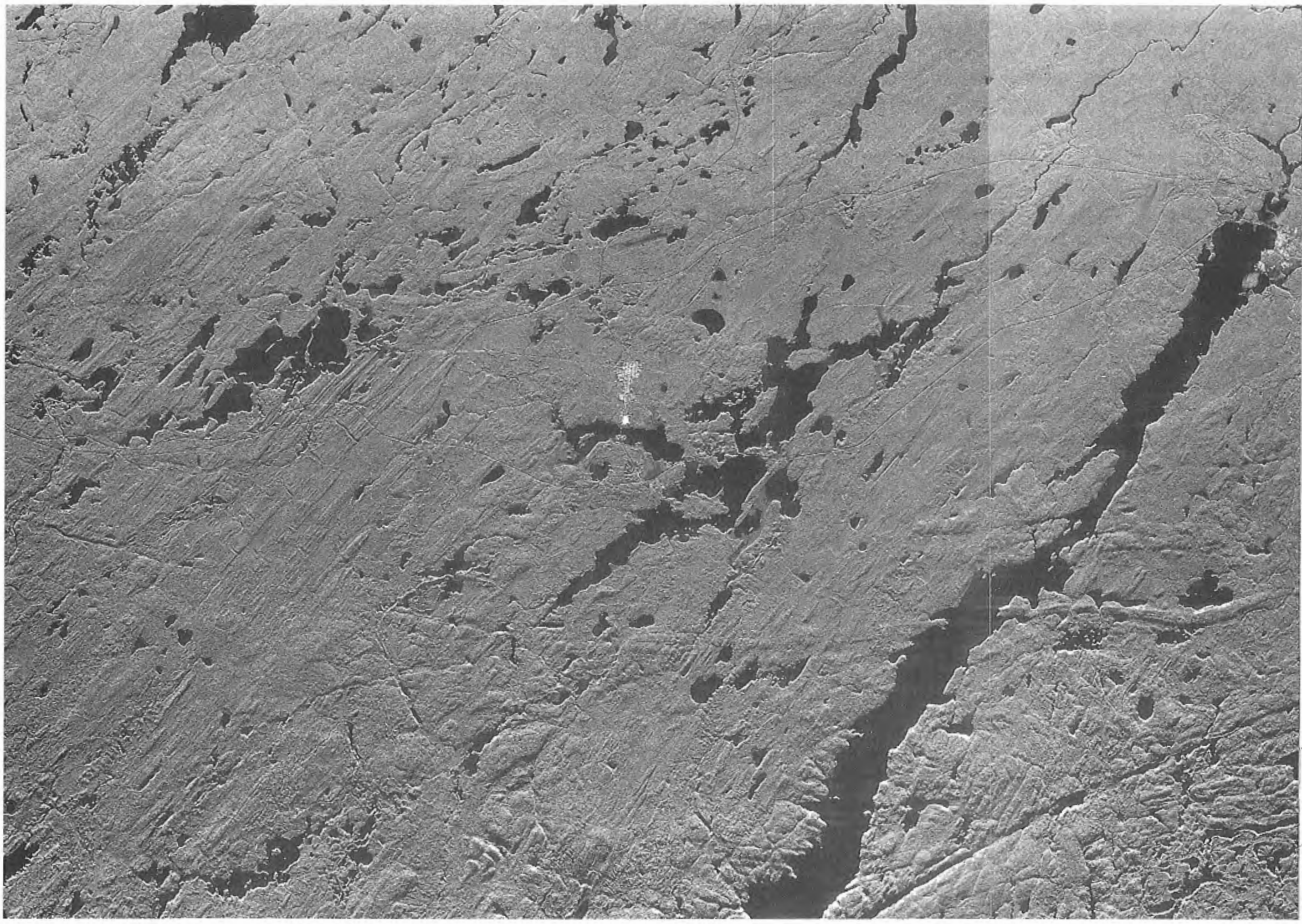


Figure 4. (cont'd.)

Zoltai (1967a) reported that glacial striae and other directional features in the region, including drumlins and an array of eskers, indicate former ice flow generally toward the southwest, but fanning to the west and south in the area east of Lake Nipigon. He identified a belt 20 to 30 miles (30 to 50 km) wide north of Lake Superior in which sandy till is composed entirely of Precambrian rock fragments. To the north, he found progressively higher concentrations of carbonate, with a maximum about the latitude of Geraldton. Farther north, he encountered an irregular distribution of calcareous till, but the material of drumlins in these areas was invariably calcareous. Paleozoic carbonate material was found in eskers in areas where the till is entirely free of this material. Within the study area, Zoltai (1967a) recognized a group of washboard moraines near Sturgeon River, south of Wildgoose Lake.

Zoltai (1965b, 1967a) described major end moraines located to the north and south of the study area (Fig. 6). To the south, the Nipigon Moraine, earlier recognized by Wilson (1910) and Elson (1957), extends along the western side of Lake Nipigon and curves eastward to the north shore of Lake Superior. The moraine typically consists of a large single ridge of sand and gravel. A similar stratified end moraine or group of moraines, the Nakina I and Nakina II moraines, occurs 60 km north of the study area. Along the southwestern flanks of the Nakina moraines, Zoltai (1967a) identified large outwash plains consisting of flat expanses of crudely stratified sand and gravel. Layers of silt or varved clay beneath a cover of sand were attributed to deposition of the outwash in lakes along the moraine. Large sand flats south of the Nakina moraines were interpreted as deltas of interlobate streams. In the area between the Nipigon and Nakina moraines, Zoltai (1965b, 1967a) recognized two additional features which he interpreted to be moraines. Northeast of Lake Nipigon (Fig. 6), a prominent ridge of sand and gravel lying parallel to regional ice flow and at the convergence of several tributary eskers was named the Onaman Interlobate Moraine. The distinction between interlobate moraine and esker was apparently made on the basis of size and presence of tributary eskers. In the area north of Lake Nipigon, a similar feature was named the Crescent Moraine (Zoltai, 1965b).

The truncation of the Kaiashk interlobate moraine, west of Lake Nipigon, by the Nipigon moraine, implied to Zoltai (1965b) that a radiating re-advance of the ice margin was responsible for the Nipigon Moraine. This episode of ice flow was named the Nipigon phase (Zoltai, 1965b). The Onaman Interlobate Moraine was attributed to a division of this ice mass into two lobes. The Crescent moraine was cited as a recessional position of the northern lobe. A re-advance to the Nakina I moraine was considered responsible for truncation of the Crescent moraine. A subsequent slight re-advance of this fluctuating ice margin was called upon for formation of the Nakina II moraine.

Zoltai (1965a, 1967a) interpreted a series of features within the study area as a spillway that carried the discharge of a glacial lake. The feature, which he named the Jellicoe spillway, was said to originate at 1130 ft. (345 m) elevation east of Wildgoose Lake as several small channels, leading into the eastern end of the lake. West of Wildgoose Lake two channels, one coming from the east and another from the south, were reported to join, thus forming a single wide channel, which divides into two branches west of Jellicoe. The northern, smaller branch cut through a delta of an esker at 1050 ft. (320 m) east of Lake Nipigon, but built its own delta closer to the lake at 910 ft. (280 m). The southern branch was interpreted as ending in deltas west of Beardmore at 900 ft. (275 m) elevation. The material in the spillway channels was described as gravelly east of Jellicoe, but becoming nearly stone-free sand farther west. Zoltai (1967a) encountered pockets of varved clay in valleys in a 20 mile (30 km) wide belt along the eastern shore of Lake Nipigon. The upper limit of these deposits was found to rise from 950 ft. (290 m) in the south to about 1050 ft. (320 m) in the north. Varved clays as well as silt and sand interpreted as lacustrine sediments were also encountered north and east of Geraldton. In the Geraldton area, a lack of lacustrine sediments in many areas was noted, but inundation by a proglacial lake was called upon to explain a water-washed appearance of till and eskers as well as occasional lag concentrates in the area.

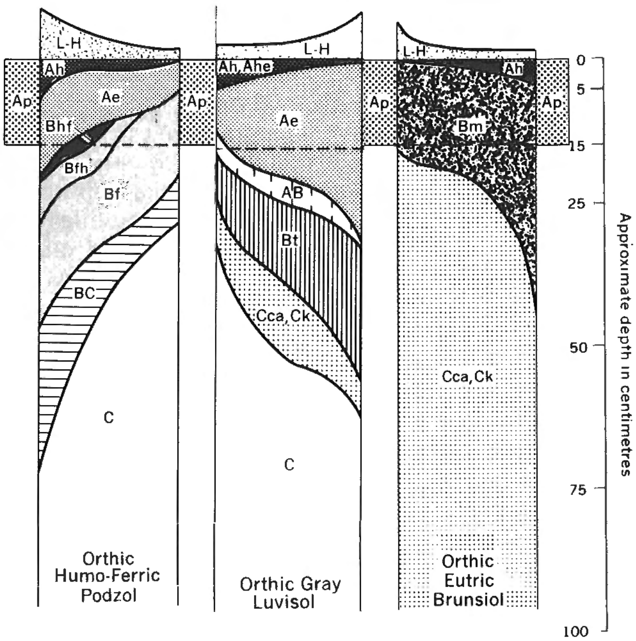


Figure 5. Soil profiles typical of the study area (Agriculture Canada, 1987).

In explaining the glaciolacustrine features of the area, Zoltai (1967a) concluded that a series of proglacial lakes formed in contact with the retreating ice margin (Fig. 7). These inferred water bodies represented an extension of research carried out in the Superior basin by Farrand (1960). As the ice margin retreated from the southwestern Superior basin, the Duluth levels of Lake Superior (Fig. 8) existed (Farrand, 1960). Rapid ice marginal recession, probably aided by calving of icebergs, opened outlets and caused the drawdown of Lake Superior to a level determined by the St. Mary's River at the Sault and the development of a lake which filled the entire basin, one of the Minong series. Isostatic depression of the northern part of the basin relative to the south, combined with a barrier presented by the outlet prior to downcutting (Farrand, 1960), produced high lake levels which extended far to the north of the present extent of Lake Superior (Zoltai, 1967a).

As ice retreated, areas surrounding the present extent of Lake Nipigon were inundated by glacial Lake Kelvin (Zoltai, 1965b). Eastward drainage of Lake Agassiz entered the Nipigon basin at this time (Zoltai, 1967b). As the ice margin retreated across the study area, between the Nipigon and Nakina ice marginal positions, a significant local ponding formed in the area southwest of Wildgoose Lake (Zoltai, 1967a; Fig. 7). Water impounded between the Nakina ice margin and the drainage divide was named glacial Lake Nakina (Zoltai, 1965b). This lake extended across the Geraldton area and drained by the Jellicoe spillway and also by the Pikitigushi spillway north of Lake Nipigon. According to Zoltai (1967a), the early stages of Lake Nakina were confluent with Lake Superior through straits near the western

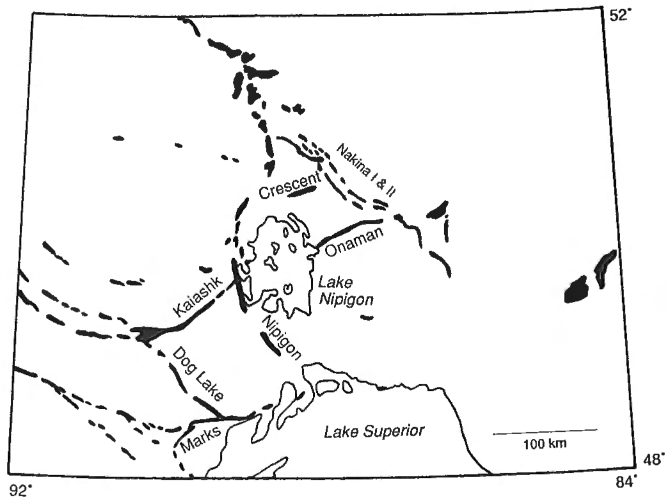


Figure 6. Moraines in the region surrounding the study area (Zoltai, 1965b, 1967a; Prest et al., 1968).

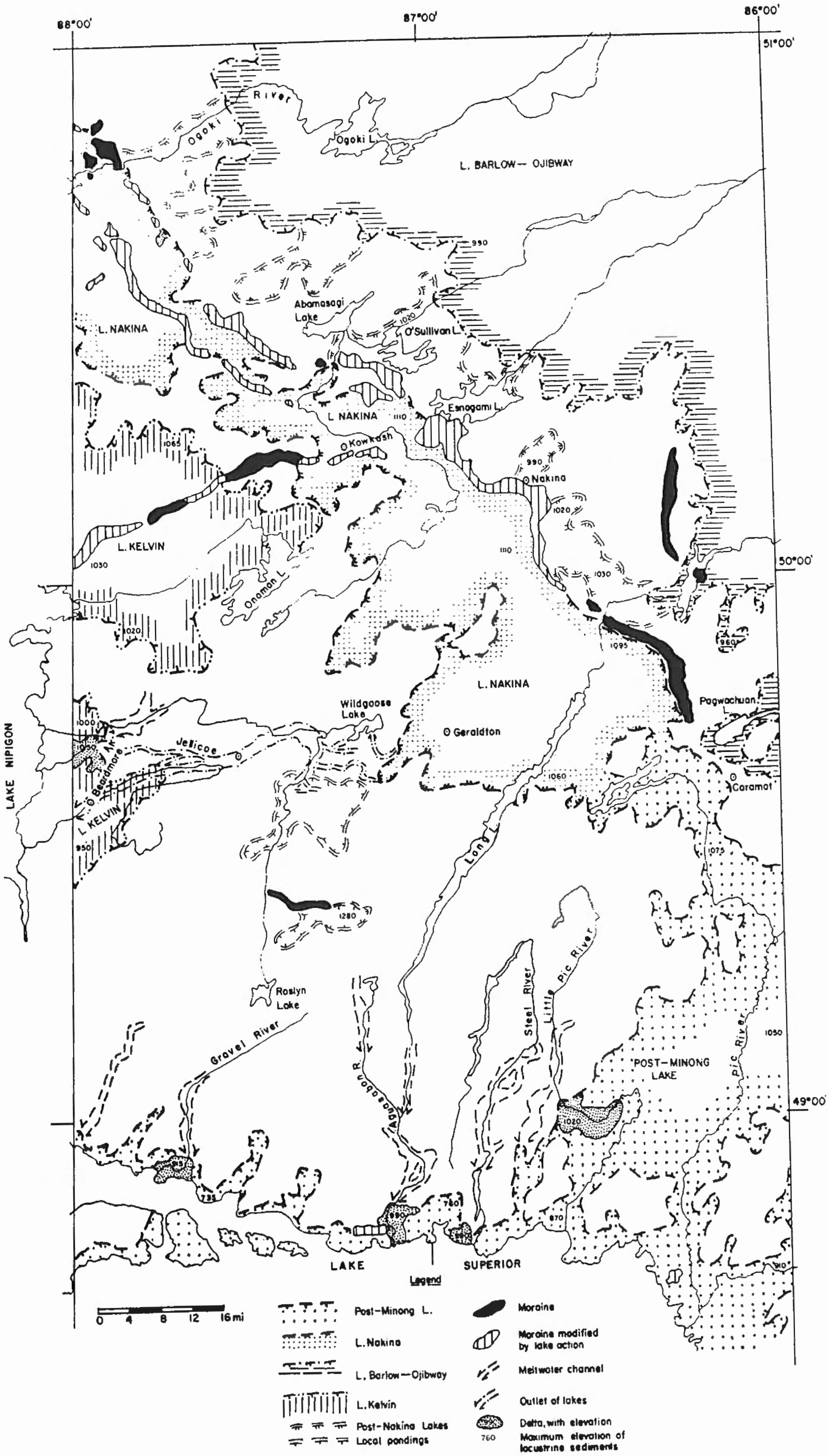


Figure 7. Summary of lacustrine features and approximate extent of glacial lakes (after Zoltai, 1967a).

part of the study area. Lake level lowered in the Superior basin thereafter due to outlet downcutting and isostatic rebound. Lake Nakina eventually drained northeastward into Lake Ojibway as ice retreated from the Nakina II moraine (Zoltai, 1967a).

Zoltai (1967a) considered the role of Long Lake a problem in the history of Lake Nakina. The original elevation of Long Lake was 1017 ft. (310 m) but the lake level was raised by a dam constructed across its northern outlet to 1025 ft. (312 m), permitting its diversion to Lake Superior by a channel, which was excavated as part of the same project, through the low divide at approximately 1050 ft. (320 m) (Coleman, 1909). Zoltai (1967a) concluded that the south end of the lake was sufficiently uplifted to be raised above the level of Lake Nakina, preventing its use as an outlet. This conclusion was necessitated by his observation of large, sharp-crested esker ridges in the valley south of Long Lake, which show no modification by fluvial erosion.

The mapping carried out by Zoltai (1965b, 1967a), as well as similar work to the east by Boissoneau (1966), was subsequently incorporated into a synthesis of the surficial geology of Canada produced by the Geological Survey of Canada (Prest et al., 1968; Prest, 1969, 1970). The Jellicoe spillway was extended to the area north of Longlac by Prest et al. (1968). The Onaman interlobate moraine was re-interpreted as an ice marginal feature by Prest (1969). Apparently on the basis of the Jellicoe spillway extending to a supposed delta at about 900 ft. (275 m) just east of Lake Nipigon (Zoltai, 1967a), Prest et al. (1968) suggested that inundation by glacial lakes extended inland into the study area only about 5 km from Lake Nipigon.

Regional engineering terrain conditions in the Beardmore-Geraldton area were mapped at a scale of 1:100 000 under the Northern Ontario Engineering Terrain Study (NOEGTS), which was initiated in 1977 (Gartner et al., 1980). This mapping was based on interpretation of aerial photographs at a scale of 1:50 000, following a literature review and limited field work. Near surface geological conditions, including landforms, materials, topography, and drainage were mapped using a multiple parameter legend. A discussion of engineering and planning significance of terrain units, such as bedrock plateaus, knobs and ridges, morainal landforms, glaciofluvial landforms, glaciolacustrine landforms, organic terrain, and sand dunes was included in the reports and is summarized below under the heading "Engineering geology". Three NOEGTS reports and accompanying data base maps, extending from 49°30' to 50° latitude, cover the Beardmore-Geraldton study area. The area between Beardmore and Lake Nipigon, west of 88° longitude, was included in the Mount Royal Map area (NOEGTS 26, Mollard and Mollard, 1981). The Jellicoe map area (NOEGTS 27, Gartner, 1979a) extends from 88° to 87° longitude. The Longlac map area (NOEGTS 28, Gartner, 1979b) extends from 87° to 86° longitude. A sand and gravel potential map was included with the Longlac report (Gartner, 1979b).

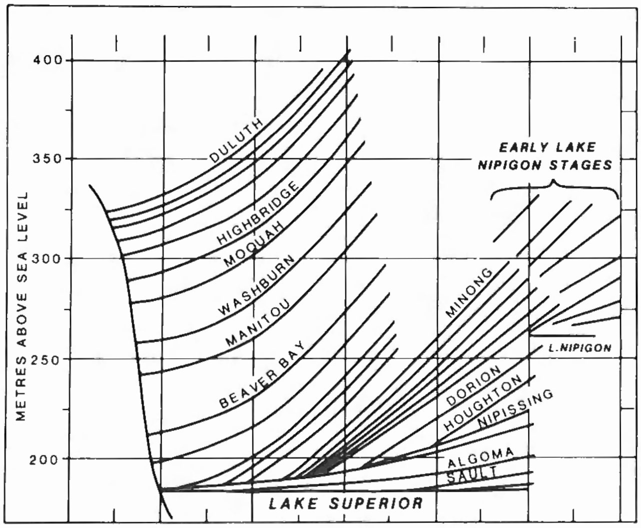


Figure 8. Superior basin proglacial lake levels; vertical lines correspond to isobases or lines of equal postglacial uplift, at 100 km intervals (Teller and Thorleifson, 1983).

Peatland inventories

A review of the peat industry and the extent of peatlands in Ontario completed by Monenco Ontario Limited (1981) included a map of peatland distribution in the study area. A subsequent more detailed peat and peatland inventory of the Longlac-Nakina area, including most of the Beardmore-Geraldton study area, was undertaken by Dendron Resource Surveys Limited (1986) for the Ontario Geological Survey. The dominant peat type in the Longlac-Nakina area was found to be woody sedge-sphagnum peat. Riley and Michaud (1989) included the Longlac-Nakina survey in a synthesis of several similar surveys and drew attention to the general lack of peat deposits on rugged shield terrain in the area and the common occurrence of peatlands on glaciolacustrine, outwash, and till deposits. They indicated that the high calcium carbonate content of drift in the area has resulted in a predominance of strongly minerotrophic (deriving nutrients from the substrate) peatlands, with relatively few ombrotrophic (deriving nutrients from the atmosphere) bogs. High pH values of 6.0 to 7.0 indicated that the material has limited horticultural potential.

Drift provenance

Following the earlier reports of Paleozoic carbonate dispersed southwestward onto the shield from the Hudson Bay Lowland by, for example, Bell (1870), Dell (1963), Zoltai (1967a), and Boissoneau (1966), analysis of this exotic drift continued in association with the implementation of regional geochemical surveys. Coker and Shilts (1979) and Shilts (1980b, 1981) attributed high pH values for lake water north of Lake Superior to a sheet of calcareous till and glaciolacustrine sediment derived from the Paleozoic carbonate rocks in the Hudson Bay Lowland. They also suggested that ice lobes formed during glacial retreat by channelling in depressions or by surging probably had little effect on the composition of the drift, but that the general pattern of carbonate dispersal may have been perturbed by late glacial lobations of the ice margin. These data were later discussed by Friske (1985).

Broad aspects of carbonate dispersal were discussed by Shilts (1980a, 1982b). Pattison (1985) mapped the concentration of carbonate in till and glaciofluvial sediments across the region north of Lake Superior. Karrow and Geddes (1987) acknowledged earlier reports of drift carbonate in the region, but expressed surprise at values of 40% carbonate in the silt-clay matrix and 50% in the pebble fraction of till in the Hemlo area, which is located 150 km south of the bedrock source. They also noted the probable influence of drift carbonate on accuracy of radiocarbon dating and fossil mollusc preservation as well as the need for more detailed mapping of drift composition over large areas.

Drift prospecting

Several projects in the Beardmore-Geraldton area led to the design of the research presented in this report. Sado (1975) evaluated the genesis of the thick calcareous till which hampers mineral exploration in the area between Jellicoe and Geraldton. The till was described as a single unit divisible into ablation facies at surface and a minimally exposed basal facies on the basis of texture, compactness, internal structure, and pebble lithology. The ablation till was described as sandy, loose material with a low silt-clay content and occasional internal stratification. The predominance of Paleozoic clasts in the ablation till was attributed to distal provenance in the Hudson Bay Lowland. The basal till was reported to be poorly exposed but readily found along the incised flanks of abandoned stream channels and the stoss slopes of drumlinoid ridges. The till was described as very compact with a blocky, somewhat fissile internal structure and a higher silt-clay content. A predominance of locally derived, metavolcanic and metasedimentary clasts was reported for the basal till. Hummocks and ridges apparently composed of ablation till along with pockets of blocky basal till and lenses of sand and gravel in a chaotic structural arrangement were attributed to a stagnant ice environment.

A stream sediment survey was subsequently carried out in the Wildgoose Lake area by Closs (1976a, b, c, d, e, f). Clastic stream sediments were not favoured due to their probable derivation from exotic drift. Instead, methods for sampling organic stream sediments developed in Scandinavia were chosen for the study. A total of 556 organic sediment samples, consisting of dead organic material and roots with varying proportions of mineral matter, and 161 clastic sediment samples were collected. Closs found the results to be partially controlled by organic carbon content or Eh/pH conditions. Closs and Sado (1981) later analyzed soils and noncalcareous glacial sediments collected near gold mineralization in the Beardmore area for gold and several other elements. The results indicated that gold itself provides the most consistent indicator of its deposits.

As part of a continuing program of mapping glacial dispersal trains, DiLabio (1982) collected near-surface till samples down-ice from a copper-silver-gold prospect at Onaman River, 80 km north of Beardmore. A dispersal train defined by the distribution of mineralized boulders and increased abundances of copper, silver, and zinc in till was traced 600 m down-ice from mineralized bedrock. Sulphide boulders in malachite-cemented till were encountered. Till in the area contains fossiliferous Paleozoic limestone pebbles and contains about 25 to 35% carbonate in the silt-clay matrix.

Kristjansson (1984) described an overburden drilling project carried out by Cominco Limited in till 2 to 45 m thick near Wildgoose Lake. Till intersected at two sites was subdivided into two units, an upper, loose, sandy till dominated by Paleozoic carbonate rocks of distant provenance overlying a more compact, finer grained till composed mainly of rocks of local provenance. Kristjansson attributed the entire sequence to subglacial deposition on the basis of the strongly streamlined surface. The lower till was attributed to lodgment from sliding ice and the upper to meltout deposition from stagnant ice. Re-activation of ice flow following sedimentation from stagnant ice was proposed to explain the streamlined surface. An overlying thin, discontinuous veneer of extremely bouldery morainic debris was considered to be a minor supraglacial component. The lower till was strongly recommended as the sampling medium for mineral exploration in the area.

Glacial geology of adjacent areas

Glacial geological research in the Hemlo-Manitouwadge area, northeast of Lake Superior, has strongly influenced published research dealing with the Beardmore-Geraldton area.

Garrett (1969) and Grant (1969) examined surficial deposits in the Manitouwadge area as part of GSC geochemical investigations. Grant observed that pasty, highly calcareous till plastered over mineralized bedrock generally failed to produce geochemical anomalies. It was suggested that topographic setting and mechanical properties of the till had prevented ore mineral dispersal and that the till resulted from wholesale transport of easily eroded material from Paleozoic terrane. Garrett (1969) noted that locally derived till preferentially occurs on the down-ice side of major hills.

Major gold discoveries during the early 1980s in the Hemlo area led to additional surficial surveys. Geddes (1984a), who led Ontario Geological Survey surficial mapping at Hemlo, reported thin, locally derived till in areas of high relief and/or thin drift in the area. Elsewhere in the Hemlo area, calcareous sandy silt till was divided into two facies, an upper, commonly observed loose, buff-grey, subcompact and commonly substratified till and an underlying, occasionally observed dark grey, stone poor, massive and extremely dense calcareous till. In some areas, the exotic calcareous till was capped by a stony, sandy, and loose till containing more locally derived rocks. Geddes (1984b) considered structures in the calcareous till to be indicative of subglacial meltout sedimentation. The calcareous debris was attributed by Geddes to long distance, englacial transport of debris-rich bands derived from easily eroded and rapidly entrained portions of the Paleozoic bedrock in the Hudson Bay Lowland. Geddes and Bajc (1985a, b) found that thick calcareous till most commonly occurs on the glacial lee, i.e. southwest, side of major topographic highs. For example, in the area between Hemlo and White Lake, an area of calcareous till 15 km by 15 km in size lies immediately southwest of a prominent east-west bedrock ridge over 1 km wide, 15 km long, and with over 200 m of local relief. Several smaller rock knobs with calcareous till shadows, both the knob and the shadow 1 to 2 km in size and the knob having about 100 m of relief, occur south of White Lake (Geddes and Bajc, 1985b) and near the town of White River (Geddes and Kristjansson, 1986a; White, 1986). The calcareous till was considered an impediment to drift prospecting and a possible source of undesirable chert in aggregate. Use of the calcareous till as fill and possible use as core material in tailings dams was mentioned. The possible influence of the carbonate-related alkaline conditions on elemental mobility was also mentioned by Geddes and Kristjansson (1986b).

Topographic control of till distribution was also identified near the town of Manitouwadge (Kristjansson and Geddes, 1986), where two till deposits about 2 km by 4 km in area occur southwest of bedrock hills that are over 100 m high and about 4 km across. The occurrence of exotic till in the lee of bedrock hills in this area is the opposite of the observation made by Garrett (1969), who perhaps was referring to much smaller scale. Fluted deposits of calcareous till, including sites in the lee of bedrock topographic highs, were identified in the Manitouwadge area by Kristjansson and Geddes (1986) as well as for the White River area by Geddes and Kristjansson (1986a). The calcareous till was not found to the west, in the Marathon area (Bajc and Kristjansson, 1986). Geddes et al. (1985) and Geddes and Kristjansson (1986b) produced a stratigraphic model which also included thin, discontinuous deposits of locally derived subglacial till on the bedrock surface below thicker exotic deposits. The locally derived till was attributed to subglacial lodgment and the fluted exotic till to passive subglacial meltout. Hummocky outcrops of semi-local till and glacially related sediment flows occurring on topographic highs and overlying calcareous till were attributed to supraglacial sedimentation. A late stage of erosion and entrainment of relatively local material near the receding ice front was considered the source of this material.

Hicock (1986) examined aspects of the till sequence determined by Geddes et al. (1985) and added an additional unit, a second lodgment till, to the top of the calcareous sequence. The upper and lower lodgment tills were diagnosed on the basis of striated clasts, pebble fabric, and shear structures. The intervening sandier but calcareous meltout till, according to Hicock, includes percussion and splash structures around boulders and diapirs which indicate subglacial fluvial and sediment flow processes combined with meltout from stagnant ice. Hence a region-wide sequence of four basal tills, locally derived lodgment till overlain by calcareous lodgment, meltout, and lodgment, and a locally derived supraglacial unit were envisaged. Hicock indicated that the entire sequence can be explained by deposition during a single glacial advance over uplands. The model involved simultaneous stoss side upshearing of local debris to eventually produce supraglacial till and lee side downshearing of englacial exotic debris to produce subglacial tills, followed by stagnation. Hicock (1987a) indicated that the simultaneous upshearing and downshearing involved glacial transport upwards or downwards along slip lines of maximum shear stress with or without ice displacement. He also added ice streaming or surging as a component of the topographically controlled sedimentation model. Hicock concluded that the carbonate debris would have been transported farther south were it not intercepted by topographic highs. The presence of thick meltout till was attributed to the stagnation of the entire ice sheet after it reached its maximum extent. Later re-activation of flow in the ice sheet during which the upper lodgment till was deposited and drumlins and flutes were formed was tentatively correlated with the Cochrane re-advance in northeastern Ontario (Hughes, 1965) or the advance to the Nipigon moraine (Nipigon Phase of Zoltai, 1965b).

Hicock (1986) carried out a set of geochemical analyses which included the unprecedented analysis of the <2 μm fraction for gold. Hicock concluded that the supraglacial till is richest in metals and should therefore be sampled in overburden drilling projects.

Hicock (1987b) suggested that the Hemlo depositional model could be applied to the tills of the Geraldton area. Deposition of the Geraldton area calcareous till deposits was attributed to the presence of bedrock knobs 30 m high located 20 km to the northeast, although the scale of the obstructions and their separation from the deposits are unlike the Hemlo case. A structural trough of unspecified nature and which is not apparent on topographical or geological maps was suggested as a control of ice steaming southwest of Wildgoose Lake. Hicock (1987b) also suggested that wacke pebbles in the Geraldton calcareous till were derived from Proterozoic rocks of eastern Hudson Bay, as discussed for the Hudson Bay Lowland by Shilts (1980a, 1982b). Hicock (1988a) later suggested that the Drowning and Kenogami rivers of the Hudson Bay Lowland occupy valleys capable of bifurcating ice flow such that two ice streams were directed to Geraldton and Hemlo. Wahl (1988) suggested that long distance dispersal of carbonate pebbles violated established principles of glacial comminution, that the carbonate must have been derived from nearby outliers, and that the wacke surely could not have been derived from Proterozoic outcrops southeast of Winisk (the Sutton Ridge). Hicock (1988b) responded that the outliers claimed by Wahl had not been confirmed on geological maps and would not be well placed or large enough to supply the debris if they exist, that the principles of basal glacial transport referred to by Wahl do not apply to the englacial transport claimed for the carbonate debris, and that the wacke indeed was not derived from southeast of Winisk but was derived from eastern Hudson Bay. Hicock and Kristjansson (1989) concluded that some mixing between local and exotic debris occurs. Hicock et al. (1989) suggested that calcareous till on the shield acted as a low resistance substratum for ice streams by deforming and/or supporting high subglacial water pressures. The ice streams were attributed to bedrock troughs beneath the ice sheet when it was at its maximum extent during the Late Wisconsinan. A sequence of channelled ice streaming, silty till deposition, reduced bed resistance, and late glacial radiating flow was implied. Hicock et al. (1989) also suggested that drumlins near Wildgoose Lake are erosional forms produced by a subglacial sheet flood.

Summary

In summary, early surficial geological research in the Beardmore-Geraldton region concentrated on regional ice flow patterns and the presence of Paleozoic carbonate in the drift. Zoltai established the geological framework of eskers, drumlins, moraines, and glacial lakes. The pervasive influence of calcareous drift on the regional geochemical environment was recognized. Mineral exploration research made the distinction between unresponsive exotic till at Wildgoose Lake and gold-bearing locally derived till at the surface near Beardmore. NOEGTS mapping gave a more detailed account of surficial materials from an engineering perspective. Surficial mapping in the Hemlo area drew attention to the need for a genetic model explaining deposition of exotic till. Using this knowledge as a foundation, the research project summarized in this report was designed to provide 1) a surficial map more detailed than the NOEGTS maps, and 2) a thorough account of drift composition and origin which would be of use to the mineral exploration community.

Field and laboratory methods

Surficial mapping

Surficial mapping was undertaken during the summers of 1986, 1987, and 1988. Test pitting (Fig. 9) was conducted along all accessible roads at intervals ranging from 50 to 400 m. Sand, gravel, and borrow pits were also examined. These observations were supplemented by boat traverses along lake shores, and foot and motorcycle traverses to isolated locations beyond the usable road network. Data regarding the various landforms occurring within the study area and the texture, structure, and composition of associated surficial materials were obtained.

A Landsat satellite image enlargement at a scale of 1:250 000 provided an assessment of the regional context of the study area and highlighted the contrast between bedrock-dominated and drift-dominated terrain.

Conventional aerial photography (1:15 840) was used in the field and during the preparation of the Quaternary geology map. Map units were delineated by tracing the extent of sedimentary units observed in the field on 1:15 840 air photos examined in stereo.

Summaries of progress in the surficial mapping component of the project were included in the annual Ontario Geological Survey Summary of Field Work and other Activities (Kristjansson, 1986; Kristjansson and Thorleifson, 1987; Kristjansson, 1988) and also in annual reports of the

Figure 9. Drift sampling methods. Surface till samples were collected from about 0.8-1.0 m depth in existing exposures, **A**) hand-dug pits (GSC 1991-266) and **B**) in backhoe trenches (centre, GSC 1991-265). **C**) Thick drift was sampled using a rotasonic overburden drill. (GSC 1991-267)

Beardmore-Geraldton Resident Geologist (Mason et al., 1988, 1989). Three preliminary surficial geological maps at a scale of 1: 50 000 were released for the Wildgoose Lake-Treptow Lake area (Kristjansson et al., 1988), the Geraldton-Longlac area (Kristjansson et al., 1989), and the Beardmore-Northwind Lake area (Kristjansson et al., 1990).

Drilling

The development of overburden drilling methods for stratigraphic investigations and mineral exploration in northern Ontario have been discussed by Skinner (1972), Averill and Thomson (1981), Routledge et al. (1981), Averill and Fortescue (1983), Fortescue et al. (1984), Averill et al. (1986), and McClenaghan (1991).

Thick drift in the area around Wildgoose Lake, southeast of Geraldton and northwest of Beardmore was examined using a truck-mounted rotasonic overburden drill (Fig. 9C). This drilling method, as well as less expensive methods such as reverse circulation, are able to drill through frequent boulders and sample both overburden on the order of 100 m thick as well as the underlying bedrock. The more costly rotasonic method was chosen, however, due to its ability to recover continuous, intact 8 cm core, enabling detailed sedimentological and stratigraphic analysis as well as analysis of fine grained sediment fractions. Drill hole sites were located on roads in the vicinity of known or possible mineralization, at about a 1 km spacing, and where backhoe testing had proven drift thickness exceeding 3 m.

The rotasonic drilling apparatus (Averill et al., 1986; Fig. 10) uses a sequence of bit, core barrels in one or more 10 ft. (3 m) lengths, and rods which operate inside a casing shoe (bit) and casing in 10 ft. (3 m) lengths. Both bit and casing shoe are equipped with tungsten carbide buttons. The drill utilizes varying intensities of rotation, vibration, and downhole pressure to obtain continuous core of material ranging in consistency from soft clay to hard rock. Unconsolidated sediment is cored without water, but rock exceeding a few tens of centimetres in thickness requires the core to be recovered and drilling to be resumed with water pumped down the rods and core barrels to flush the bit. As the rock is penetrated, water is shut off in order to recover underlying sediment. In tough, compact sediments, resistance against both the outer and inner walls of the core barrel dictates that the bit must occasionally be raised in order to admit water to the bottom of the hole. The water subsequently

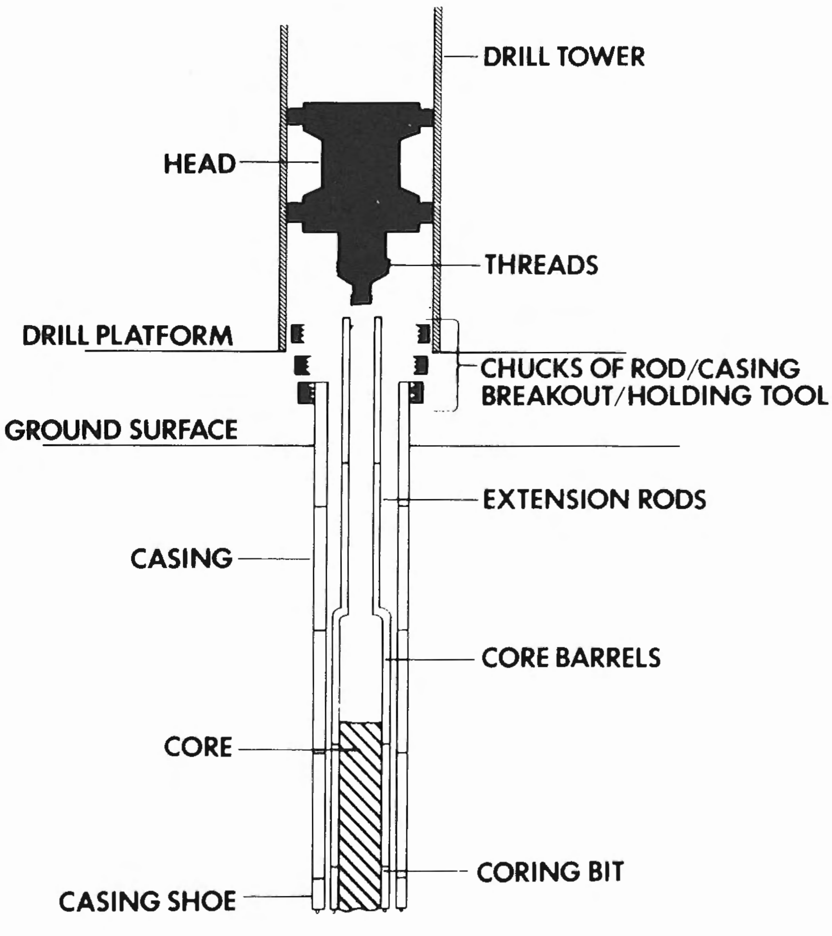


Figure 10. Schematic diagram of a rotasonic overburden drill (from McClenaghan, 1991).

lubricates drilling. A record of depths at which the bit was raised and lowered was kept. Thin sand and gravel occasionally recovered at these depths was discarded and attributed to caving as the bit was raised. Coring was completed in 10 ft. (3 m) increments as core barrels and/or rods were added. Before core was recovered, the casing was advanced to, or nearly to, the depth of the bit. Rods and then core barrels were recovered and the core was extruded from each successive 10 ft. (3 m) core barrel into plastic sleeves using a combination of water pressure and vibration to aid extrusion. Core barrels were raised and core was extruded in most cases at 10 ft. (3 m) intervals. These abnormally short drilling runs were dictated by the resistance exerted by the very compact till against the inner wall of the core barrel. Recovered core was typically found to exceed drilled depth by 50% due to stretching. Depths were assigned by interpolating between the top and bottom of each run, with the aid of depth fixes such as boulders whose actual depth was recorded during drilling as a change in drilling rate and/or much more intense vibration of the drill was noticed. Loose material present at the top of a drill run was discarded if it could be attributed to caving due to the casing falling short of total drilled depth. Caved material was, in most cases, expelled from the hole with water if the bit made contact with sediment above previously drilled depth. At two sites where nearby holes had been previously drilled and analyzed, the upper 25 m was not cored. Water was pumped down the rods in order to disaggregate and flush cored sediment. A lag of pebbles found at the top of the core collected after the water was shut off was discarded. Overburden and bedrock core was placed in 5 ft. (1.5 m) long wooden boxes which held an average of 1.1 m (true depth) of core.

A total of 5 ft. (1.5 m) of bedrock was recovered from each site. Rock was judged to be bedrock if 1.5 m was penetrated, if the character of vibration was considered by the operator to be that of bedrock, and if a rock type expected of bedrock in the area was recovered. The final foot (0.3 m) of bedrock core was recovered without flushing of the bit with water in order to retain the core. Bedrock descriptions were based solely on visual analysis of the sonic core (Thorleifson and Kristjansson, 1990). Samples of the core were filed with the Ontario Ministry of Northern Development and Mines drill core library in Thunder Bay.

Till sequences were drilled at 19 sites, 18 in the Wildgoose Lake area and one between Kenogamisis Lake and Long Lake (Fig. 11). The maximum depth to bedrock encountered at these sites was 60 m. Excluding 29 m of bedrock core, 0.4 m of peat at hole K, a 1.5 m roadbed at hole S, 2.5 m of sand at 32.5 to 34.8 m in hole D which was lost through the bit, and the upper 25 m in holes Q and R, which were not cored, a total of 452 m of continuous 8 cm core was collected. Till, which is readily distinguishable at abrupt contacts with interbedded sorted sediments, makes up 88% of the drilled material. Sand and gravelly sand beds up to 3.6 m thick comprise 8% of the material, 0.5% is gravel, and 0.5% consists of silt and/or clay. The thick, compact till in the Geraldton area produced relatively slow and difficult drilling conditions. Including moving time, an average of 37 m was drilled per 12 hour shift. In addition to the till-dominated holes, a 58 m sand-dominated sequence near Beardmore was also cored.

Rotasonic drill core was transported to a temporary logging facility in Geraldton where it was carefully split using hand tools, described in detail, and photographed. Observations regarding texture and sedimentary structures were recorded. Colour of the moist sediment was described using a Munsell colour chart (Anonymous, 1975). A 15 cm length of half-core from each metre of core was archived in sealed plastic bags. Nearly all of the remaining material from each metre of core was utilized to obtain a 15 kg sample of till or sand. This sample was broken up and homogenized at the logging facility. Splits were taken and the remaining 12 kg, which was to be used to obtain a heavy mineral concentrate, was packed at two samples per pail.

Drill hole logs in schematic form were presented by Thorleifson and Kristjansson (1988a, 1988b) and in more detail by Thorleifson and Kristjansson (1990).

Geophysical methods

Borehole geophysical logging of drill holes was carried out by GSC staff with the following objectives: 1) to determine whether till units can be distinguished using these methods, 2) to test for heterogeneity in what appears to be thick massive till, and 3) to determine whether sulphide-rich till can be detected in order to guide subsequent sampling and analyses. Four sonic drill holes in the Wildgoose Lake area were cased with 10 cm thin-walled PVC pipe to ensure that they remained open for these measurements. The casing for one hole was perforated with vertical slots to facilitate electrical resistivity and induced polarization measurements. All the holes were logged in a continuous logging mode using natural gamma ray, gamma-gamma density, magnetic susceptibility, and temperature tools. Only the gamma ray, density, and magnetic susceptibility logs were successful in providing useful information.

Data for natural gamma-ray, gamma-gamma density, magnetic susceptibility, and temperature, were obtained in holes O, R, Q, and P (Mwenifumbo et al., 1989). The natural gamma ray tool measures variations in natural radioactivity due to changes in the concentrations of the trace elements uranium and thorium, as well as the major element potassium which occurs in clay minerals and feldspars. Only the total count gamma ray logs which monitor the overall natural gamma radiation from the surrounding media were plotted. Low count rates observed in these sediments, in addition to the attenuation of gamma rays by the casing and fluids in these large diameter holes, produced gamma counts in the K, U, and Th windows with poor counting statistics. No attempt, therefore, was made to convert these data into concentrations of the three radioelements. The gamma-gamma density probe consists of a gamma ray source and a detector. Gamma rays are backscattered in proportion to the electron density of the material. The magnetic susceptibility measurements are an indication of the amount of ferromagnetic minerals such as

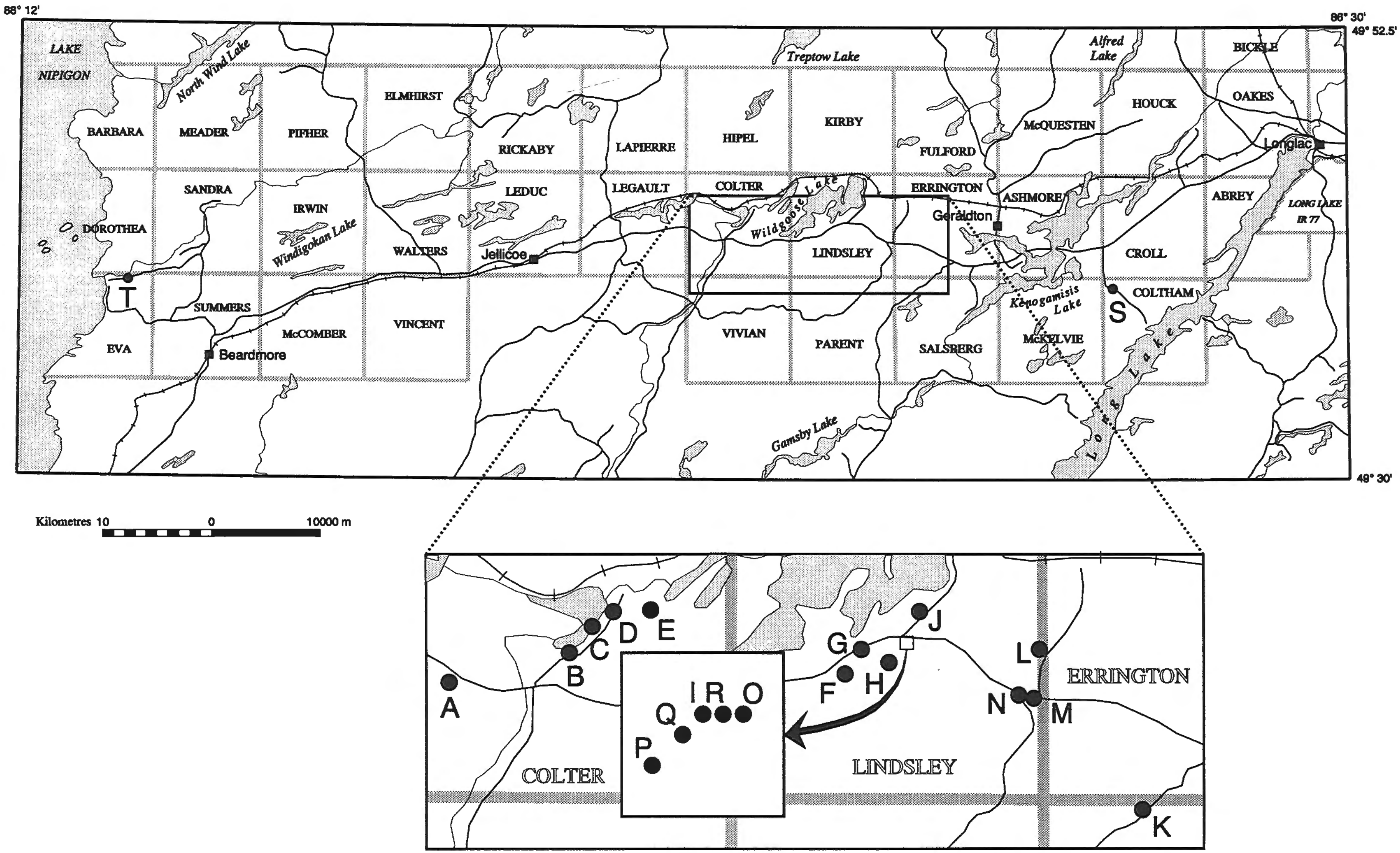


Figure 11. Location of rotasonic drill hole sites.

magnetite, ilmenite, and pyrrhotite in the sediment. Temperature measurements are used in deep diamond drill holes to indicate differing thermal properties of rock, groundwater flow, or chemical reactions. Thermal observations in these shallow, large diameter holes are, however, primarily related to interaction with the atmosphere and thermal stratification of water below the water table.

Engineering seismic methods were used by GSC staff at sites near Wildgoose Lake and near Lake Nipigon to profile major contacts within the overburden sequence as well as the overburden/bedrock contact. Optimum offset shallow seismic reflection methods, with 12 gauge shotgun shells as energy sources, were used (Pullan et al., 1987; Hunter et al., 1989). The seismic lines intersected existing drill hole sites in order to take advantage of known depths to contacts and bedrock in the interpretation of the data, as well as to allow downhole determinations of seismic velocities to be made.

Subbottom surveys using a low-frequency acoustic profiler set up on a 5 m inflatable boat were carried out on Lake Nipigon and Long Lake. Attempts to obtain profiles on Wildgoose and Kenogamisis lakes were unsuccessful due to both gravelly bottom sediments and equipment failure. Surveys were carried out by the senior author, initially with the guidance of A. Blais of the GSC. A Raytheon RTT-100A portable survey system was used, powered by a 12 volt automobile battery and equipped with a low-frequency (3.5/7 kHz) transducer, a high-frequency (200 kHz) transducer, a dry-paper stripchart recorder and a transceiver. The reflection of the high-frequency signal delineates the sediment-water interface. The low-frequency signal penetrates the underlying sediment. Navigation was by dead reckoning between points on shore at constant speed up to 5 knots. Excellent records of bottom morphology and at least the upper part of sediments overlying bedrock were obtained (Appendix 1).

Sample collection

Glacial sediments were sampled to: 1) determine the bedrock sources of the sediment, 2) to assess the nature of processes of erosion and weathering responsible for the present composition of the sediment, 3) to test for the presence and nature of lateral and vertical compositional zoning, and 4) to determine background trends in compositional variables, including indicator minerals and geochemistry.

Surface till and sand samples were collected throughout the area (Fig. 12) during collection of map data from existing exposures such as roadcuts and pits and from shallow excavations dug by hand as well as by backhoe (Fig. 9). Most samples were collected from a depth of 0.7 to 1.0 m.

The material at the sampling depth is considered to be oxidized on the basis of lack of sulphide minerals and its brownish colour in the case of fine grained, calcareous till, which is olive grey below a depth of several metres. Furthermore, calcareous parent materials above about 0.5 to 0.8 m depth are at least partially leached of carbonate. The Agriculture Canada (1987) soil horizon definition which best fits leached material below the A horizon is that of the Bm horizon, a horizon slightly altered by hydrolysis, oxidation, or solution, or all three to give a change in colour or structure, or both. A Bm horizon from which carbonates have been partially removed is referred to as the Bmk, although a colour change only is adequate for designation as Bm. Oxidized till lacking preserved sulphide minerals could, therefore, be referred to as the Bm using strict application of these definitions, despite the occurrence of such material to depths of as much as 7 m. In practice, the destruction of sulphide minerals and the colour change relative to the parent material, assuming olive grey at depth is not a diagenetic colour, is ignored by soil scientists. The presence of carbonate in material at the sampling depth from 0.7 to 1.0 m would lead most workers to assign a C horizon designation. Material only partially leached of carbonate at about 0.5 to 0.8 m could, however, be given a Bmk designation if detailed analytical data were available for carbonate.

The upper C horizon was chosen for the analysis of clastic dispersal and hence drift provenance because it is the least weathered material available from surface. Evaluation of the use of shallower soil horizons for geochemical exploration was not included in the mandate of the project.

Sampling and drill hole sites are located at roughly 1 km spacing along roads where appropriate material was available. A total of 900 till samples was collected, 505 from surface excavations and 395 from rotasonic drill core. The 505 surface till samples included 383 from within the map area and 122 from transects outside the study area. The latter samples were collected at sites ranging from near Lake Superior to the Hudson Bay Lowland and were obtained in order to examine regional compositional trends. A total of 87 samples of glaciofluvial sand and gravel were collected, including 36 samples from pits in eskers, 24 samples from sand and gravel interbedded with till in drill holes, and 29 samples collected from a hole drilled through a sand deposit near Beardmore. The 36 esker samples included 21 from the map area and 15 from sites to the north and northeast of Geraldton, including several sites in the Nakina area.

Large samples were required for analysis of rare indicator minerals. Geochemical analysis for base metals in the silt-clay fraction may be carried out on as little as 0.5 g of material or less, because the material to be quantified is evenly present in this mass of material. In contrast, gold grains and kimberlite indicator minerals occur at a mean concentration on the order of one grain per several kilograms of sediment, if not several tens or hundreds of kilograms (e.g., Averill, 1988). A sample likely to contain these mineral grains must therefore weigh many kilograms. A quantitative analysis of principles governing sample size in indicator mineral analysis was presented by Clifton et al. (1969). They emphasized that selection of sample size must be based on a specified desired degree of precision. As a general rule, they found that a sample containing at least 20 particles of interest is sufficient for most purposes.

During the initial phase of the project, 3 kg till samples intended only for textural and matrix carbonate analysis were collected from the Geraldton-Longlac area. Subsequently, larger samples appropriate for the analysis of gold grains and other indicator minerals were collected, but the small samples were also used. The larger samples weighed approximately 15 kg and were obtained from an excavation or from sections of homogenized drill core typically 1 m in length. Clasts larger than about 10 cm were generally excluded. Four subsamples totalling about 3.5 kg were removed at the field base from till samples (Fig. 13) for: 1) preparation of fractions for fine grained sediment geochemistry (1 kg), 2) grain size (0.5 kg), 3) follow-up geochemical experiments (1 kg), and 4) an archive subsample (1 kg). The remaining material, about 12 kg (Fig. 14), was processed for the heavy mineral concentrate in which indicator minerals were sought as well as a gravel fraction sample. Sand samples were submitted for heavy mineral concentration only.

Sample processing

Compositional analysis of sediments was undertaken using various principles established by previous research regarding the choice of analytical fractions and the distinguishable materials to be quantified by their weight or frequency proportion of a certain fraction (Dreimanis and Vagners, 1971; Shilts, 1971).

Separation of the high density or 'heavy' mineral fraction of drift samples is a widely used technique because this fraction contains gold grains, ore minerals, and other indicator minerals, and also because it is easily separated. Methods of heavy mineral preparation and analysis have been developed for a broad range of applications in sedimentary

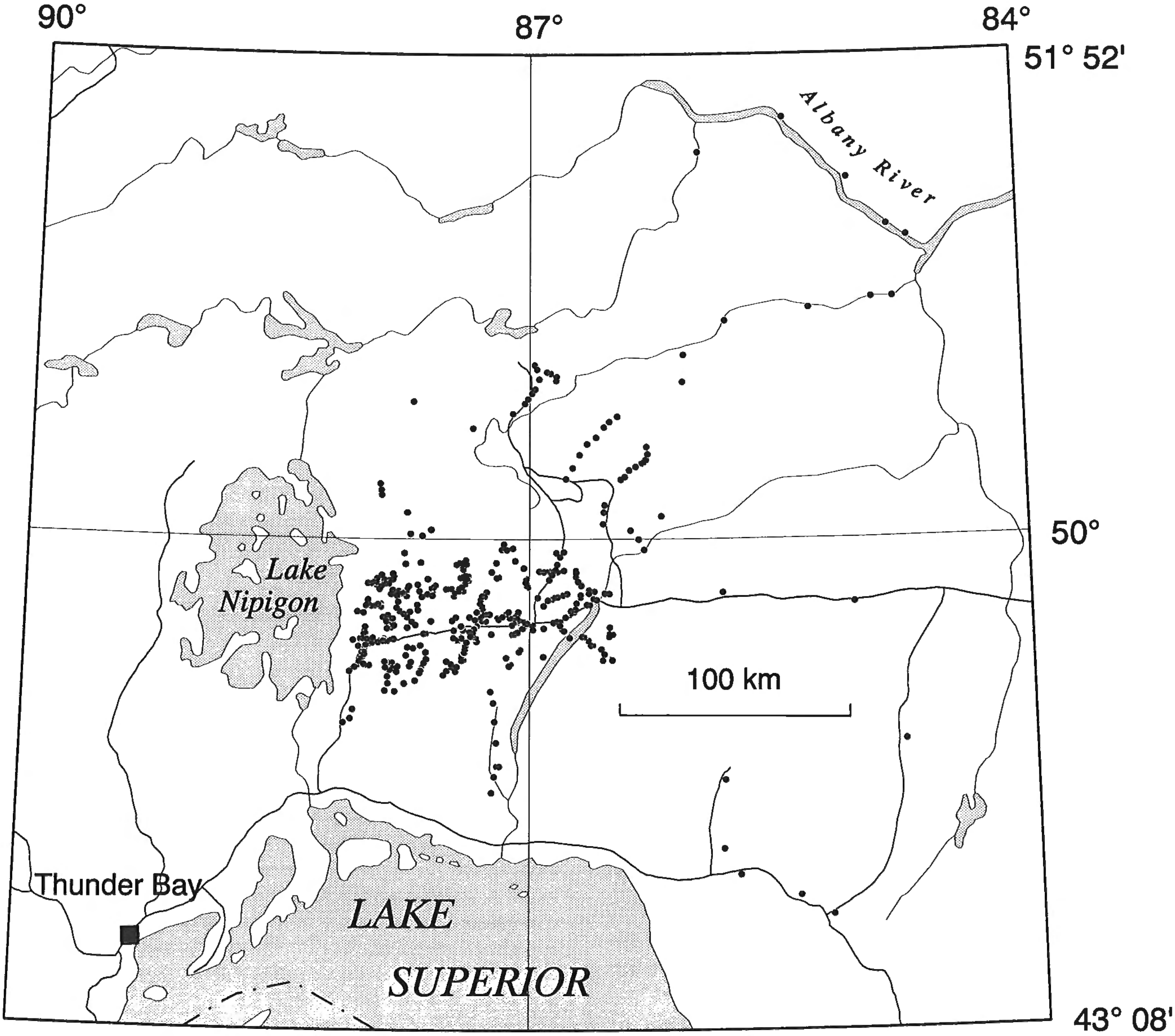


Figure 12. Location of surface till sample sites.

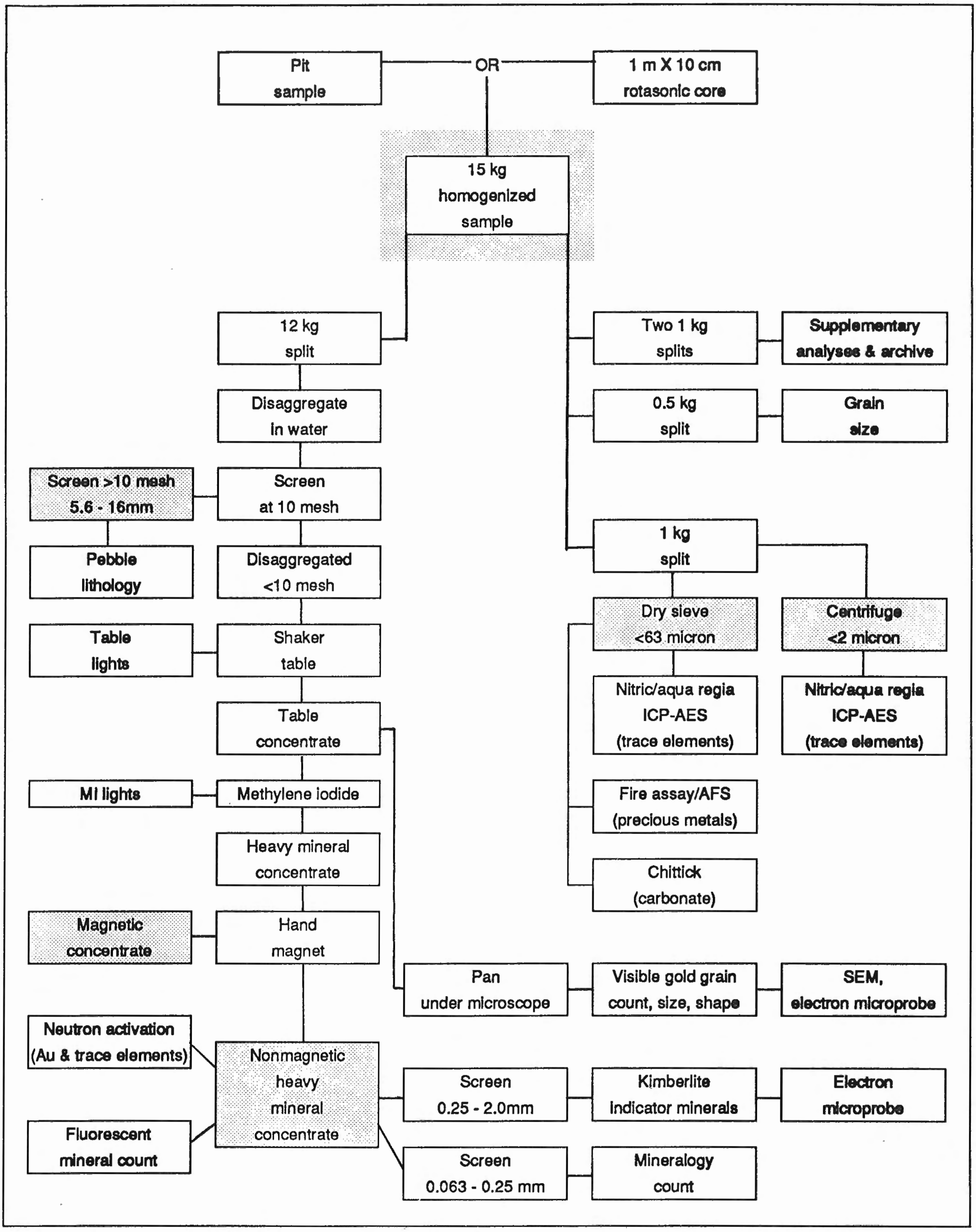


Figure 13. Sample processing flowchart.

petrology (Parfenoff et al., 1970; Carver, 1971; Griffiths, 1967; Peuraniemi, 1990). The most common heavy mineral separation technique used in the past has been the flotation of light minerals on a heavy liquid such as bromoform with a specific gravity of 2.9 or tetrabromoethane with a specific gravity of 2.96. Recently, the more dense liquid methylene iodide, with a specific gravity of 3.3, has come into more common use. This liquid excludes micas and most of the amphiboles and clinopyroxenes. These minerals have diverse sources and occur in numbers sufficient to mask other more sensitive indicators (Shilts, 1975).

The heavy mineral concentrate was obtained from the sample material remaining following the removal of subsamples from the original 15 kg sample, about 12 kg (Fig. 13). These samples were processed by Overburden Drilling Management Ltd. of Nepean, Ontario (Averill et al., 1986; Averill and Zimmerman, 1986; Averill, 1988). The material was disaggregated and screened at 10 mesh (2 mm). The heavy mineral fraction was recovered from the -10 mesh fraction. A shaking table was used to reduce the material to a preconcentrate. The final concentrate was obtained by flotation of the light minerals on methylene iodide (Fig. 13). Magnetite and other magnetic minerals were separated from the nonmagnetic concentrate using a hand magnet. The method used for removal of magnetic minerals is designed to remove strongly magnetic minerals such as magnetite and pyrrhotite only. Hence weakly magnetic minerals such as ilmenite occur in the nonmagnetic heavy mineral concentrate.

The +10 mesh fraction, shaking table light fraction, methylene iodide light fraction, the magnetic heavy mineral concentrate, and the nonmagnetic heavy mineral concentrate were retained. Weights for moist sample used, +10 mesh, table feed, table concentrate, methylene iodide lights, total concentrate, nonmagnetic concentrate, and magnetic concentrate were recorded.

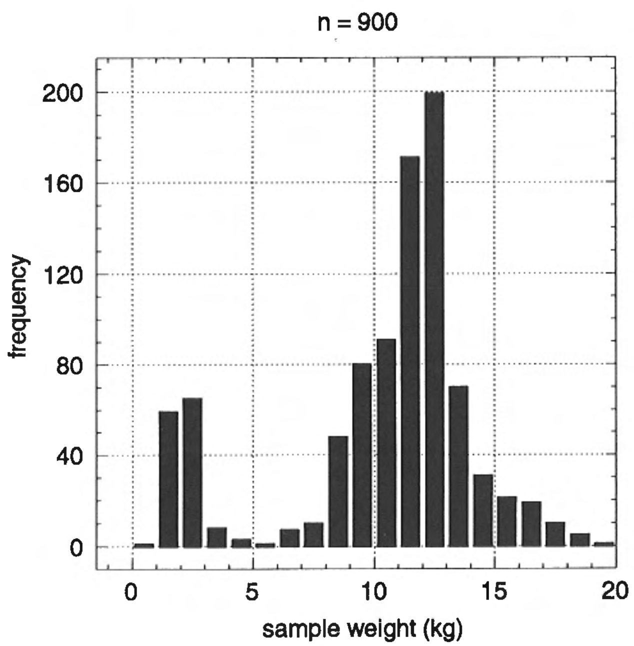


Figure 14. Weight of till used to obtain a heavy mineral concentrate, after the removal of subsamples for other procedures. n = number of observations.

A 1 kg split of homogenized till samples (Fig. 13) was prepared by Chemex Labs Ltd. for geochemical analysis of the fine grained sediment fractions. The <63 μm fraction was obtained by dry sieving a subsample through a stainless steel 230 mesh screen. The <2 μm fraction was obtained by centrifugation in a 5 g/l sodium metaphosphate solution according to the method of Jackson (1969). The sediment was first suspended in the solution using a mixer. The suspension was immediately poured into a centrifuge bottle. Sand and gravel were left in the mixing container. In the first centrifugation step, the >2 μm material was removed from suspension at low RPM. The supernatant was then decanted into another centrifuge bottle and the <2 μm material removed from suspension by centrifugation at high RPM.

Pebble lithology

Tracing of glacial erratics provides data on the bedrock source of glacially transported debris. Tracing of mineralized clasts may furthermore be used in mineral exploration (e.g., Bouchard and Salonen, 1990). Observations on the provenance of boulder-sized erratics were made in the field, but systematic data collection was only carried out on pebble and granule-sized clasts recovered from till samples during preparation of the heavy mineral concentrate and from esker samples in the field.

The 5.6 to 16 mm fraction was examined because these clasts are large enough to be easily identified and were available in sufficient quantities for reproducible counts as a result of the collection and processing of large samples. The upper limit was arbitrarily selected in order to exclude large clasts which would have reduced reproducibility. The lower limit was chosen to avoid either a gap or overlap with the upper limit of the 2-5.6 mm fraction which has been analyzed by, for example, Shilts (1982b) and Thorleifson (1989) for till samples from across northern Ontario and Hudson Bay. Shilts analyzed this fraction because more easily identified coarser clast sizes were not available in sufficient numbers from 3 kg samples collected on helicopter traverses. A sample of about 1 kg of 5.6-16 mm material was used for the count. The pebbles were classified as Paleozoic carbonate, granitic, or metasedimentary-metavolcanic. The 2-5.6 mm fraction (40 g split) from selected samples was also screened from the +10 mesh fraction and classified in order to obtain a comparison to earlier work on this fraction (Shilts, 1982b). These pebble and granule lithology counts were carried out by GSC staff and by Consorminex Inc. of Gatineau, Quebec.

Pebble count data were published by Thorleifson and Kristjansson (1990).

Grain size analysis

Two measures of textural analysis were utilized. Processing of large samples presented an unusual opportunity to examine gravel (>2 mm) content of till samples. Data reported by

Overburden Drilling Management Ltd. following preparation of heavy mineral concentrates included total weight of the moist sample and weight of the +10 mesh (>2 mm) material removed from the sample prior to shaking table concentration. Gravel content was obtained by dividing the weight of +10 mesh material by the total sample weight. The upper limit of this gravel determination is, however, not well defined due to the fact that a limit was simply applied at the time of collection by rejecting material coarser than about 10 cm.

Grain size analysis of the <2 mm (-10 mesh) fraction was carried out for selected till samples by the Geoscience Laboratories of the Ontario Geological Survey. Sand fractions were quantified by dry sieving at one phi intervals. The silt and clay fractions (-230 mesh, <63 μm) were analyzed by pipette analysis. The results of the latter analyses are reported as a percentage of the <2 mm fraction.

Matrix carbonate content

The <63 μm fraction of till samples was analyzed at the Geoscience Laboratories of the Ontario Geological Survey as well as the Sedimentology Laboratory of the GSC for carbonate minerals using a Chittick gasometric apparatus according to the method of Dreimanis (1962). This procedure has been empirically calibrated using the assumption of typical occurrences of calcite and dolomite in the acid soluble material. Gas production at 30 seconds and at completion of reaction, several tens of minutes, are used to calculate calcite and dolomite content, respectively. Matrix carbonate data were published by Thorleifson and Kristjansson (1990).

Mineralogy

Heavy mineral identification methods described by Paré (1982) were applied by the staff of Consorminex Inc. to determine the dominant minerals in selected nonmagnetic concentrates. The fine sand fraction discussed by Shilts (1971) (63 to 250 μm fraction), was utilized for counts of major mineral types. This size fraction spans the range in which heavy minerals preferentially occur and includes size ranges used by several authors (Vagners, 1969; Dreimanis and Vagners, 1971; Karrow, 1976; Gwyn and Dreimanis, 1979). A few milligrams of this fraction was mounted in araldite on glass slides. A stereoscopic binocular microscope, rather than a petrographic microscope, was used because of its superiority in the examination of opaque and turbid mineral grains. The microscope was equipped with polarizing light capabilities in order to test for birefringence. A total of 250 grains were identified in each sample. Certain minerals were subdivided on the basis of distinctive forms. However, for subsequent data interpretation, these groups were recombined. Percentage frequency of each class was calculated using a total number of grains which excluded clinopyroxenes and amphiboles. The specific gravity of these minerals spans that of methylene iodide, so slight changes in the density of the heavy liquid or differences in the separation procedure could significantly influence yield.

Visible gold grains obtained on the shaking table and by panning under a binocular microscope were classified by the staff of Overburden Drilling Management Ltd. on the basis of size and morphology, and a predicted assay was calculated (Averill, 1988). Table concentrates were panned if three or more gold grains were observed on the table. Gold grain abundance data from the first phase of surface sample collection were published by Thorleifson and Kristjansson (1987). Counts from the first phase of drilling were subsequently released (Thorleifson and Kristjansson, 1988b). Visible gold grains coarser than 100 μm were removed from a few selected samples in order to permit immediate scanning electron microscope and electron microprobe analysis of the gold at GSC laboratories. Visible gold-bearing bedrock samples provided by the Beardmore-Geraldton Resident Geologist's office were also analyzed by microprobe for comparison.

The coarse nonmagnetic heavy mineral fraction, 0.25 to 2.0 mm, was visually examined for kimberlite indicator minerals under a binocular microscope by Consorminex Inc. This size range, medium to very coarse sand, was used as this is the typical grain size range in which the common kimberlite indicator minerals occur in their source rocks (Wolfe et al., 1975; Stewart et al., 1988). The grains which were selected were: 1) purple garnet, considered possible peridotitic chrome pyrope; 2) orange garnets, considered possible eclogitic garnet; 3) vitreous, jet black, conchoidally fractured ilmenite, considered possible magnesian ilmenite; and 4) emerald green diopside, considered possible chrome diopside. All grains visually selected as possible indicators were subsequently analyzed by GSC staff by electron microprobe in order to obtain a conclusive identification.

The entire nonmagnetic heavy mineral concentrate was examined by the staff of Consorminex Inc. for fluorescent minerals using a short wave ultraviolet lamp. The sample was scattered over a 30 cm by 30 cm grid drawn on a sheet of nonfluorescent paper. Counts of grains fluorescing yellow, blue, and green were visually obtained either by counting the actual total or by extrapolating from a count of a portion of the grid. Grains fluorescing yellow, usually several thousand grains per sample, were visually identified as zircon. The blue grains, as well as a few similar but greenish grains, were visually identified as scheelite. The latter identification was confirmed by electron microprobe analysis of six grains.

Mineralogical data were published by Thorleifson and Kristjansson (1990).

Geochemistry

The <63 μm fraction was analyzed at Chemex Labs of Vancouver for Au, Pt, and Pd by fire assay/atomic fluorescence spectrometry analysis of 30 g of material. A 0.5 g split of both the <63 μm and <2 μm fractions was analyzed by Chemex Labs for trace elements using nitric-aqua regia partial extraction followed by inductively coupled plasma-atomic emission spectrometry (ICP-AES). This package included analysis for Al, Ag, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Se, Sr, Ti, Tl, U, V, W, and Zn.

A 7/8 split of nonmagnetic heavy mineral concentrates, weighing about 10 g, was analyzed by Bondar-Clegg & Co. Ltd. of Ottawa by instrumental neutron activation analysis for gold as well as Na, Sc, Cr, Fe, Co, Ni, Zn, As, Se, Br, Rb, Zr, Mo, Ag, Cd, Sn, Sb, Te, Cs, Ba, La, Ce, Sm, Eu, Tb, Yb, Lu, Hf, Ta, W, Ir, Th, and U. The concentrates were returned by the lab after a cool-down period of, for these materials, about 10 months. A shorter cool-down period would have been required for return to a facility licensed to handle low-level radioactive material. Destructive analyses such as wet chemistry, which would have been required for satisfactory base metal data, were not utilized in order to enable indicator mineral analysis and neutron activation analysis of as much material as possible. The 1/8 split of the concentrate was retained for reference and backup.

Magnetic concentrates from the Beardmore area and from holes D, E, I, K, and N were analyzed by Chemex Labs Ltd. of Vancouver for Au, Pt, and Pd by fire assay/atomic fluorescence spectrometry and by ICP/AES following perchloric-nitric-hydrofluoric total extraction. The latter procedure produced data for Mo, W, Zn, P, Pb, Bi, Cd, Co, Ni, Ba, Fe, Mn, Cr, Mg, V, Al, Be, Ca, Cu, Ag, Ti, Sr, Na, and K.

High detection limits prevented the acquisition of usable data for some elements. Duplicates split after preparation as well as bulk reference materials were used in each batch in order to monitor precision. The geochemical analyses were carried out in several batches over three years.

Bedrock core from rotasonic overburden drill holes was crushed and analyzed at Chemex Labs by the same methods as the <63 μm fraction of till samples. Three samples, representing a range of depths and degrees of sulphide mineralization, were obtained from the bedrock core from each hole.

Thirty-six till samples, most gold-bearing, were selected for more detailed geochemical analysis. Several grain size fractions (<5.6 mm, 2-5.6 mm, 0.25-2 mm, 63-250 μm, <63 μm, and <2 μm) and material resulting from heavy mineral processing (table lights and methylene iodide lights), were analyzed at Chemex Labs Ltd. for gold by fire assay (10 g) twice in separate batches, in order to test for heterogeneity with respect to gold, for arsenic by atomic absorption, as well as by the methods and for the elements listed above for the fine grained and magnetic fractions using both partial and total extractions.

Geochemical data were published by Thorleifson and Kristjansson (1990).

PHYSICAL GEOLOGY

The distribution of surficial geological features in the study area is shown in accompanying Map 1768A at a scale of 1:100 000. Regional physical geology is discussed below on the basis of field data, air photo interpretation, analysis of surface drift samples and overburden drill core, and literature review. Historical and applied geology are discussed in later sections.

Bedrock-dominated terrain

Small areas where bedrock constitutes greater than about 75% of the surface (map unit 1) occur in the western half of the area and east of Long Lake. Only scattered occurrences of very thin, discontinuous drift and colluvium are present in these areas. Within surrounding and much more extensive areas of bedrock-drift complex (map unit 2), minor to moderate exposures of bedrock (between about 15 and 75% outcrop) are associated with thin and/or discontinuous drift and colluvium which is generally less than 1 m thick but locally can be as thick as 2 to 3 m. Bedrock therefore occurs at, or very near, the ground surface in these areas. Consequently, the geometry of the bedrock surface controls topography.

The most prominent bedrock landforms in the area are related to Proterozoic diabase outcrops near Lake Nipigon (Fig. 15). These rocks are generally undeformed and overlie strongly deformed Archean rocks. Erosional remnants of thick diabase dykes and sills form large, flat topped hills with talus accumulations along their flanks. Bedrock ridges oriented east-west, parallel to the strike of Archean rock units, are prominent between Beardmore and Jellicoe, but in some cases may be traced from Beardmore to Long Lake (Fig. 4). In the northern part of the map area, elliptical granitic bedrock highs several kilometres long and wide trend northeast to southwest.

Smaller erosional forms observed on the bedrock surface were formed, in most cases, by sliding glacial ice. Striated (Fig. 16) and grooved bedrock surfaces, bedrock stoss and lee features, whaleback forms, and bedrock drumlins resulting from the scouring action of sliding glacial ice are well developed and common features of the Beardmore-Geraldton area.

Evidence for an earlier episode of ice flow occurs as rare facets on bedrock surfaces with striations oriented between approximately 190° in the Geraldton area and 210° in the Beardmore area (Fig. 16). The facets are remnants of an early phase of glacial erosion and bedrock streamlining to the south and south-southwest. The facets are located on the southwest side of bedrock highs which formed obstacles or irregularities on the bed of the glacier.

During the subsequent period of ice flow that is ubiquitously recorded across the area, the bedrock surface was abraded and streamlined in a southwest to west direction. Glacier flow directional features from the southwest phase of flow form a diverging or radial flow pattern. In the eastern half of the study area, the orientation of glacial striations diverges from about 200° east of Long Lake to 230° in the central part of the study area. In the western half of the study area, the trend reaches values as high as 260° near Lake Nipigon (Fig. 17).

Sculpted bedrock erosional forms or S-forms ranging in size from a few centimetres to a few metres, including bow-shaped furrows referred to as sichelwannen (Dahl, 1965; Allen, 1984), are present in the area. Excellent examples occur adjacent to the open stope of the former Hardrock mine (Fig. 18). Boulton (1974) attributed these features to differential abrasion by debris-laden ice being diverted around an obstruction. However, the frequently observed lack of an apparent obstruction, occurrence of the forms on surfaces sheltered from ice flow, their association with parallel striations, and the apparent requirement for turbulence in the erosive flow suggests they were formed by subglacial meltwater flows (Allen, 1984; Shaw, 1988; Sharpe and Shaw, 1989; Shaw and Gilbert, 1990; Kor et al., 1991).

Diamict

The terms diamicton and the lithified equivalent, diamictite, were defined by Flint et al. (1960a, b) as descriptive terms without genetic implications for nonsorted or poorly sorted, noncalcareous, terrigenous sediments that contains a wide range of particle sizes. The term noncalcareous was included to exclude bioclastic carbonate sediments; sediments that contain abundant rock fragments of older limestone were specifically included. The terms were proposed as replacements for descriptive terms such as boulder clay, conglomeratic sandy mudstone, and pebbly mudstone. The general term diamict, which is used in this report, was proposed by Harland et al. (1966). In fluvial sequences, diamicts are referred to as matrix supported gravels (Miall, 1978). Confusion has resulted from use of the word till as a nongenetic synonym for diamict, the uncritical genetic interpretation of diamicts as till, and the misconception that diamict is till-like sediment of enigmatic origin. Diamicts may be generated by several processes (e.g., Dreimanis, 1989, 1990), specifically slope failure (tilloids, Pettijohn, 1975; flowtills, Hartshorn, 1958), rafting by floating ice (paratills, Harland et al., 1966; ice rafted debris or IRD, Eyles and Eyles, 1982), ploughing by ice bergs (ice berg turbate, Vorren et al., 1983) or by the direct action of glacier ice (orthotills, Harland et al., 1966).

In the context of genetic interpretation, only the last group is here referred to as till. The term till is also used, however, as a loose term for sediment at a large number of sampling sites which is believed in most cases to be till deposited in contact with glacial ice.

Description

Diamicts were observed throughout the Beardmore-Geraldton area in excavations and overburden drill core. Distinction between diamict and sand or gravel was readily made in nearly every case, if the upper soil horizons were penetrated and slightly weathered material was observed. In the field, diamicts were recognized as gravel-bearing sediments with a silty matrix. Analysis of several hundred shovel holes was generally limited to preliminary textural and compositional observations only. In the walls of excavations such as ditches, road cuts, and trenches, additional features such as clast arrangement and interbedding were observed. Drilling permitted the observation of the entire sequence of strata overlying bedrock, but information on clast arrangement was limited to vertical trends in coarse clast frequency only.

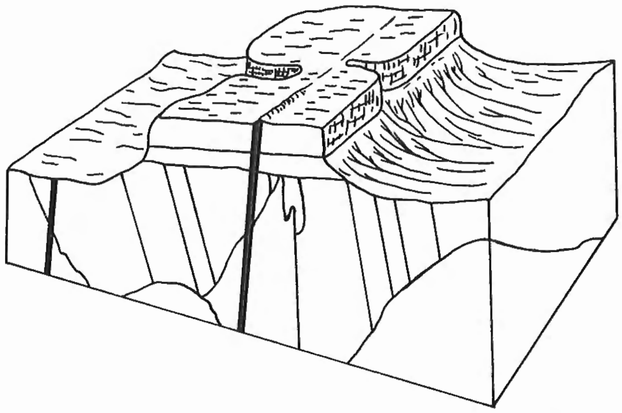


Figure 15. Bedrock topography, produced by undeformed Proterozoic diabase which overlies deformed Archean rocks in the Beardmore area (from Pye et al., 1966). The schematic block diagram represents an area about 10 km x 10 km.

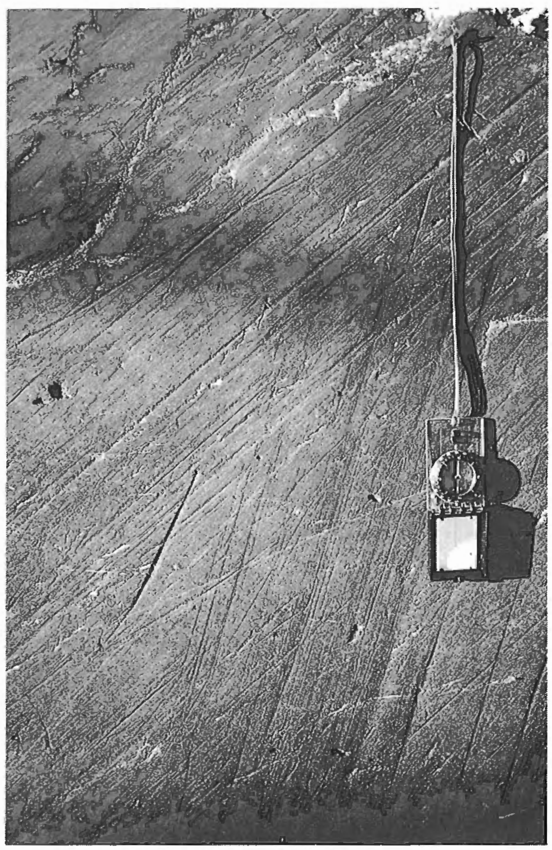


Figure 16. Crossing striations at a site near Highway 11 at Kenogamisis Lake; older set at 190° crossed by younger southwestward flow. Compass is oriented to true north. (GSC 205458A)

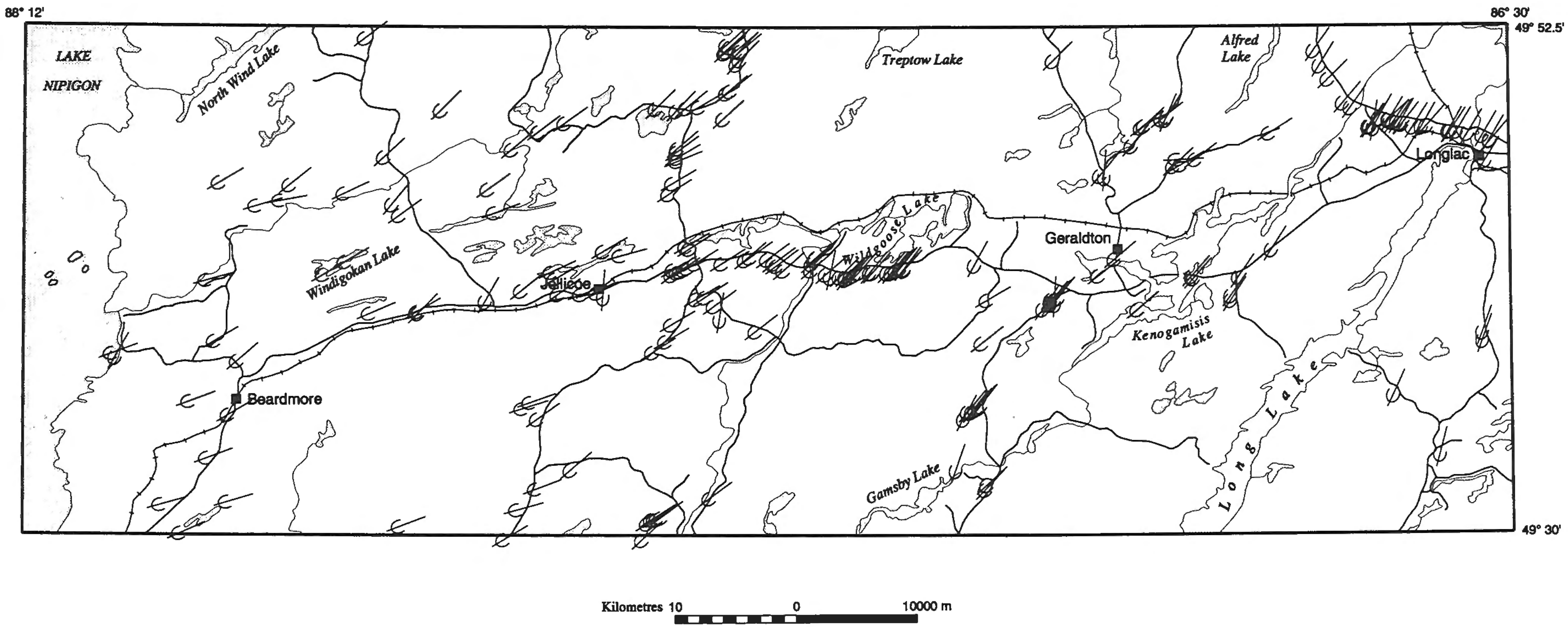
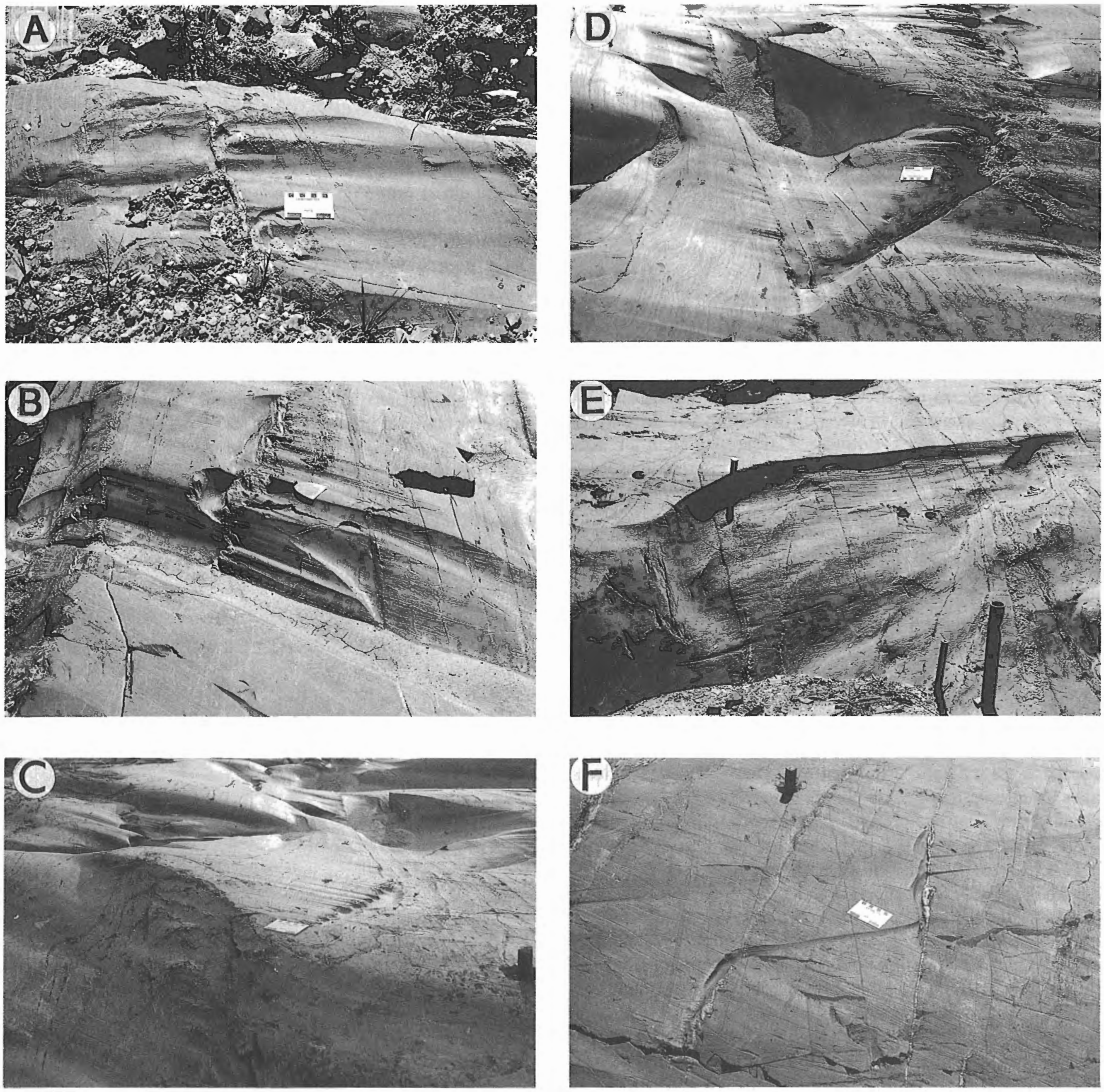


Figure 17. Orientation of glacial striations on bedrock.



A. Two converging depressions associated with an obstacle (GSC 204258-P);
B. Linear depressions crosscut by expanding and shallowing depression (GSC 204258-U);
C. Depression on north side of obstacle (GSC 204258-Y);
D. Asymmetric depression, expanding southward, includes small linear forms (GSC 204258-N);
E. Horseshoe-shaped depression crosscutting southwest striations (GSC 204258-V);
F. Repeated redirection at obstacles of elongate depression, which crosscuts southwest striations (GSC 204258-Z).

Figure 18. Sculpted erosional forms on bedrock, Hardrock mine, Geraldton. Photographs by D.R. Sharpe, GSC.

Diamicts examined in shovel holes could readily be classified as being 1) sandy and noncalcareous, 2) silty and calcareous, or 3) intermediate between these end members. Carbonate content was confirmed using dilute hydrochloric acid, although significant carbonate content was recognizable in the field on the basis of visible silty texture and consistent colour, light brownish grey or Munsell 2.5Y 6/2. Angular metasedimentary and metavolcanic pebbles similar to local greenstone bedrock were observed in the sandy, noncalcareous material. Light brown, commonly fossiliferous Paleozoic carbonate pebbles, rounded black greywacke, and granitic pebbles were present in the calcareous diamicts. Because there are no Paleozoic outliers in the Beardmore-Geraldton region, the Paleozoic carbonate clasts must be exotic, that is, derived from outside the greenstone belt. Angular clasts similar to local bedrock also occur, however, in calcareous drift. Noncalcareous diamict was generally observed in areas of discontinuous drift cover and abundant bedrock outcrop. Calcareous diamict also occurs in these areas as well as consistently occurring in areas of fluted thick drift and rare bedrock outcrop.

Diamict deposits were also examined in the walls of excavations at several sites (Hicock, 1988a; Hicock and Kristjansson, 1989). In order of apparent frequency, these occurrences include massive diamicts, massive diamicts in which cobbles have horizontal striated facets on their upper surfaces (Fig. 19), thin diamicts interbedded with sandy sediments, and graded diamicts up to several metres thick. More generally, as summarized by Hicock (1988a), the surface exposures are divisible into compact, massive diamicts and an apparently overlying assemblage of less compact graded and partially stratified sequences. The long axes of elongate pebbles in massive diamicts commonly show southwest-northeast orientations, with a secondary mode transverse to this orientation; striations on pebbles and cobbles in the diamict are generally more strongly oriented southwest-northeast (Hicock, 1988a; Hicock and Kristjansson, 1989). A 3.5 m thick, graded diamict which overlies sand and which has a concentration of randomly oriented, angular granitic cobbles and boulders in the lowest metre (Fig. 19B) was observed in a roadcut northwest of Geraldton, near Fulford Lake (site 7 of Hicock, 1988a). This compact, calcareous material includes lenses of sorted sediment several centimetres in thickness and lateral extent. Hicock (1988a) referred to the concentration of cobbles and boulders as a boulder pavement, although it is not a striated boulder pavement (Flint, 1971).

Diamicts readily distinguishable at abrupt contacts with interbedded sorted sediments make up 88% of material drilled in the Geraldton area (Fig. 20).

Virtually all of the drilled diamict contains a readily apparent gravel fraction in a matrix ranging from silty sand to clayey silt. Visual compositional analysis was sufficient to distinguish diamicts with a significant component of Paleozoic carbonate pebbles (Fig. 21) from those lacking this material. The latter sediments (Fig. 22) were intersected in the lowermost parts of holes D, E, I, R, O, N, and K. Diamicts varied in consistency from friable in the upper few metres of most holes, to easily disaggregated, locally derived sandy diamicts overlying bedrock, to hard in thick silty diamicts below 10 m depth. Core from these hard units in some cases could only be cut by striking a knife with a hammer, but the material was not brittle.

Cobbles and a few boulders exceeding core width in diameter make up 4% of the cored diamict thickness. These large clasts range up to 1 m in cored thickness but average 0.2 m. Granite and gneiss comprise 65% of cored cobbles and boulders. The remaining 35% consists of metasedimentary and metavolcanic rocks whose observed frequency relative to granitic rocks increases close to the bedrock surface.

Diamict colour patterns in drill holes are monotonous, but are clearly divisible into two groups, brown and grey. In the upper 2 to 7 m, colour ranges from greyish brown (Munsell 2.5Y 5/2; moist) to pale yellow (2.5Y 7/4), but are most commonly light brownish grey (2.5Y 6/2). The lower limit of these brownish to yellowish colours in every case is an abrupt change to dark grey (5Y 4/1), grey (5Y 5/1), or olive grey (5Y 5/2). Slightly olive grey colours continue down to bedrock, although a few cases of neutral grey (N 6/; N4/) were encountered.

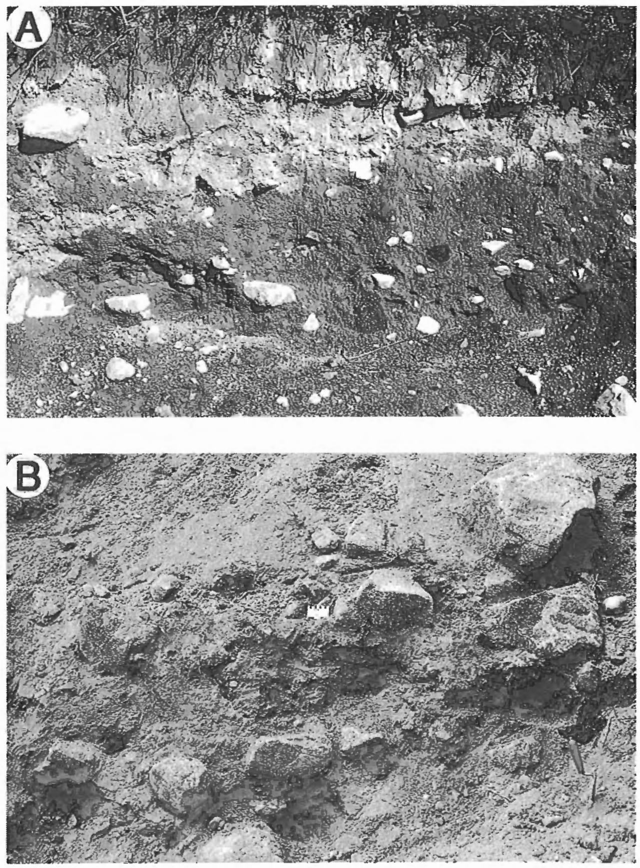


Figure 19. Diamicts in surface exposures: **A)** massive sediments with faceted clasts, Peddle Lake (GSC 1991-101-RR), and **B)** graded diamict, Fulford Lake. (GSC 1991-101-QQ)

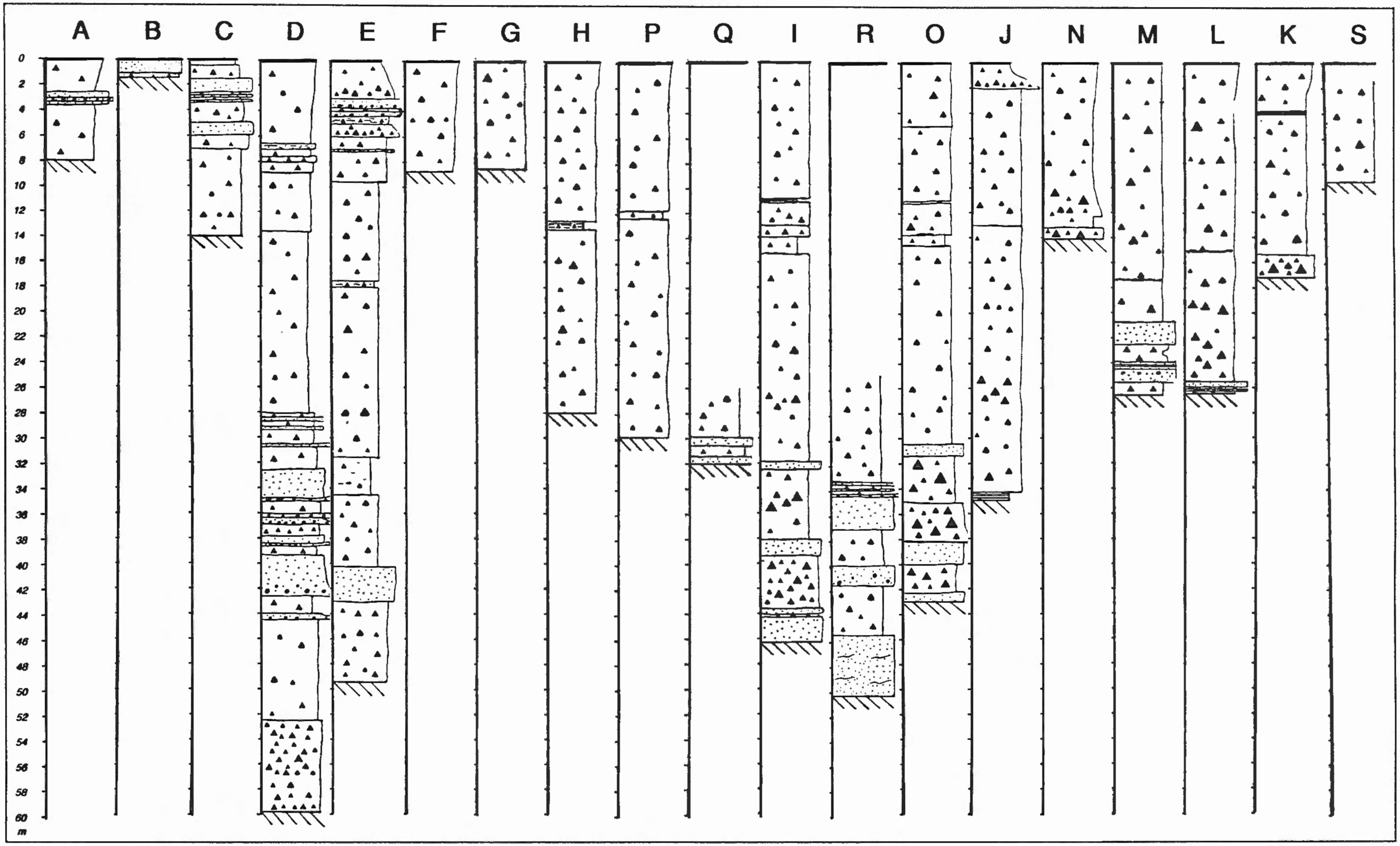
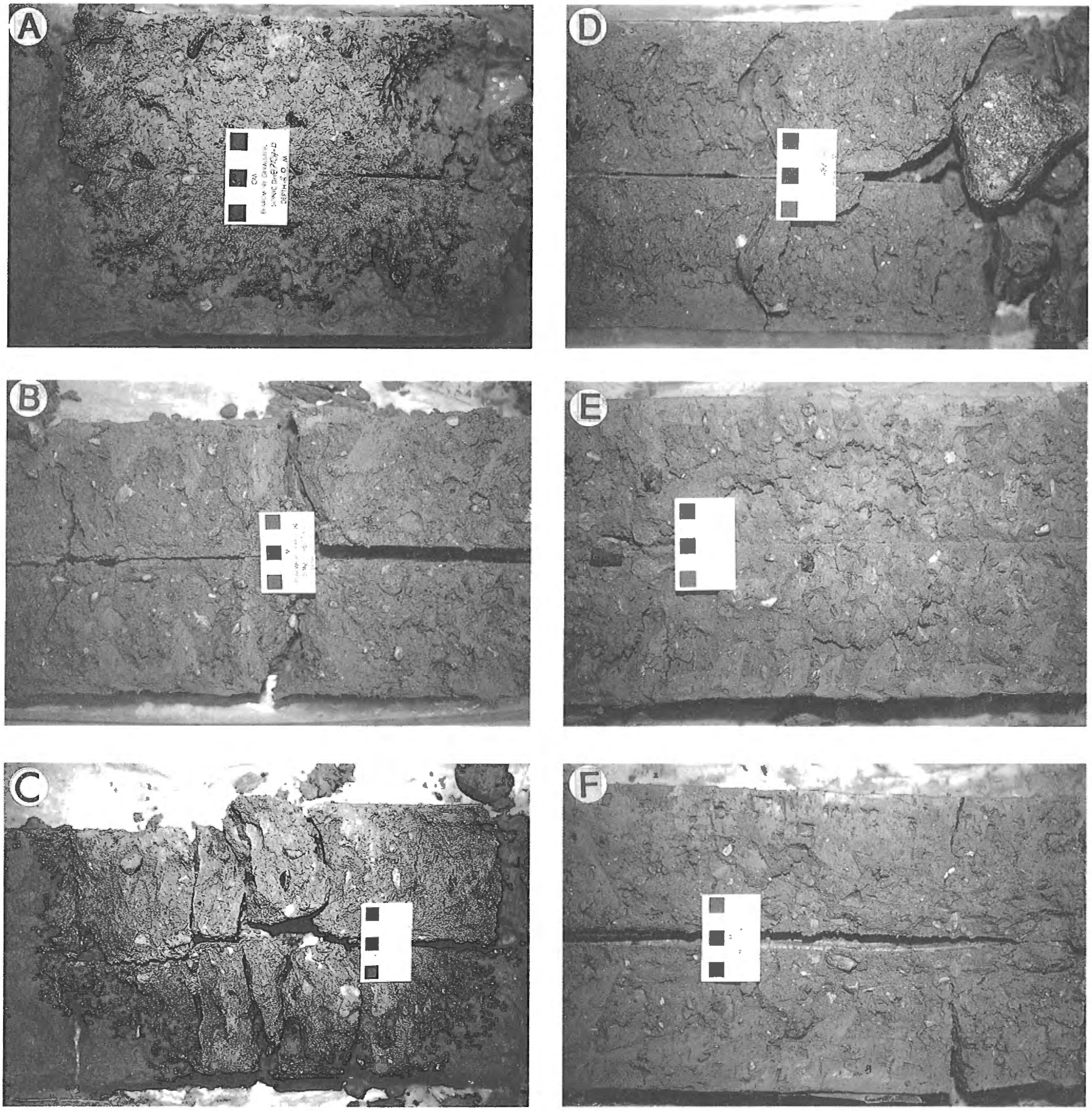
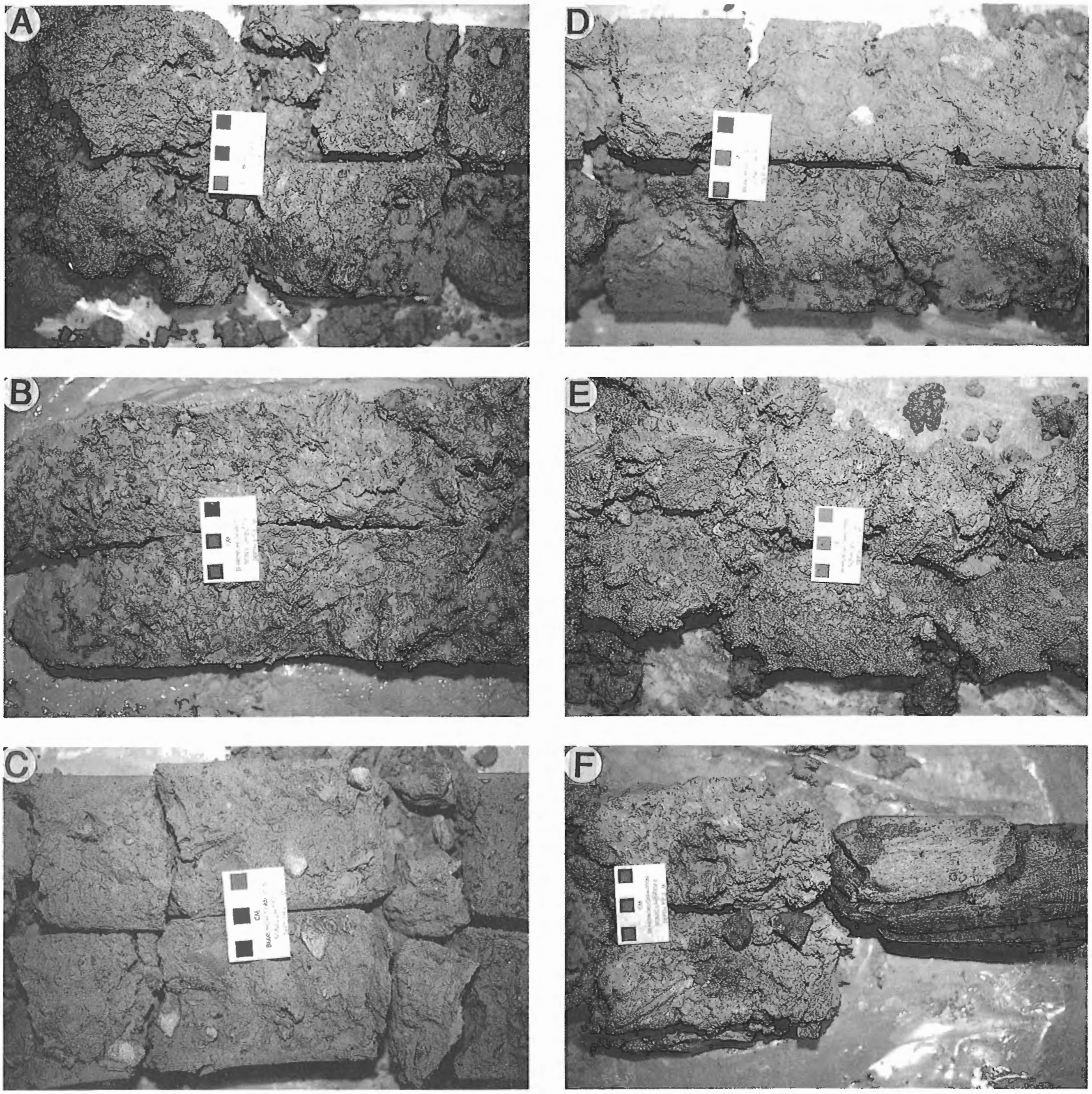


Figure 20 . Drill hole lithofacies profiles; triangles represent diamicts, triangle size and frequency indicates relative size and frequency of pebbles and cobbles in the sediment, dot patterns indicate sand and gravel, horizontal lines represent laminated silt and clay, oblique line pattern indicates bedrock.



A. Near surface oxidized diamict (hole D at 2.0 m, GSC 1991-101-OO);
B. Upper of two thick diamicts (hole I at 6.5 m, GSC 1991-101-PP);
C. Upper of two thick diamicts (hole H at 5.5 m, GSC 1991-101-NN);
D. Lower of two thick diamicts (hole E at 22.0 m, GSC 1991-101-MM);
E. Lower of two thick diamicts (hole H at 21.5 m, GSC 1991-101-KK);
F. Lower of two thick diamicts (hole I at 26.5 m, GSC 1991-101-LL).

Figure 21. Massive exotic diamicts in sonic drill holes. Scale increments = 1 cm.

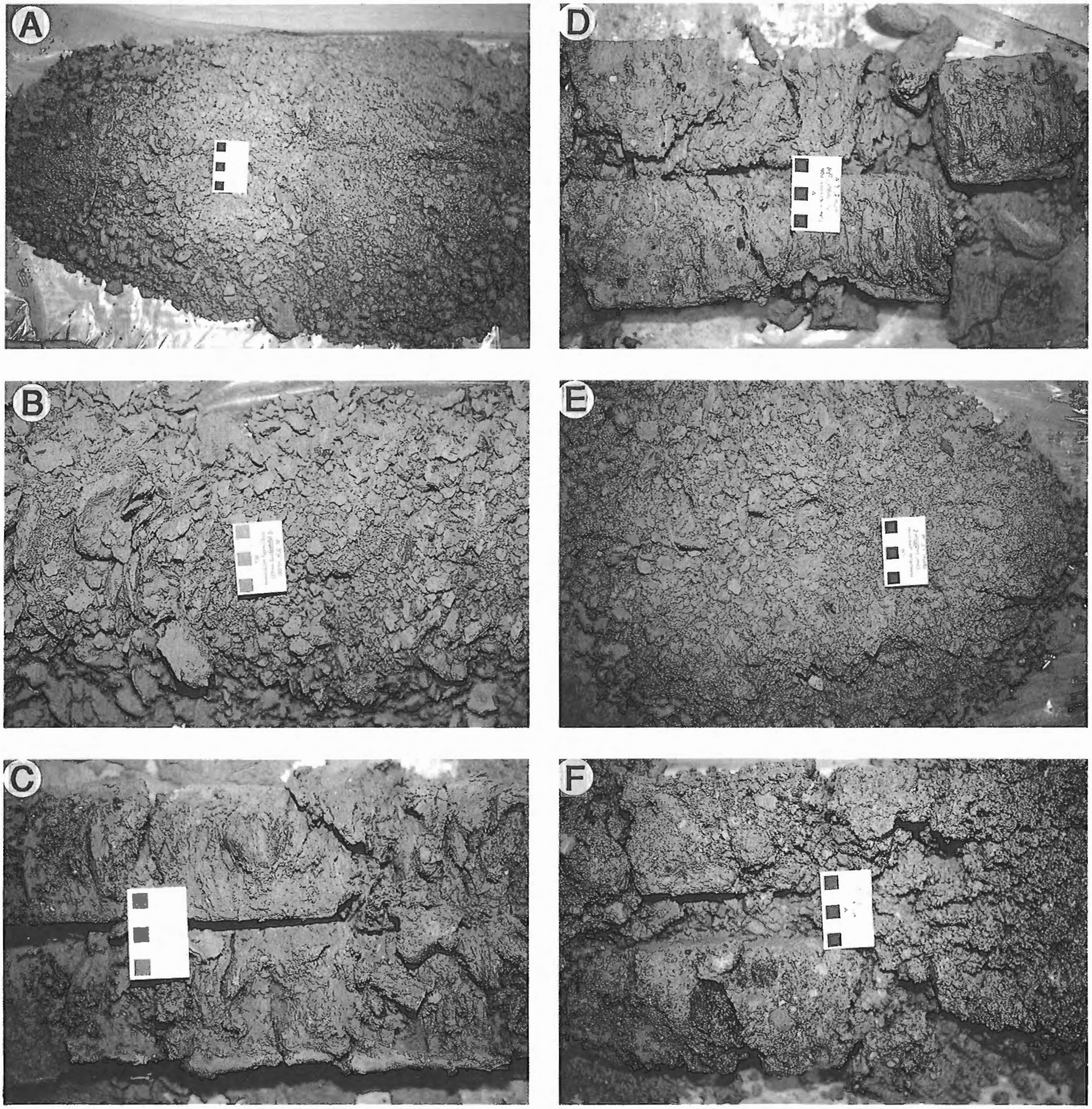


A. Hole D at 59.2 m, GSC 1991-101-EE;
B. Hole E at 48.8 m, GSC 1991-101-BB;
C. Hole I at 42.0 m, GSC 1991-101-CC;

D. Hole K at 16.0 m, GSC 1991-101-AA;
E. Hole N at 13.5 m, GSC 1991-101-Z;
F. Hole E at 49.3 m, GSC 1991-101-Y.

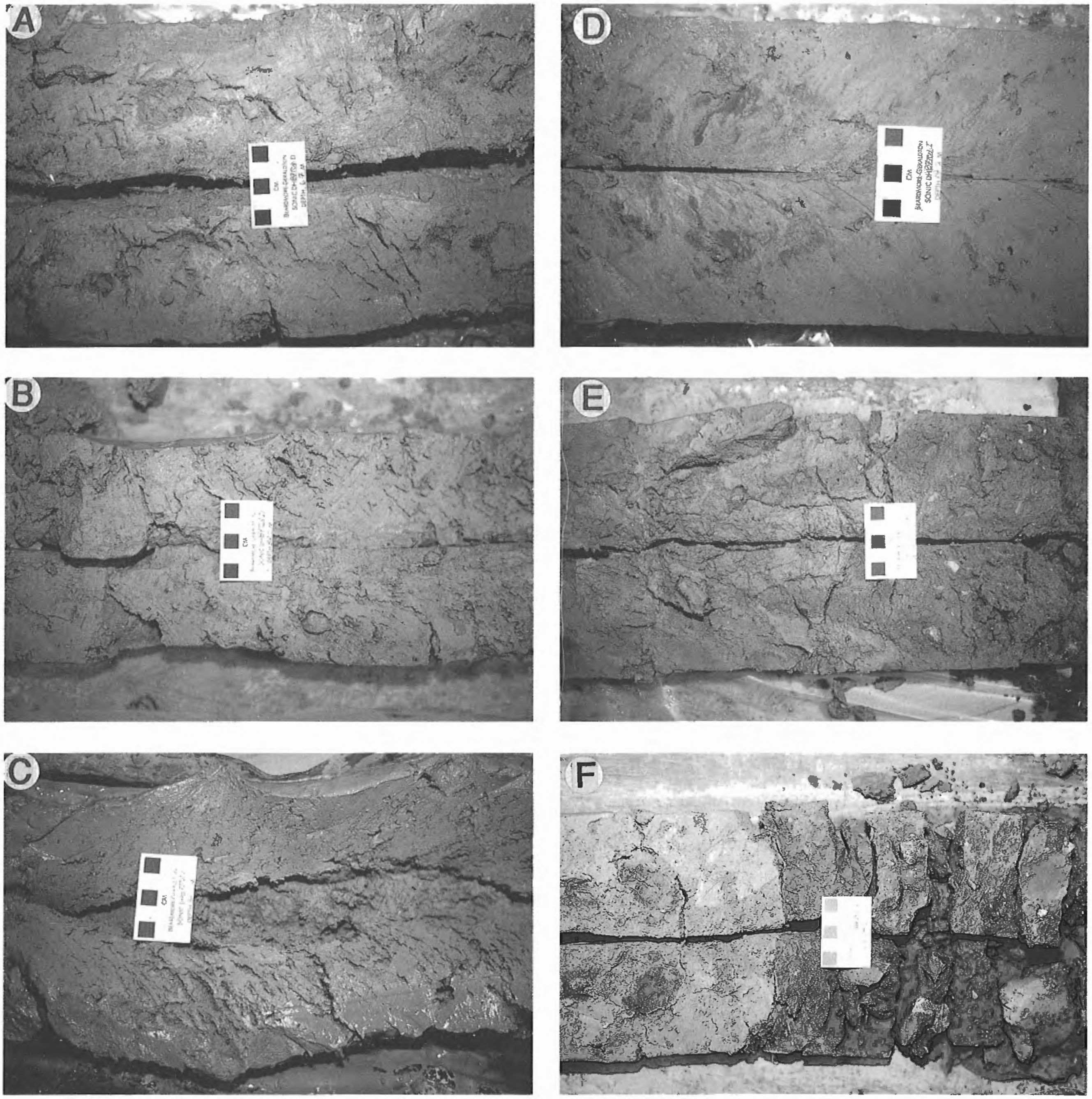
Figure 22. Massive, locally derived diamicts in sonic drill holes. Scale increments = 1 cm.

Fissility was observed within 2 m of surface (Fig. 23) at 4 out of 17 sites where surface sediments were cored and in 5 cases at depth in zones about 1 m thick. In holes C, E, F, and I, core from the upper 2 m fell apart as flakes and blocks a few millimetres in size. This behaviour probably corresponds to the well developed fissility which is occasionally observed in surface exposures. At hole C, silt at 0.5 m depth is fissile. At hole S from 3.5 to 4.5 m depth,



A. Disaggregated core probably related to fissility (hole C at 0.5 m, GSC 1991-101-II);
B. Fissile diamict (hole S at 4.0 m, GSC 1991-101-D);
C. Fractures possibly related to primary fissility (hole G at 6.4 m, GSC 1991-101-A);
D. Fractures possibly related to primary fissility (hole A at 5.2 m, GSC 1991-101-B);
E. Upper very silty portion of a graded diamict (hole E at 1.5 m, GSC 1991-101-C);
F. Gravelly lower portion of the same graded diamict (hole E at 3.0 m, GSC 1991-101-H).

Figure 23. Fissile and graded diamicts in sonic drill holes. Scale increments = 1 cm.



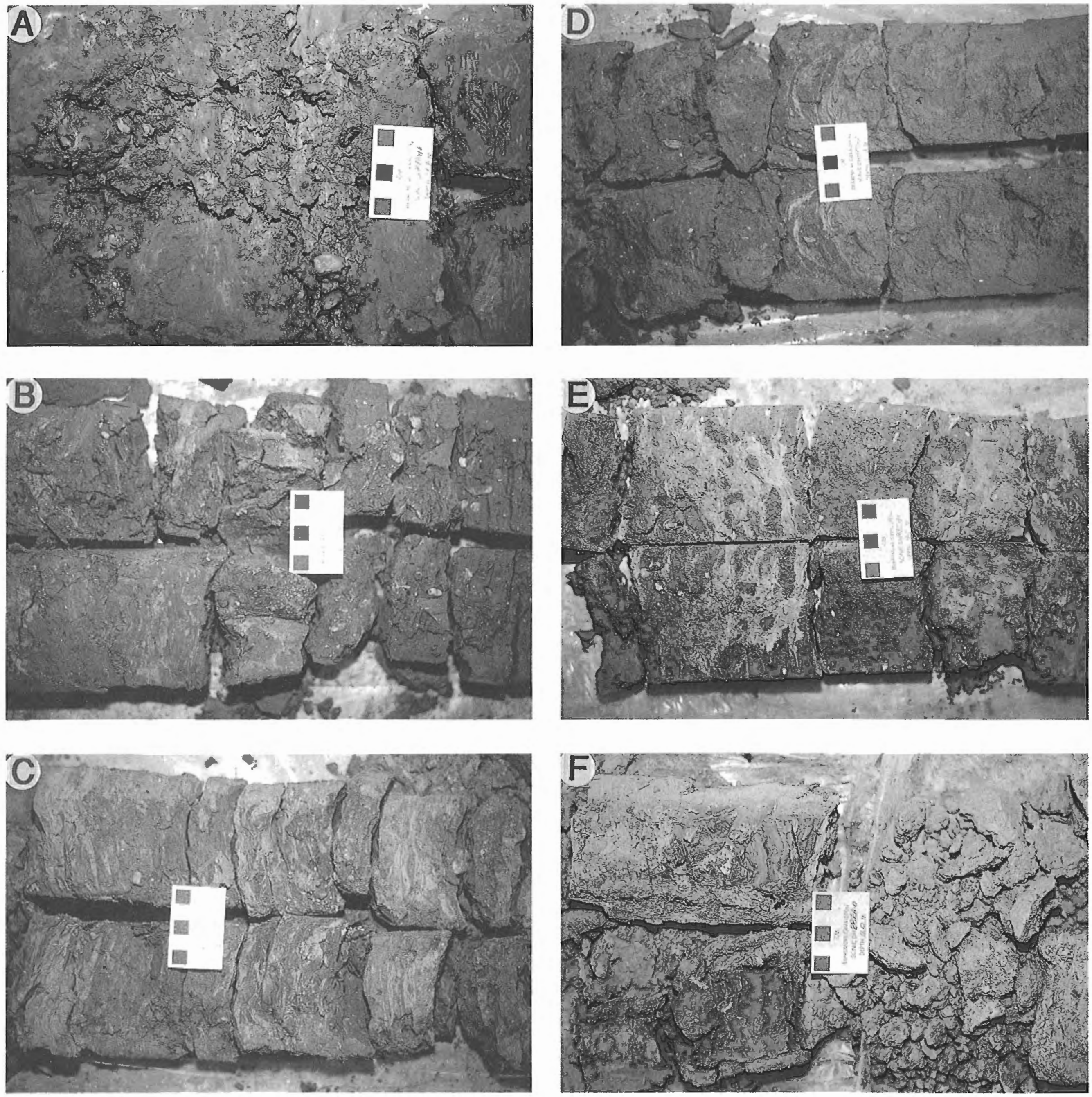
A. Hole D at 6.7 m, GSC 1991-101-N;
B. Hole D at 52.0 m, GSC 1991-101-W;
C. Hole E at 32.0 m, GSC 1991-101-HH;
D. Hole I at 14.2 m, GSC 1991-101-FF;
E. Hole I at 15.3 m, GSC 1991-101-GG;
F. Hole O at 14.5 m, GSC 1991-101-DD.

Figure 24. Soft diamicts in sonic drill holes. Scale increments = 1 cm.

fissility caused the core to disaggregate into large flakes a few millimetres thick. Horizontal fractures about 1 cm apart which could be regarded as fissility were observed in intervals about 1 m thick in hole A at 5 m depth, at hole E at 16 m and from 38 m depth, at hole G at 7 m depth, and at hole H at 18 m depth.

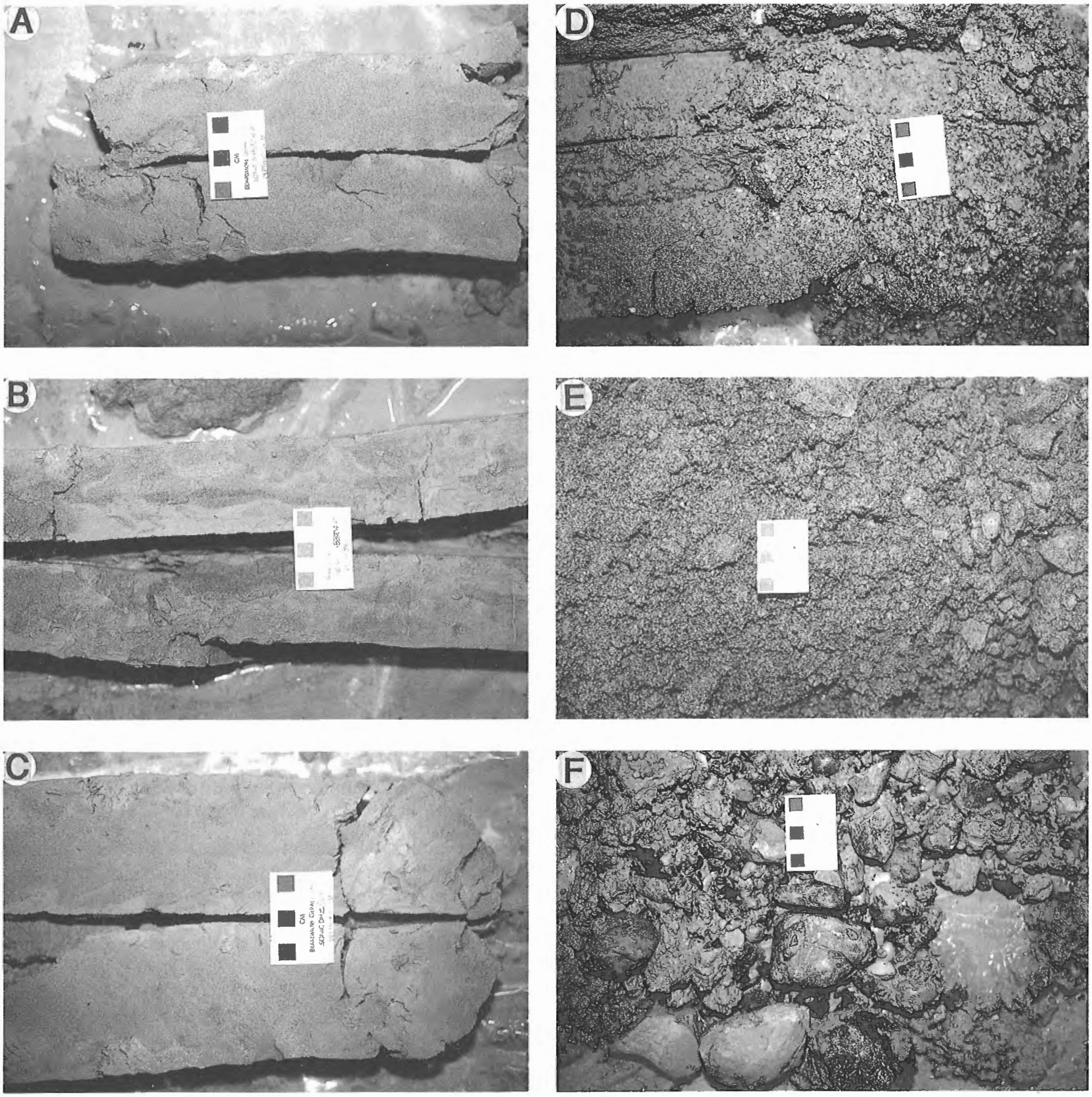
Graded diamicts (Fig. 23) were recognized in near surface sediments in holes E and J. These units, 3, 1.4, and 2 m thick, grade from very silty near the upper contact, down to very gravelly at the base.

In eleven drill holes, soft diamicts and laminated silt and clay which were considered in situ sediments were recovered. These sediments are rare exceptions compared to the thicker



A. Hole E at 17.7 m, GSC 1991-101-G;
B. Hole E at 39.7 m, GSC 1991-101-E;
C. Hole H at 13.0 m, GSC 1991-101-F;
D. Hole I at 10.7 m, GSC 1991-101-I;
E. Hole K at 4.0 m, GSC 1991-101-P;
F. Hole O at 11.0 m, GSC 1991-101-M.

Figure 25. Laminated silt and clay in sonic drill holes. Scale increments = 1 cm.



A. Hole M at 24.2 m, GSC 1991-101-JJ;
B. Hole R at 46.0 m, GSC 1991-101-U;
C. Hole I at 45.0 m, GSC 1991-101-V;
D. Hole E at 4.2 m, GSC 1991-101-T;
E. Hole O at 38.5 m, GSC 1991-101-X;
F. Hole D at 36.1 m, GSC 1991-101-L.

Figure 26. Sand and gravel in sonic drill holes. Scale increments = 1 cm.

and more abundant compact massive diamicts. Included are sediments from within a drilling run, which correspond to a depth interval where fast drilling conditions were recorded, and/or which recur at similar depths at nearby holes, hence these sediments were not considered artifacts of drilling.

Seven occurrences of sediments described as soft diamicts (Fig. 24) have abrupt contacts with enclosing very compact diamicts. The units range from 0.4 to 3.0 m thick and occur at depths ranging from 6.5 to 47.5 m. These sediments typically occur midway through a sequence of thick, compact to extremely compact diamicts. In hole D from 6.5 to 7.0 m, slightly compact, soft sandy silt diamict with rare laminae, and clots of poorly sorted sand, was recovered. In hole D from 47.5 to 52.5 m depth, soft sandy silt diamict includes clots of sand. In the lowest 15 cm of this unit are diamict clasts possibly representing ripups from the underlying material. In hole E from 31.5 to 34.5 m, at a depth where fast drilling conditions were recorded, a soft, sandy, very silty diamict with variable but low pebble frequency and slight lamination was recovered. In hole I from 14.0 to 15.3 m, also at an interval exactly coinciding with recorded fast drilling conditions, soft sandy silt diamict with deformed clay inclusions and numerous granules and pebbles was recovered. At hole O, 100 m to the east of hole I, at a similar depth of 13.7 to 14.5 m, slightly compact sandy silt diamict with 2 to 3 cm rounded clots of diamict resembling the enclosing material and few pebbles was obtained. At hole P, about 200 m southeast of hole I, soft diamict 0.4 m thick was observed at 11.8 to 12.2 m depth. At hole R from 42.4 m to 45.5 m, diamict was described as loose and soft.

Seven intersections of laminated silt and clay (Fig. 25) were encountered in the diamict sequences. These units range from 0.1 to 0.7 m thick and occur at depths ranging from 3.9 to 39.6 m. In holes I and O, these sediments occur about 3 m above soft diamicts. In holes E, H, and K, laminated silt and clay occurs at a depth and stratigraphic position similar to the laminated and soft units in holes I and O. At hole E from 17.5 to 18.0 m, sandy silt diamict is interbedded with two units, 10 cm and 30 cm thick, of deformed laminated silty clay with rare pebbles. In hole E from 39.6 to 39.7 m depth, deformed laminated silt and clay with diamict clots is enclosed by compact diamict. At hole H from 12.7 to 13.4 m, diamict is interbedded with 5 laminated silt and clay units, 5 to 10 cm thick. At hole I from 10.9 to 11.2 m depth, massive silt overlies laminated silt/clay couplets each about 2 mm thick. At hole J, from 34.3 m to the bedrock surface at 34.9 m depth, irregularly laminated silt and clay couplets, 2 to 50 mm thick, occur. At hole K, from 3.9 to 4.2 m, two 10 cm thick units of silt, with clasts of brecciated clay about 1 cm in size, are separated by a 10 cm diamict unit. At hole O from 11.0 to 11.1 m, laminated silty clay occurs.

Sand and gravel (Fig. 26) interbedded with thin diamicts were intersected in the uppermost few metres at the westernmost sites, holes A, B, D, and E. Sand and gravel also occur, again interbedded with thin diamicts, in deep bedrock lows in three areas: 1) holes D and E; 2) holes Q, I, R, and O; and 3) in holes L and M. Sand units range from 0.1 to 4.8 m thick and average 0.9 m. The most common sand texture is medium- to coarse-grained. Very fine sand, fine to medium

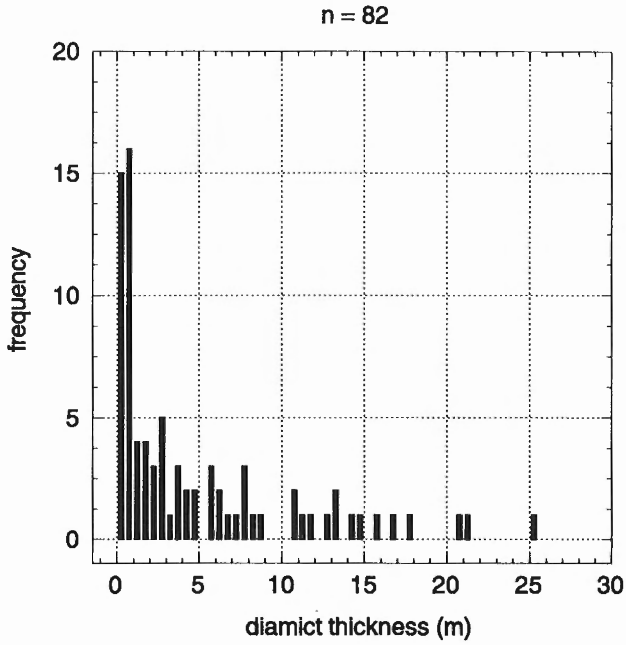


Figure 27. Thickness of diamict units in drill core.

sand, medium to very coarse sand, and pebbly very coarse sand also occur. Several units show grading from pebbly coarse sand at the lower contact to fine or medium sand at the upper contact. In hole M between 24 m and 25 m depth, clay units 5 and 10 mm in thickness occur within a silty, fine to medium sand sequence. Deformed silt laminae are present in a 4.8 m thick silty fine sand unit overlying bedrock at hole R. This unit grades to poorly sorted coarse sand in the lowest 0.3 m. Sorted gravel was encountered in holes A, D, and R and is hence a very minor component of the sequences. These pebble gravel units range from 0.1 to 0.4 m in thickness.

Contacts in the diamict sequences were drawn where an abrupt change in consistency was observed or at the boundary with sorted sediments. Only abrupt contacts with sorted sediments were observed. A total of 82 drill hole intersections of diamict could not be further divided on the basis of visual analysis. These units range from 0.1 to 25 m in thickness and average 5 m (Fig. 27). Units between 11 and 18 m thick tend to occur at the top or middle of overburden sequences in the Wildgoose Lake area. Thin units, less than 5 m thick, tend to occur in multiple unit sequences associated with sand beds either near the surface or at depth in thick sequences. Thin units also occur between two thick units in holes E, H, P, I, and O. Thickness trends thus indicate two assemblages of sediments; 1) thin diamicts interbedded with sand, and 2) thick diamicts.

Thin unit sequences occur at depth where they appear to fill lows on the bedrock surface. For example, holes H, P, Q, I, R, O, and J, which span 2 km, indicate the presence of a bedrock low running parallel to and under Highway 11 that is filled with thin diamicts and sand up to the level of the higher bedrock surface which occurs in holes H and P, south of the highway, and hole J, north of the highway. Thin diamicts interbedded with sand also occur at surface in holes A, B, C, D, E, and J. The surface sequences include graded diamicts in holes E and J.

Between the thin unit sequences or at surface where a surface thin unit sequence is absent are thick diamicts, commonly about 15 m thick and in several cases occurring as two units separated by a single thin soft diamict or laminated fine grained sediment.

Geophysical analysis

Useful borehole geophysical data were obtained from gamma ray, density, and magnetic susceptibility logs.

Hole R was cased with PVC pipe into which vertical slots had been cut. Contact between borehole water and surrounding sediment was required for application of electrical resistivity and induced polarization measurements. Application of these techniques was not, however, successful, due to high noise relative to the signal level. This may indicate that the design of the perforated casing was inadequate.

Borehole geophysical analyses at hole O (Fig. 28) may be used to subdivide the sediments into 5 units. The upper three units are in the upper sequence of Paleozoic carbonate-bearing sediments. The lower, locally derived sequence was divided into two units. As discussed by Mwenifumbo et al. (1989), unit A from 0 to 14.5 m corresponds to compact silty diamict, unit B from 14.5 to 30.1 m corresponds to very compact silty diamict, and unit C from 30.1 to 35 m corresponds to sand and sandy diamict. Unit A is fairly heterogeneous with respect to gamma ray and density logs and is characterized by a lower, more variable gamma radioactivity, density, and susceptibility than unit B. Variations in the gamma ray signature are probably due to variations in clay content. Some of the higher susceptibility values between 3.5 to 5 m and around 7.5 m correlate with higher density. Unit B is characterized by fairly uniform

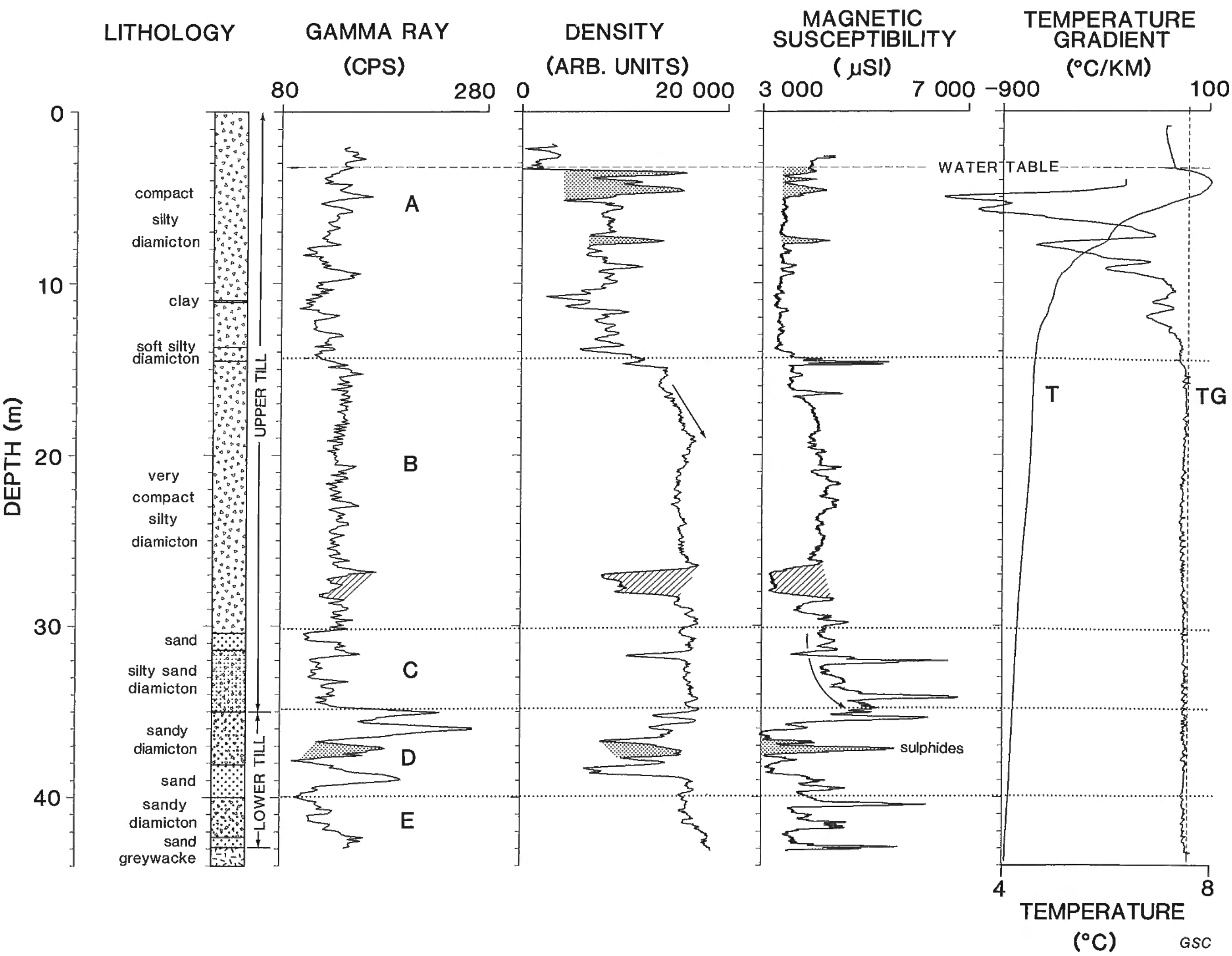


Figure 28. Borehole geophysical analysis of hole O. The letters A, B, C, D, and E indicate units interpreted from the geophysical measurements. Sections showing strong correlation between density and magnetic susceptibility are shaded.

gamma radioactivity. The density and susceptibility logs show an increase in both parameters from 15 to 19 m followed by a fairly constant response towards the base of the unit with the exception of a prominent low density, low susceptibility section around 27 to 28 m. This zone is similar in character to unit A. The sand layers in unit C are characterized by lower radioactivity than the silt layers which have higher levels of gamma ray activity similar to those observed in unit B. There is a general increase in susceptibility towards the base of unit C with two fairly prominent narrow high susceptibility anomalies, presumably due to concentrations in magnetic minerals.

The lower sequence, consisting of sediments lacking or with few Paleozoic carbonate pebbles is divided into two units on the basis of borehole geophysical analysis. Unit D extends from 35 to 40 m and unit E from 40 m to bedrock. Both units contain sand and sandy diamict layers. Unit D, however, is very heterogeneous with several zones of higher radioactivity. The average density and susceptibility are lower than unit C above and unit E below, but are highly variable.

Hole R is located 50 m west of hole O. At this site, the upper 25 m were not cored in order to reduce costs. The hole was cased with perforated pipe to a depth of 52.1 m, 1.8 m below the bedrock surface at 50.3 m. Borehole geophysical tools encountered blockage, however, at 40 m, perhaps due to oozing of sediment through the perforated casing. The Paleozoic-carbonate rich sediments in this hole are divisible into three units (Fig. 29) which correlate with those at hole O, 50 m away. These differences are discernible in the gamma ray activity, but the density and susceptibility logs do not distinguish the units as clearly as was observed for hole O. High density and susceptibility values were obtained in the upper 5 m. Although induced polarization and resistivity data were of low quality, higher resistivity was observed below 32 m.

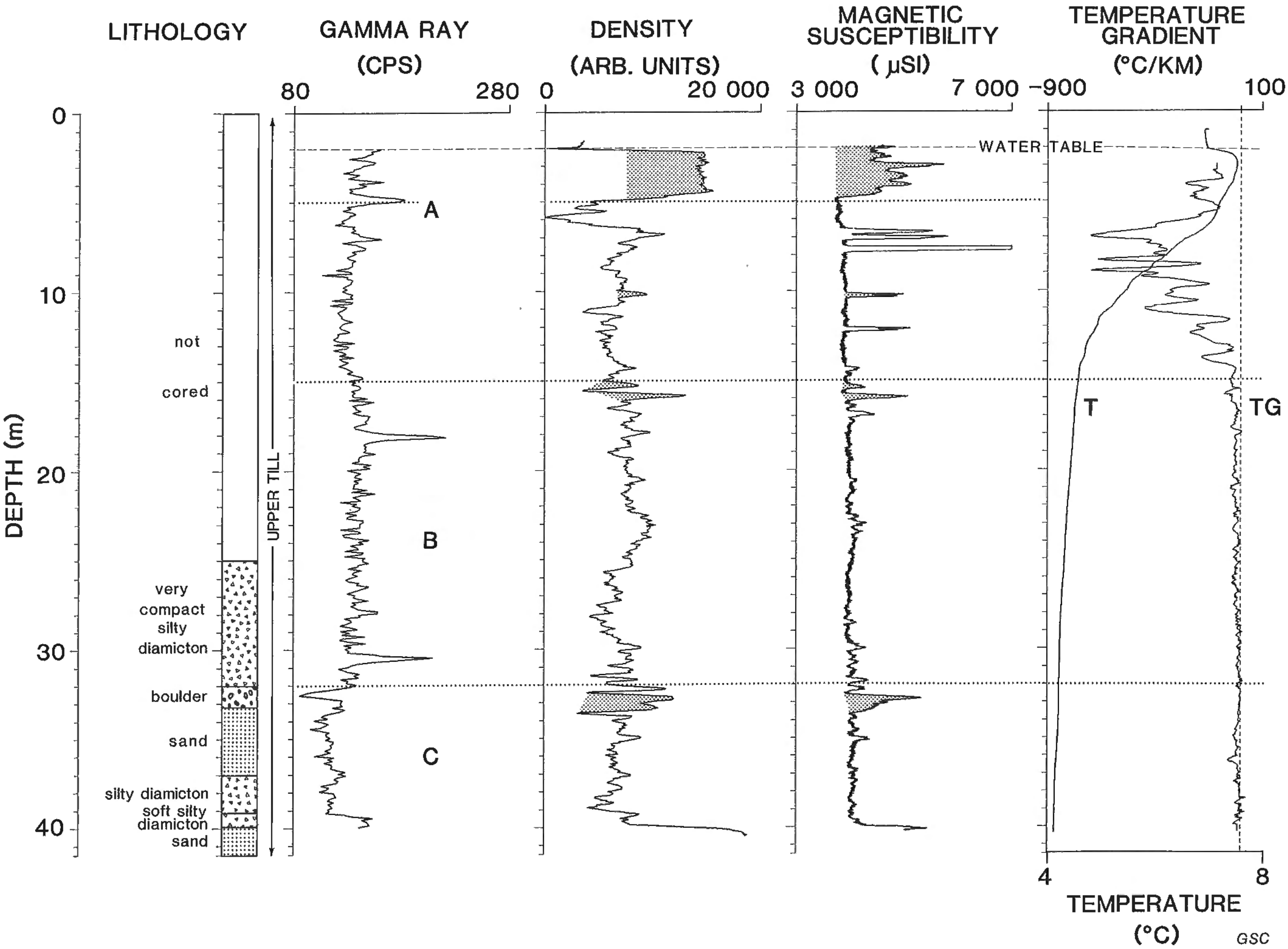


Figure 29. Borehole geophysical analysis of hole R. Letters indicate correlation to geophysically defined units at hole O. The hole was cased with perforated casing to 50.3 m, but geophysical data collection stopped at a blockage at 40 m. Sections showing strong correlation between density and magnetic susceptibility are shaded.

Hole Q is located 100 m west and 50 m south of hole R. The upper 25 m were not cored at this site. Paleozoic carbonates are present to the bedrock surface which, at 32.0 m, is shallower than nearby holes I, R, and O. Correlation to units A, B, and C at hole O may be tentatively made, but, as was the case for hole R, are not as clear (Fig. 30). The intermediate-high-low radioactivity sequence is present, but the density log shows low values in the midsection of unit B. Magnetic susceptibility is uniformly low, except for higher values near the bedrock surface. These higher values may be due to locally derived debris mixed with exotic calcareous sediments.

Hole P is located 75 m south of hole Q. The depth to bedrock at this site, 29.8 m, is similar to hole Q. The sediments at hole P consist entirely of diamict, with division into two major units at a soft interval at 12 m. This division is very clearly displayed in the borehole geophysical analysis (Fig. 31). An abrupt increase in density, a shift to rising susceptibility values and higher radioactivity differentiate the two units, which are correlated to units A and B of hole O.

In summary, the borehole geophysical analysis revealed sediment properties which were not apparent on the basis of visual analysis, although breaks apparent in the logs correspond to contacts recognized in the core. Furthermore, physical property differences only tentatively recognized as a result of description and hand penetrometer testing of split core were clarified. More compact diamicts were generally observed at greater depth, but the geophysical data indicate a consistent division into upper and lower thick diamict sequences, units A and B, and a variable and complex lower sequence, units C, D, and E, which includes both the lower carbonate-rich sediments and the locally derived diamicts. Borehole geophysical data indicate that the upper thick carbonate-rich diamict is less dense and has lower radioactivity and magnetic susceptibility than the underlying thick carbonate-rich unit. The variable nature of the density contrast from hole to hole may indicate complex zoning of compactness, rather than a simple layered pattern. Attempts to identify sulphide-rich sediments were inconclusive.

An example of an optimum offset shallow reflection profile, along a pipeline access road leading to hole H, is shown in Figure 32. This section was obtained using a constant source-receiver offset of 36 m. The undulating event seen at 40-55 ms is interpreted to be the energy reflected from the bedrock surface. The depth scale, which has been calculated from velocities determined from downhole seismic surveys in holes O and R, suggests that this surface varies from 30-45 m below surface along this line. These results are in good agreement with the depths to bedrock at the drill hole sites.

The shallow seismic reflection profiles obtained at these sites provided a means of mapping the bedrock topography away from the drill hole locations. There are also indications on the seismic sections of some structure within the overburden, but the data quality and resolution are not sufficient to allow any confident interpretation of structure within the drift units.

Pebble lithology

Pebbles in the 5.6-16 mm size fraction recovered from till samples were classified in three general rock types: 1) Paleozoic carbonate rocks, 2) granitic rocks, and 3) metasedimentary and metavolcanic rocks (Fig. 33). Paleozoic carbonate in the pebble fraction (5.6-16 mm) of surface till samples (Fig. 34) diminishes gradually from Hudson Bay Lowland Paleozoic terrane to Geraldton, hence long distance glacial transport, rather than erosion of a nearby Paleozoic outlier, was responsible for carbonate in Beardmore-Geraldton area sediments. The pebble fraction of sediments overlying the carbonate source in the Hudson Bay Lowland contains only about 60% carbonate due to the presence of metasedimentary and granitic erratics.

The second most abundant rock type in calcareous tills are metasedimentary and metavolcanic rocks (Fig. 33). In calcareous sediments in the Geraldton area, on the shield to the northeast, and in the Hudson Bay Lowland, this class is dominated by rounded, unfoliated black greywacke and includes occurrences of oolitic or granular iron-formation and banded siliceous carbonate. These three rock types occur in the Proterozoic sequence of the Sutton Ridge (Bostock, 1971), which is located near the junction of Hudson Bay and James Bay. Similar rocks occur in the Belcher Island region of eastern Hudson Bay. Exotic metasedimentary and metavolcanic debris has therefore been transported with the carbonate from the Hudson Bay Lowland. In noncalcareous till, however, the pebble fraction is dominated by angular, foliated metasedimentary and metavolcanic rocks similar to nearby bedrock (Fig. 33). The transition from dominance of exotic to local debris is in many cases abrupt (Fig. 34, 35). Along Highway 11, the western limit of carbonate dominated debris occurs a few kilometres west of the Namewaminikan River, although patches of calcareous drift occur as far southwest as 8 km south of Beardmore (Fig. 34).

In drill holes in the Wildgoose Lake area, pebble lithology data (Fig. 36) indicate that carbonate-rich exotic debris reaches as much as 50 m thick. Some mixing occurs low in some calcareous sequences. At several sites, an abrupt transition to local debris occurs. In drill hole D, the carbonate-rich sediment includes a zone (10-20 m) rich in granite derived from the area between the Beardmore-Geraldton Belt and the Hudson Bay Lowland as well as a zone (25-40 m) of calcareous sediments enriched in metasedimentary and metavolcanic rocks. The additional material in the latter zone is interpreted as locally derived greenstone belt debris because percentages for this class exceed values encountered north of the greenstone belt and some of the observed clasts are similar to nearby bedrock. Thick carbonate-rich sediment at drill hole I has no similar zonation. Exotic debris is dominant, even at the bedrock surface, in drill hole J. Presence of up to 25% local debris deep in the sequence is indicated, however, by a near-constant percentage of metasedimentary and metavolcanic rocks as granite increases and carbonate decreases.

A noteworthy characteristic of the exotic debris is the homogeneity of the Hudson Bay Lowland component, even at the source (Fig. 37). Granite and greenstone belt debris are

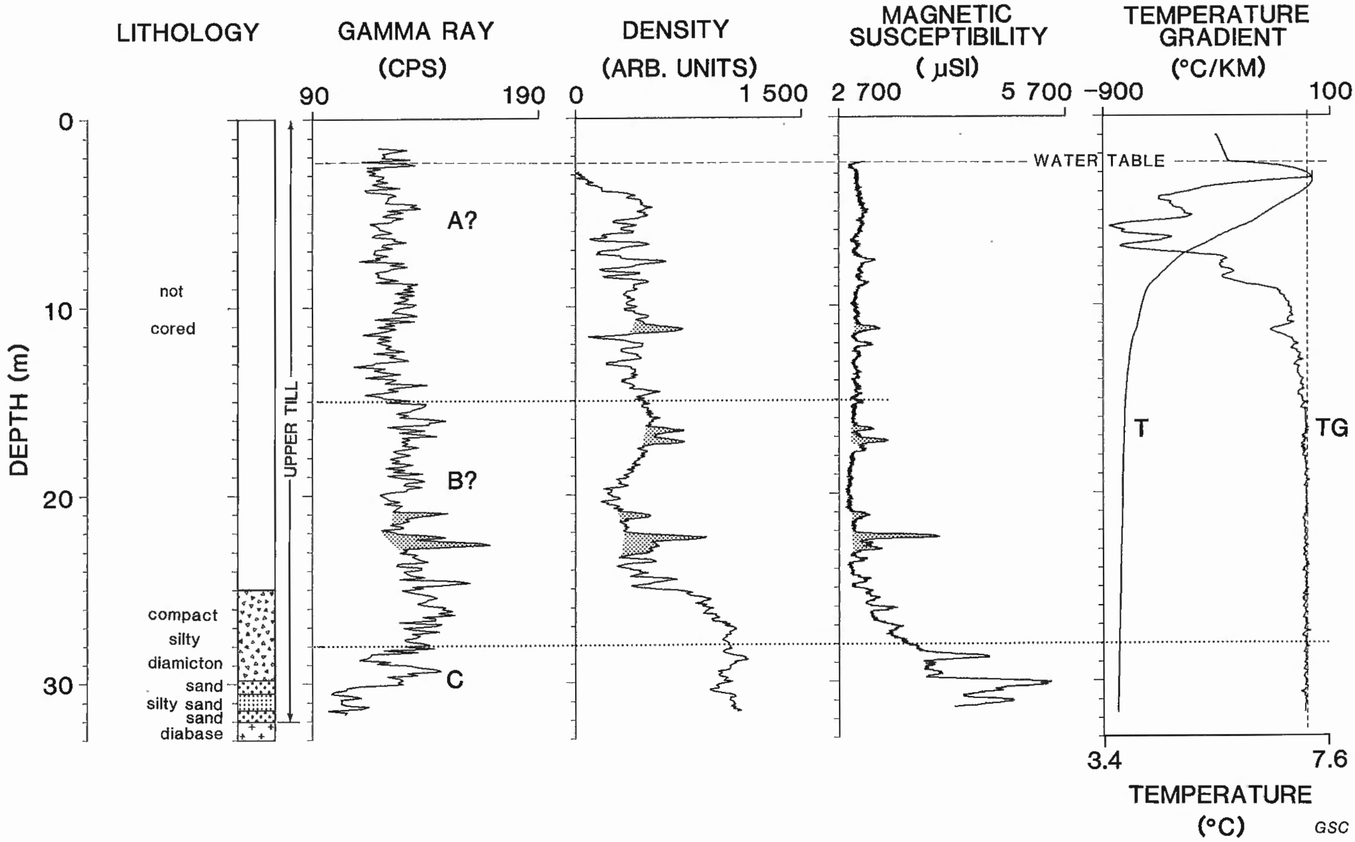


Figure 30. Borehole geophysical analysis of hole Q. Letters indicate correlation to geophysically defined units at hole O. Sections showing strong correlation between gamma ray, density, and magnetic susceptibility are shaded.

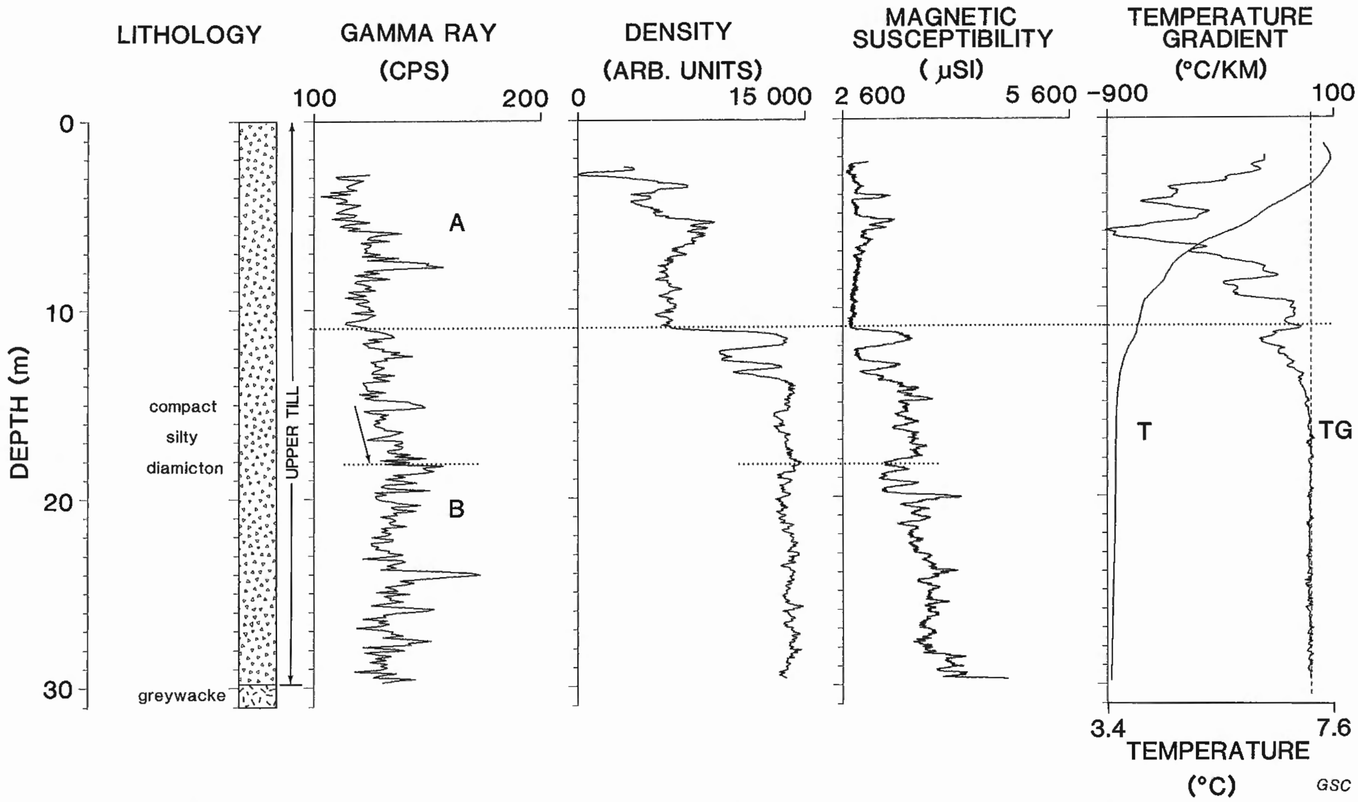


Figure 31. Borehole geophysical analysis of hole P. Letters indicate correlation to geophysically defined units at hole O.

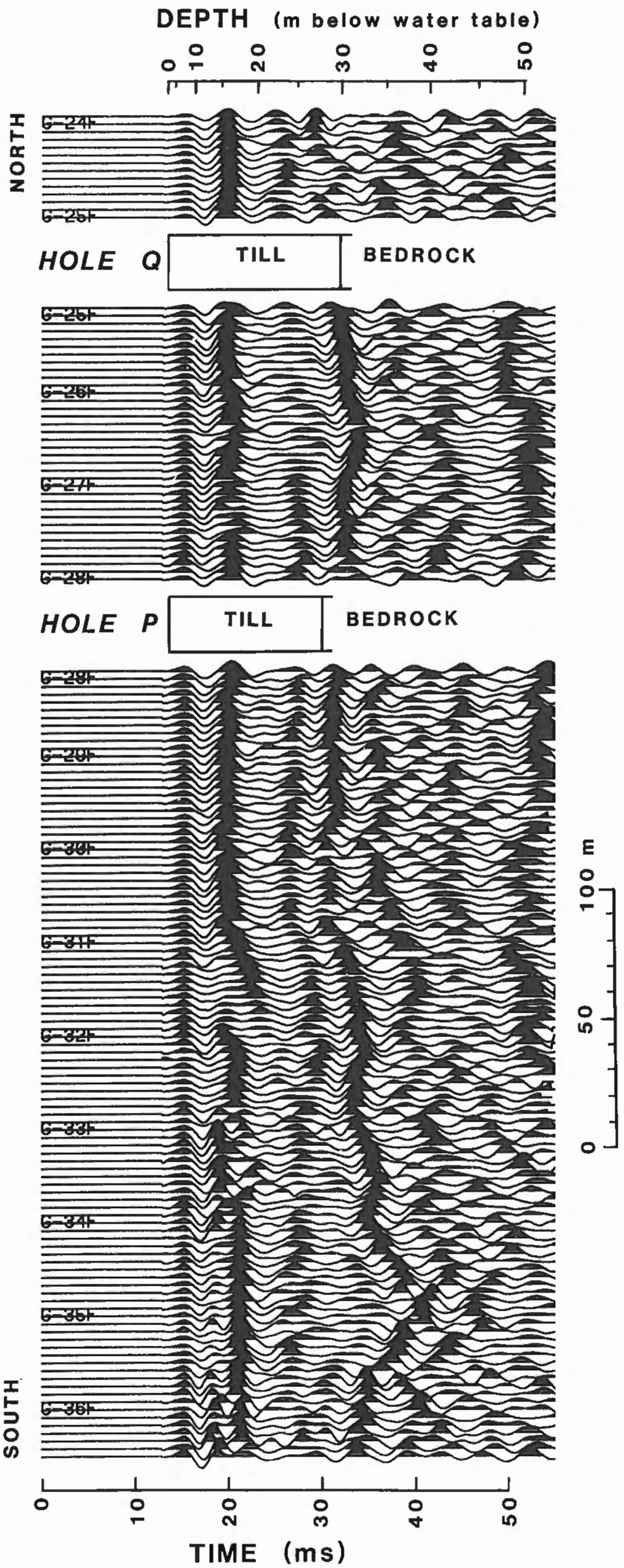


Figure 32. Seismic reflection section extending south from Highway 11 along a pipeline access road. See drill hole location map for holes P and Q sites for location.

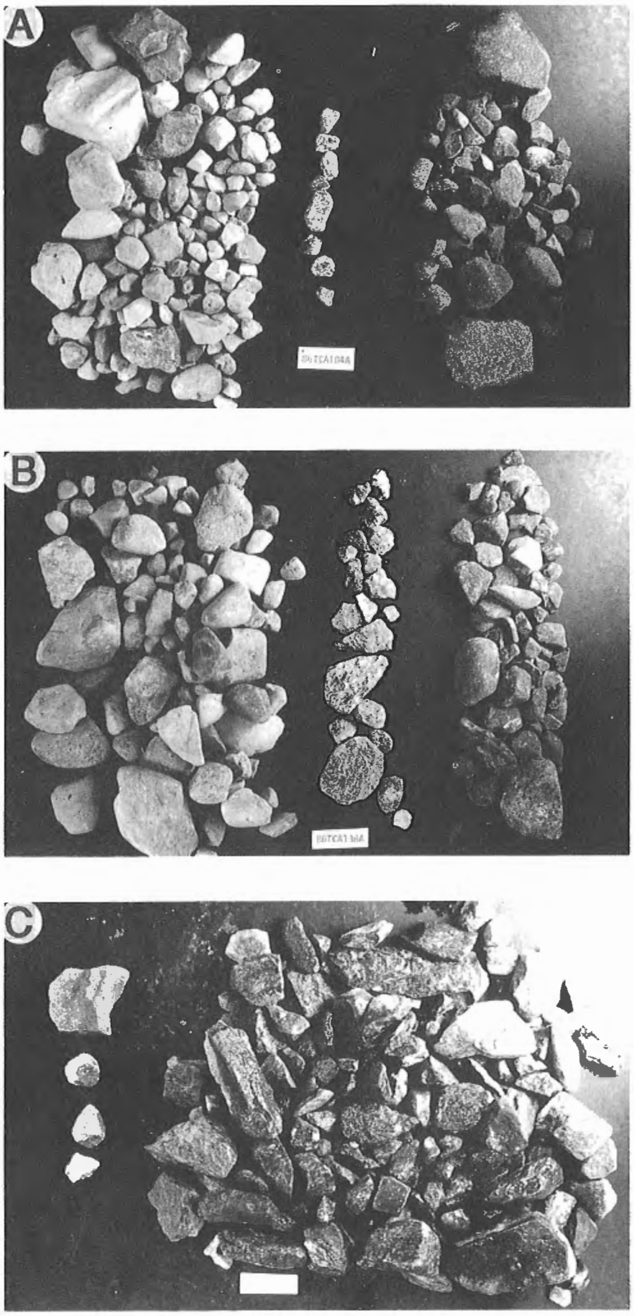


Figure 33. Pebble fraction of till samples (5.6-16 mm); Paleozoic carbonate rocks (left), granitic rocks (centre), and metasedimentary and metavolcanic rocks (right). **A**) sample 104, Albany River, Hudson Bay Lowland, GSC 1991-268-C; **B**) sample 138, Geraldton, GSC 1991-268-A; **C**) sample 635, (Beardmore) lacks Paleozoic erratics. GSC 1991-268-B

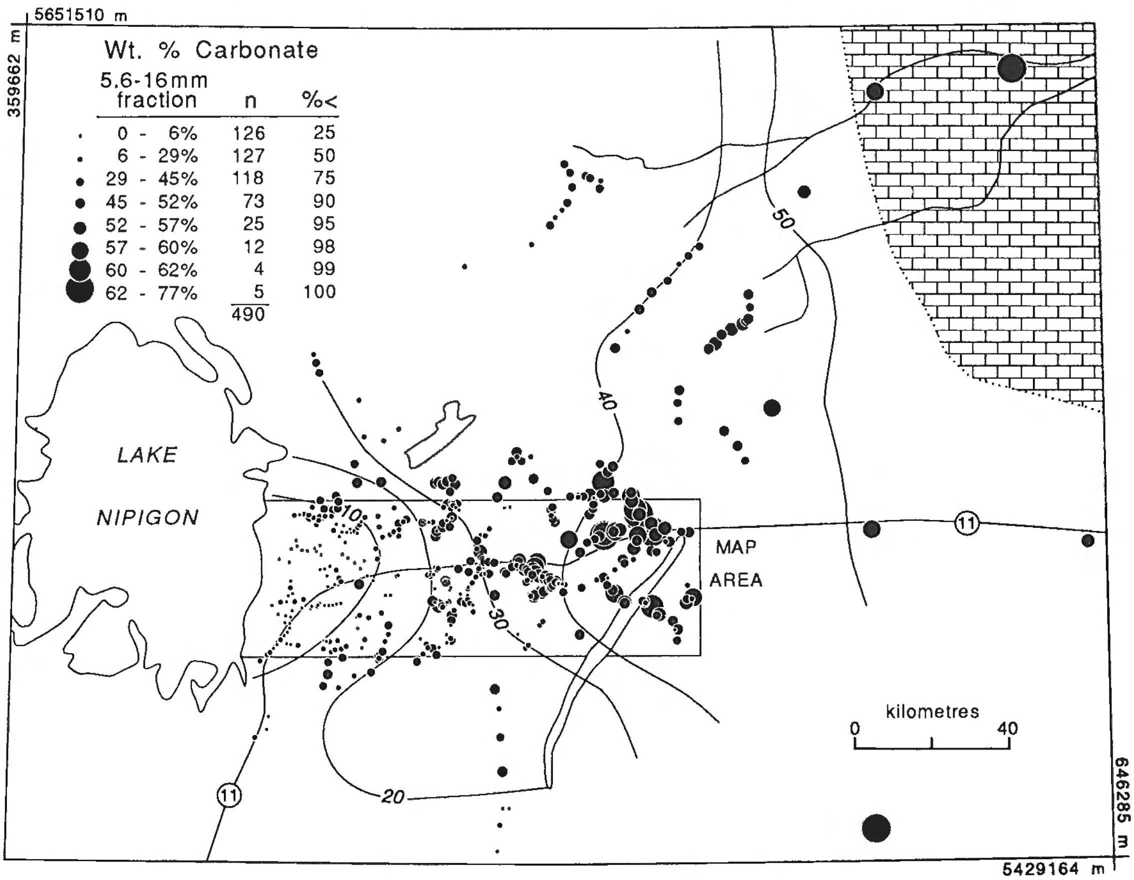


Figure 34. Paleozoic carbonate content of surface till samples (5.6-16 mm).

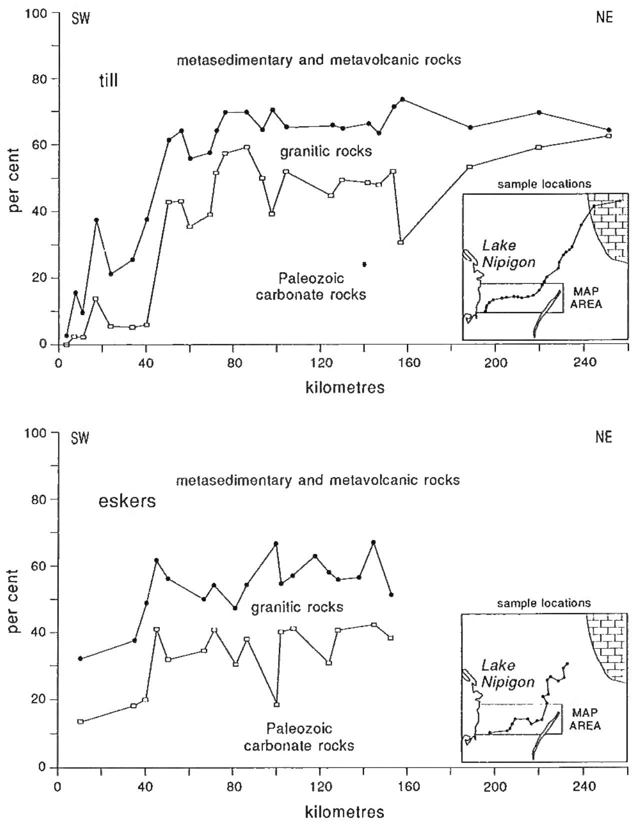


Figure 35. Pebble lithology in till and eskers (5.6-16 mm).

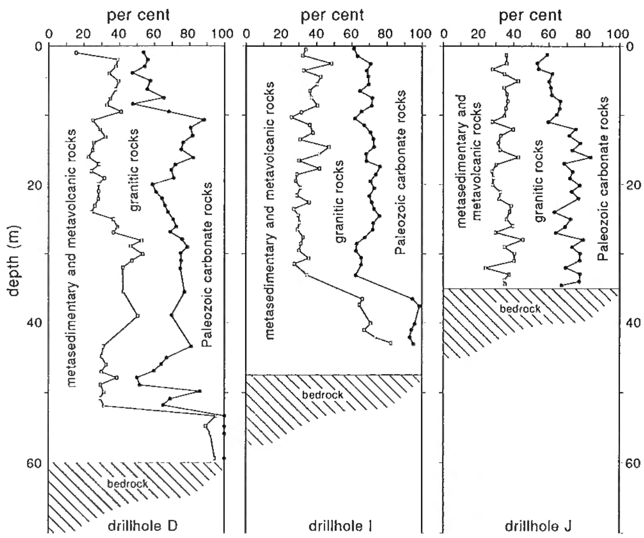
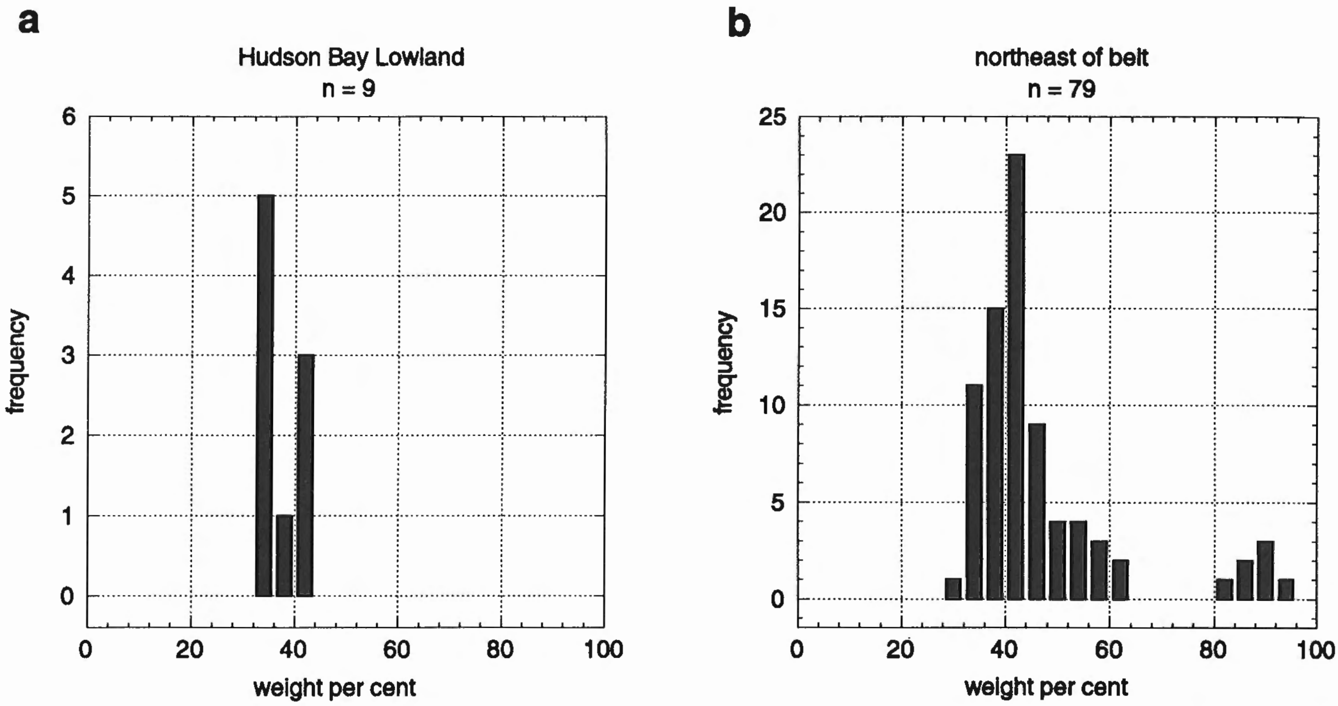


Figure 36. Pebble lithology in till from drill holes (5.6-16 mm).

mixed with the calcareous component in a highly variable manner. The ratio of carbonate to exotic metasedimentary and metavolcanic rocks, however, shows little variation. Samples from northeast of the Geraldton end of the belt and southeast of greenstones in the Nakina area indicate that metasedimentary and metavolcanic rocks consistently make up about 40% of the pebbles in this debris after granite has been excluded. Hence carbonate makes up 60% of the nongranitic pebbles in typical exotic debris. Carbonate debris has, therefore, been well mixed with Proterozoic rocks from the Sutton Ridge and eastern Hudson Bay. This implies that the Hudson Bay Lowland debris has been homogenized, probably during repeated episodes of reworking.



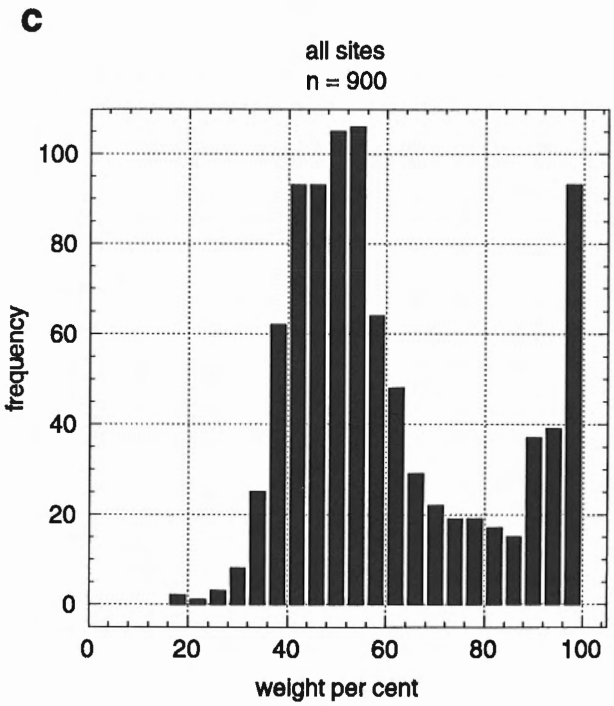
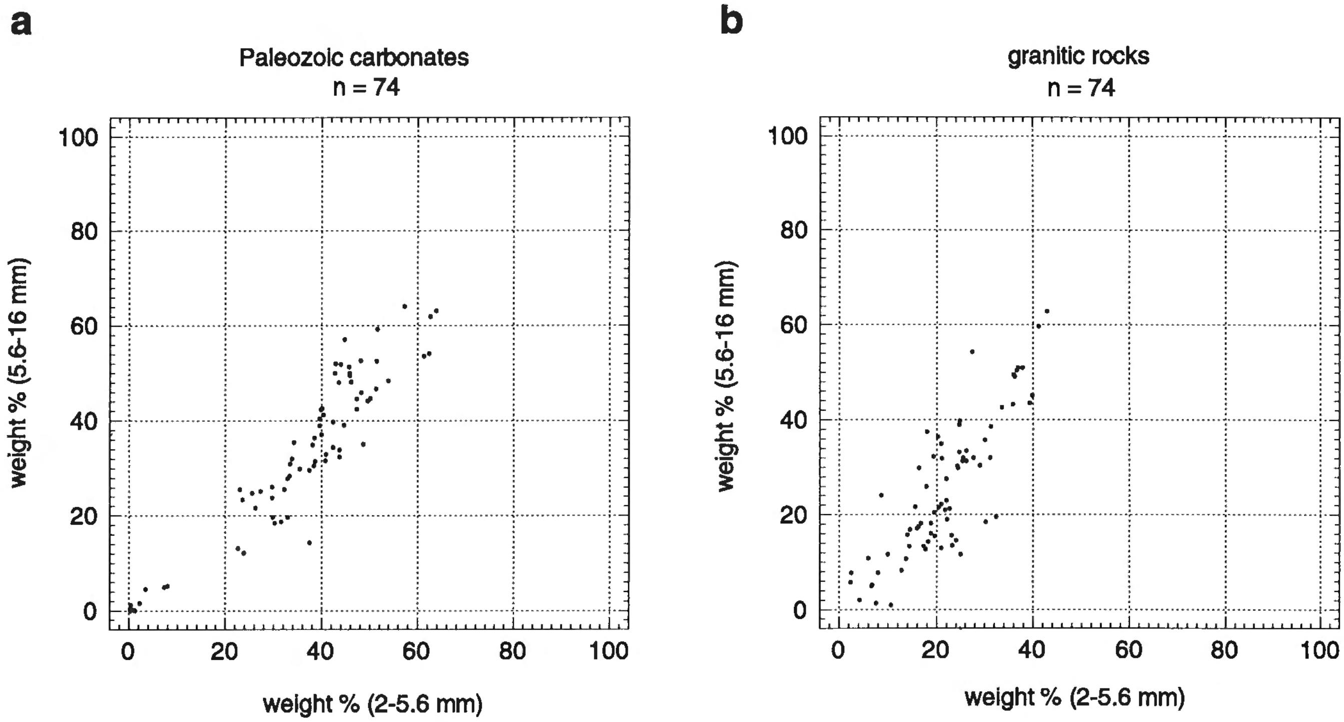


Figure 37. Lithology of the nongranitic pebbles in till samples; weight per cent metasedimentary and metavolcanic rocks. **a**) sites in Paleozoic carbonate terrane of the Hudson Bay Lowland; **b**) sites northeast of the greenstone belt, on granitic and carbonate terrane; **c**) all sites.

This observation leads to a simple method by which the local component of till samples may be estimated. Exotic debris contains about two parts Proterozoic metasedimentary and metavolcanic rocks for every three parts Paleozoic carbonate. If two thirds of the weight per cent carbonate is deducted from the weight per cent metasedimentary and metavolcanic rocks in a sample from within the belt, the remaining amount in the latter class must consist of debris derived from within the belt, hence the local component.

Comparison of pebble fraction (5.6-16 mm) lithology data with data for the granule fraction (2-5.6 mm) indicates that results from the two fractions are similar (Fig. 38). The



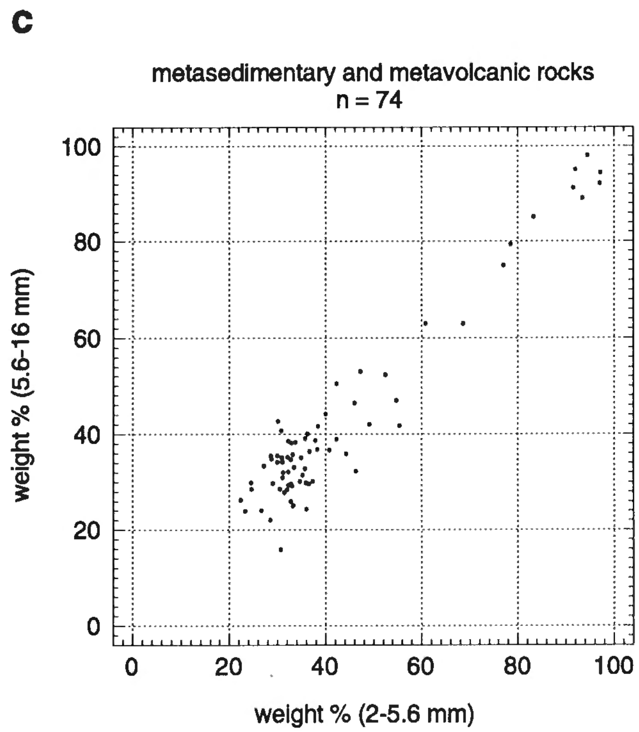


Figure 38. Comparison of lithology in pebble and granule fractions; weight per cent in the 5.6-16 mm and 2-5.6 mm fractions.

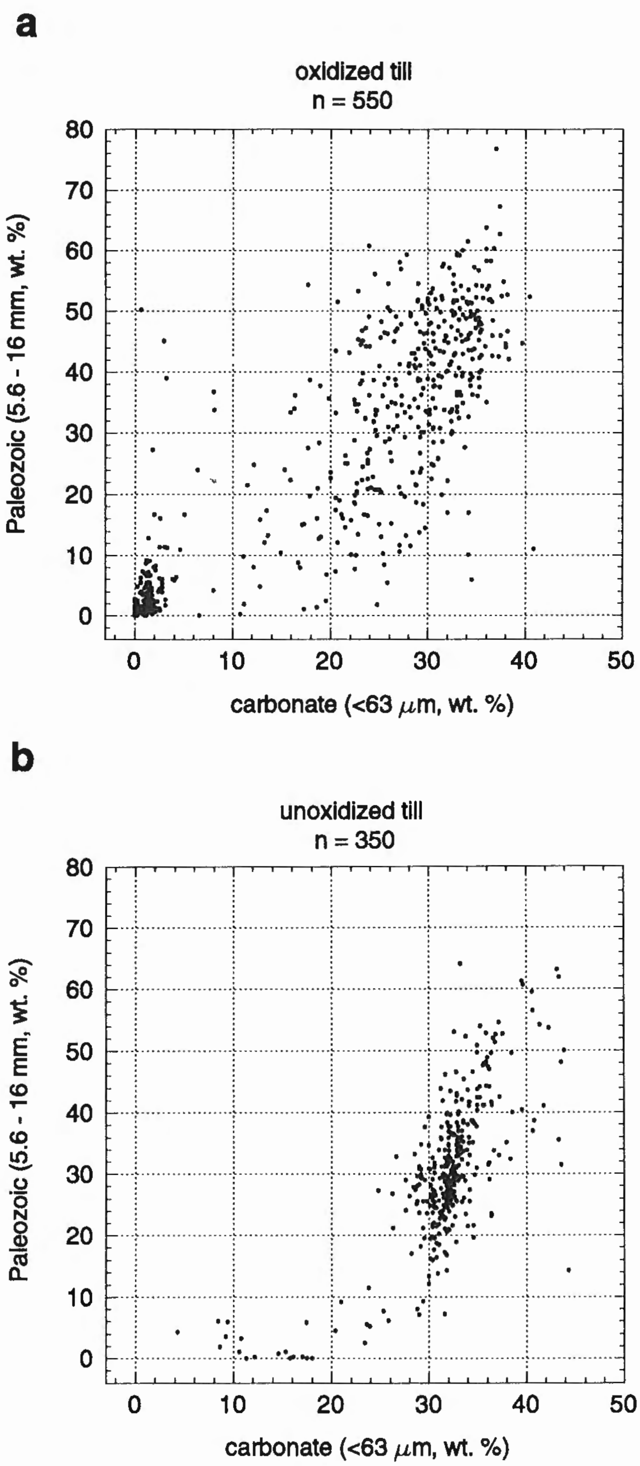


Figure 39. Comparison of carbonate in pebble and <63 μm fractions; **a**) surface till samples and **b**) unoxidized drill hole till samples.

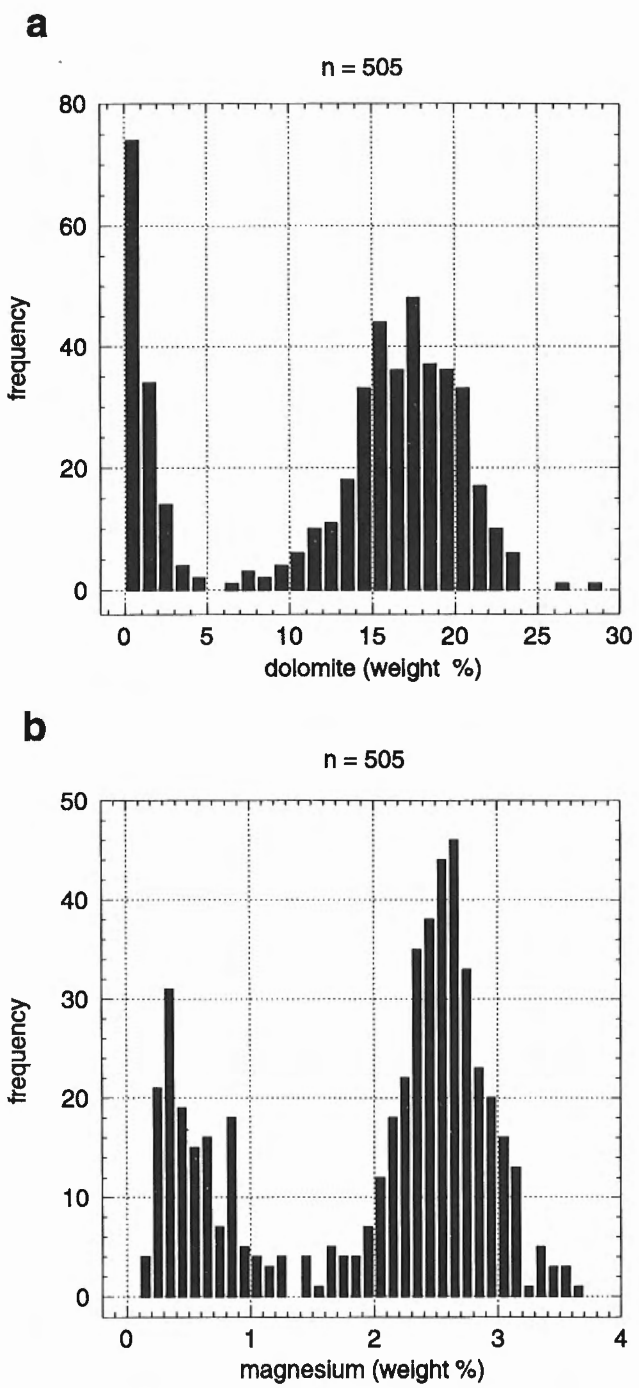


Figure 40. Dolomite in surface till samples; **a**) Chittick dolomite analysis; **b**) chemical analysis for magnesium (<63 μm fraction of surface till samples).

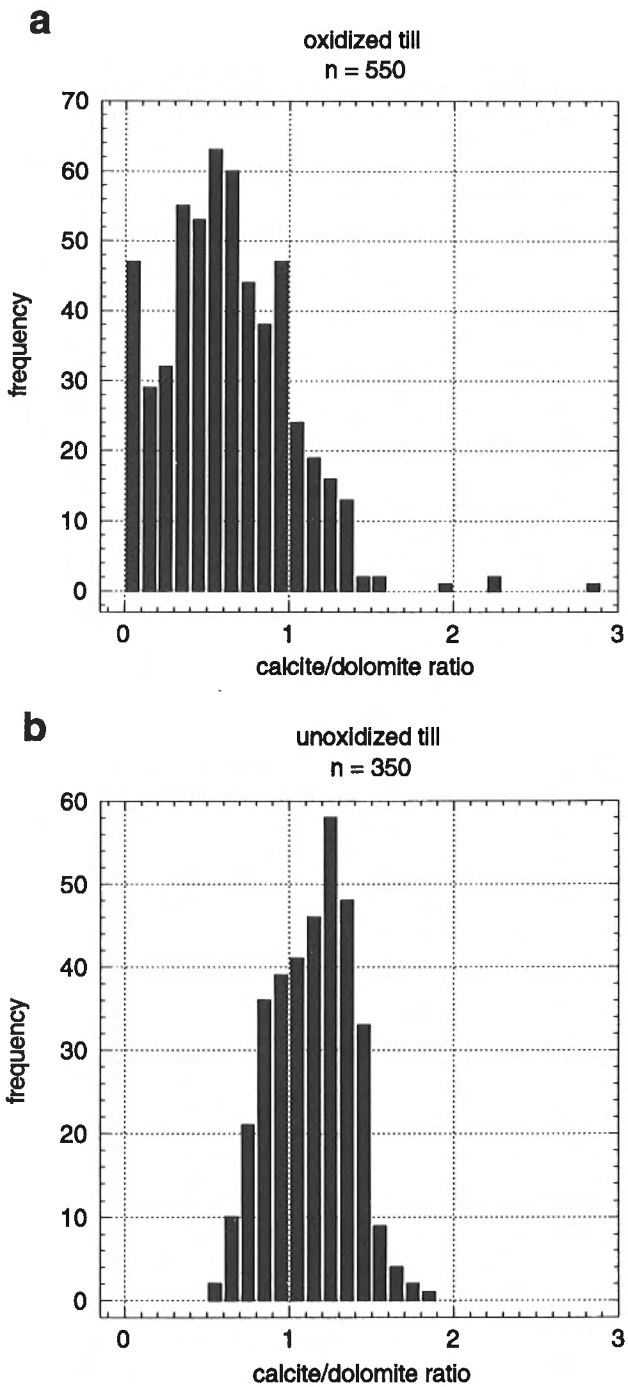


Figure 41. Calcite/dolomite ratios in **a**) weathered till and **b**) unweathered till.

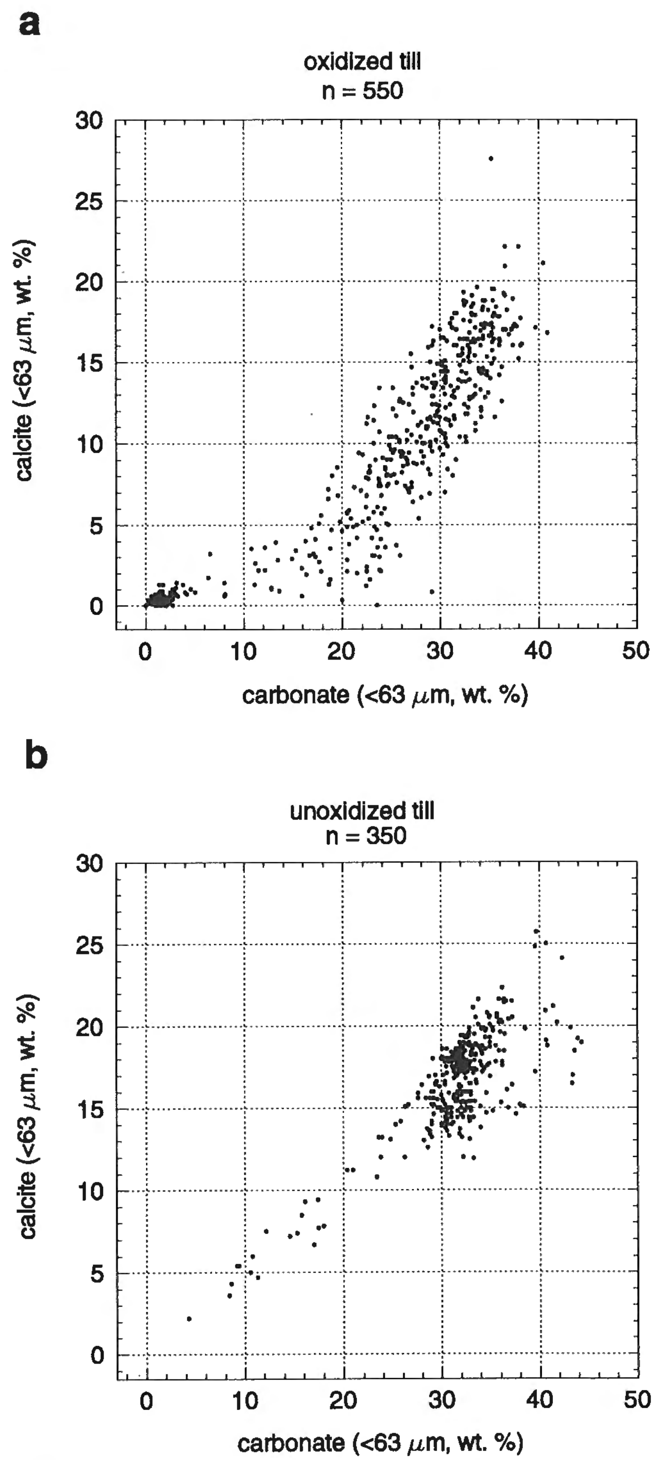


Figure 42. Contribution of calcite to total carbonate in **a**) weathered surface till samples and **b**) unweathered drill hole.

samples used for this test were surface samples along a transect from the Hudson Bay Lowland to Beardmore (see Fig. 35) as well as samples from hole D. It was found that the pebble fraction of the tested samples produce granite contents as much as 10% higher than the granule fraction of the same samples.

Matrix carbonate content

The <63 μm (silt+clay) fraction was analyzed for carbonate using a Chittick gasometric apparatus as described by Dreimanis (1962). Typical Chittick values for total carbonate in a calcareous sample are 20 to 40%, whereas noncalcareous surface samples from the Beardmore area contain less than 4% carbonate. Calcite values range from less than 1% in many samples to as much as 25%. Dolomite also commonly occurs at less than 1%, but values reach as much as 28%.

Comparison with pebble data (Fig. 39) indicates that, in unweathered material from drill holes, samples with less than 10% Paleozoic carbonate in the pebbles may have Chittick values from 5 to 30% carbonate. Values ranging from 10 to 50% carbonate in the pebbles corresponds to a range of 30 to 35% in the fine matrix. This relationship shows much more scatter in weathered surface samples from which carbonate has apparently been dissolved in the soil profile, as discussed below. Many near-surface samples show carbonate values less than would have been predicted by the pebble count.

Although mixing of exotic and local debris was observed in pebble lithology data, a much clearer distinction is implied by a strongly bimodal distribution of dolomite content for the <63 μm fraction of surface till samples (Fig. 40). A similar distribution is also shown by the routine analysis by ICP-AES of the same fraction, <63 μm, for magnesium.

The difference between partially leached surface till samples mostly from shovel holes and unweathered till in drill holes is further demonstrated by calcite/dolomite ratios (Fig. 41). Calcite to dolomite ratios in unweathered till from drill holes average 1.2, as compared to surface till samples with a calcite/dolomite ratio of about 0.5. Figure 42 demonstrates that samples with less than 20% carbonate in particular have depressed calcite values. Hence approximately 50% of the calcite has been leached from surface till samples. Carbonate has been completely leached from the A and B soil horizons, typically extending to about 0.5 m in calcareous till. Most of the samples taken at about 1 m in drill holes have calcite/dolomite ratios near one. Hence the surface samples from, in most cases, hand-dug shovel holes are from the transition from complete leaching at about 0.5 m to no leaching at about 1.0 m. An example of carbonate analyses across this transition (Fig. 43), indicates a rapid rise in carbonate content from about 2% at 0.6 m to about 25% at 0.7 m. Elevated carbonate values at 0.1 m depth at this road-cut site northwest of Geraldton may be due to disturbance during road building. Surface till samples on calcareous parent materials were therefore usually taken from the partially leached Bmk horizon or B/C transition.

Geochemical analysis by ICP-AES following nitric-aqua regia treatment of the <63 μm fraction, in addition to trace elements, included results for calcium and magnesium. These analyses are a useful indicator for carbonate content (Fig. 44). Data from weathered sediment indicates that most samples with less than 1% calcite in the <63 μm fraction have less than 1% calcium. A separate group has, however, at least 3% calcium. Values for calcite content up to 25% correspond to calcium values of about 12%. Values of dolomite content around 20% correspond to about 3% magnesium. Samples lacking detectable dolomite may contain over 1% magnesium, presumably in other minerals.

Texture

As part of the heavy mineral concentration procedure, moist samples were weighed, screened at 10 mesh, and the resulting gravel fraction (+10 mesh or >2 mm) was weighed. Clasts larger than about 10 cm were generally excluded at the sampling site. These samples are sufficiently large, 12 kg in most cases, to produce useful statistics for gravel content. Virtually all till samples collected in the area contain a gravel content (measured as weight % greater than 2 mm in moist material), of over 5% (Fig. 45). The mean gravel content of 900 till samples is about 20%. Gravel content is elevated in material derived from within the greenstone belt, hence low in carbonate (Fig. 46). Samples with high carbonate content, 20 to 50%, in the pebbles correspond to gravel contents of 10 to 20%. Among 505 surface samples, values over the 90th percentile of 40% are concentrated in the outcrop area of noncalcareous, locally derived sediments in the Beardmore area. In drill holes, background gravel contents of 10 to 20% are consistently maintained in carbonate-rich tills (Fig. 47, 48). An abrupt rise in granite content at 10 m in hole D from 25 to 60% corresponds with an increase in gravel content from 12 to 28% (Fig. 47). Zones enriched in local, greenstone belt debris have much higher gravel contents of 30 to 60%.

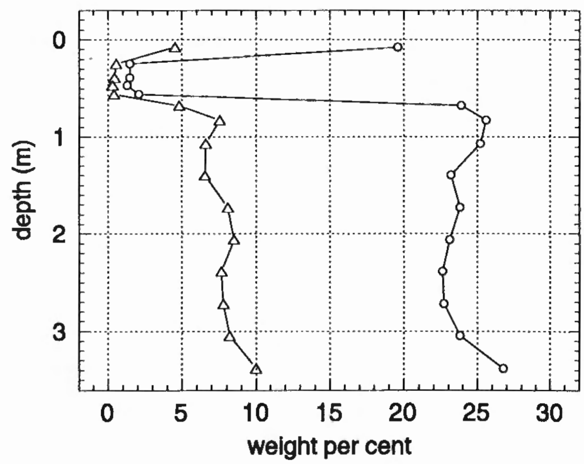


Figure 43. Leaching of carbonate in a soil profile. Triangles indicate calcite, circles indicate calcite plus dolomite or total carbonate (Chittick analysis of <63 μm fraction).

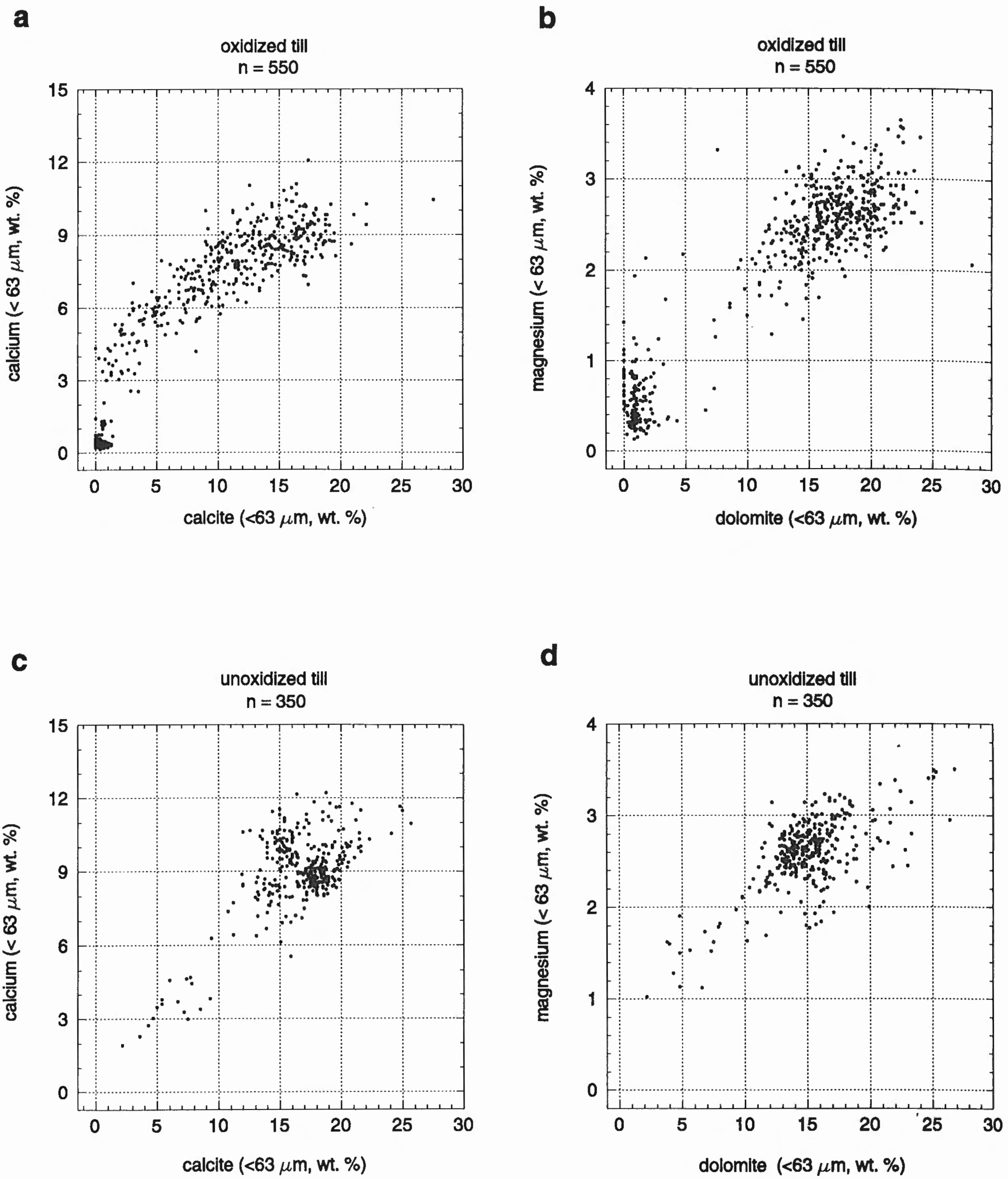


Figure 44. Geochemical indicators of carbonate content, calcium and magnesium concentrations. **a**), **b**) weathered surface till samples; **c**, **d**) unweathered drill hole samples.

Textural analyses of the <2 mm matrix were carried out for selected drill hole till samples. This material typically consists of 40 to 60% sand, 20 to 60% silt, and 5 to 20% <2 µm clay. In hole D (Fig. 47), samples with less than 40% sand in the <2 mm fraction occur above 10 m and at 50 m. Abundant gravel and sand contents over 50% are related to locally derived debris at and below 30 m. An abrupt increase in granite pebbles at 10 m influences gravel content but is not apparent as sand. Samples above 10 m depth at hole I (Fig. 48), in contrast to hole D, consist of material with over 40% sand. Very high gravel content and high sand values at hole I are related to locally derived debris below 35 m.

Samples in general (Fig. 49) indicate a cluster with about 40% sand (>63 µm; >4 phi), finer grained samples with as little as 20% sand, and sandy samples containing as much as 70% sand. Clay (<2 µm; <9 phi) contents range from 3 to over 20%. Clay may also be defined as the <4 µm or <8 phi fraction. Clay contents are 10 to 30% using this definition.

There is very little relationship between grain size and provenance data (Fig. 50). There is a very weak positive correlation between the abundance of Paleozoic carbonate clasts and silt content and between metasedimentary and metavolcanic rock abundance and sand content (Table 1).

Table 1. Correlation of texture and provenance data

	5.6-16 mm			<0.063 mm		
n=302	Pebbles: Paleozoic carbonate	Granite	Metased. & metavolc.	Chittick: Calcite	Dolomite	Carbonate
Gravel*	-0.429	-0.159	0.481	-0.568	-0.352	-0.577
Sand**	-0.209	-0.175	0.314	-0.443	-0.229	-0.421
Silt**	0.247	-0.079	-0.136	0.202	0.418	0.396
Clay**	0.003	0.427	-0.353	0.483	-0.217	0.156

*wt.% of total
**wt.% of <2 mm matrix

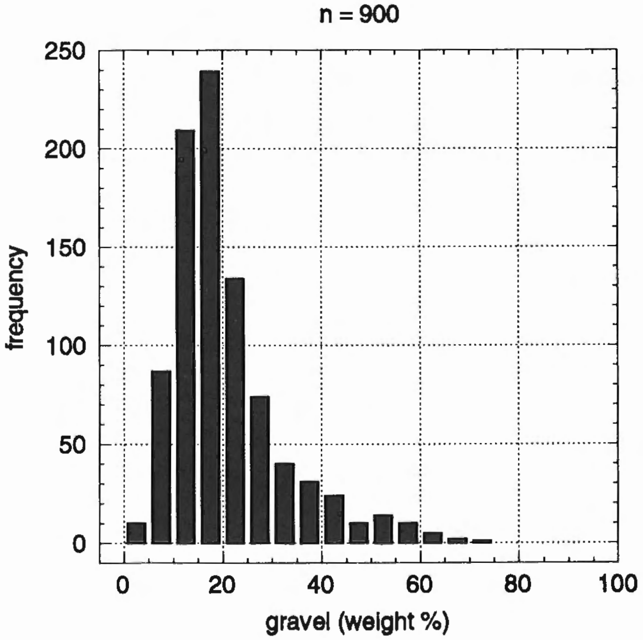


Figure 45. Gravel content of till samples (>2 mm).

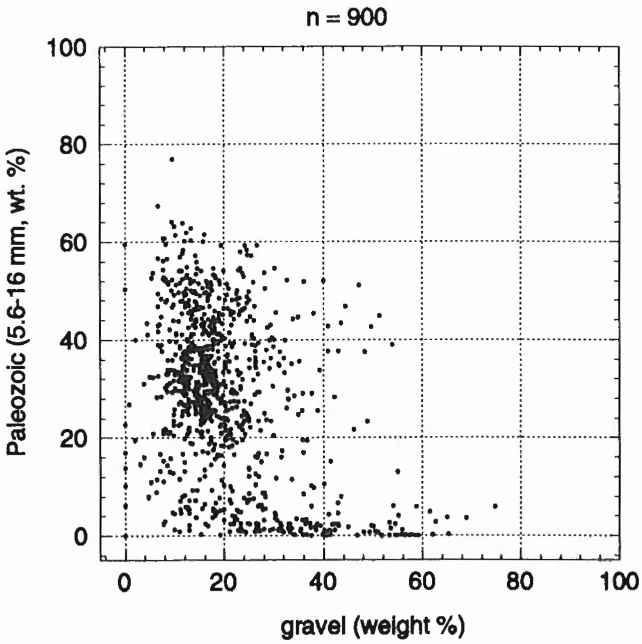


Figure 46. Relationship of gravel content to provenance: scatterplot of gravel content (weight per cent >2 mm) and provenance of till, as indicated by Paleozoic carbonate content of the pebble fraction (5.6-16 mm).

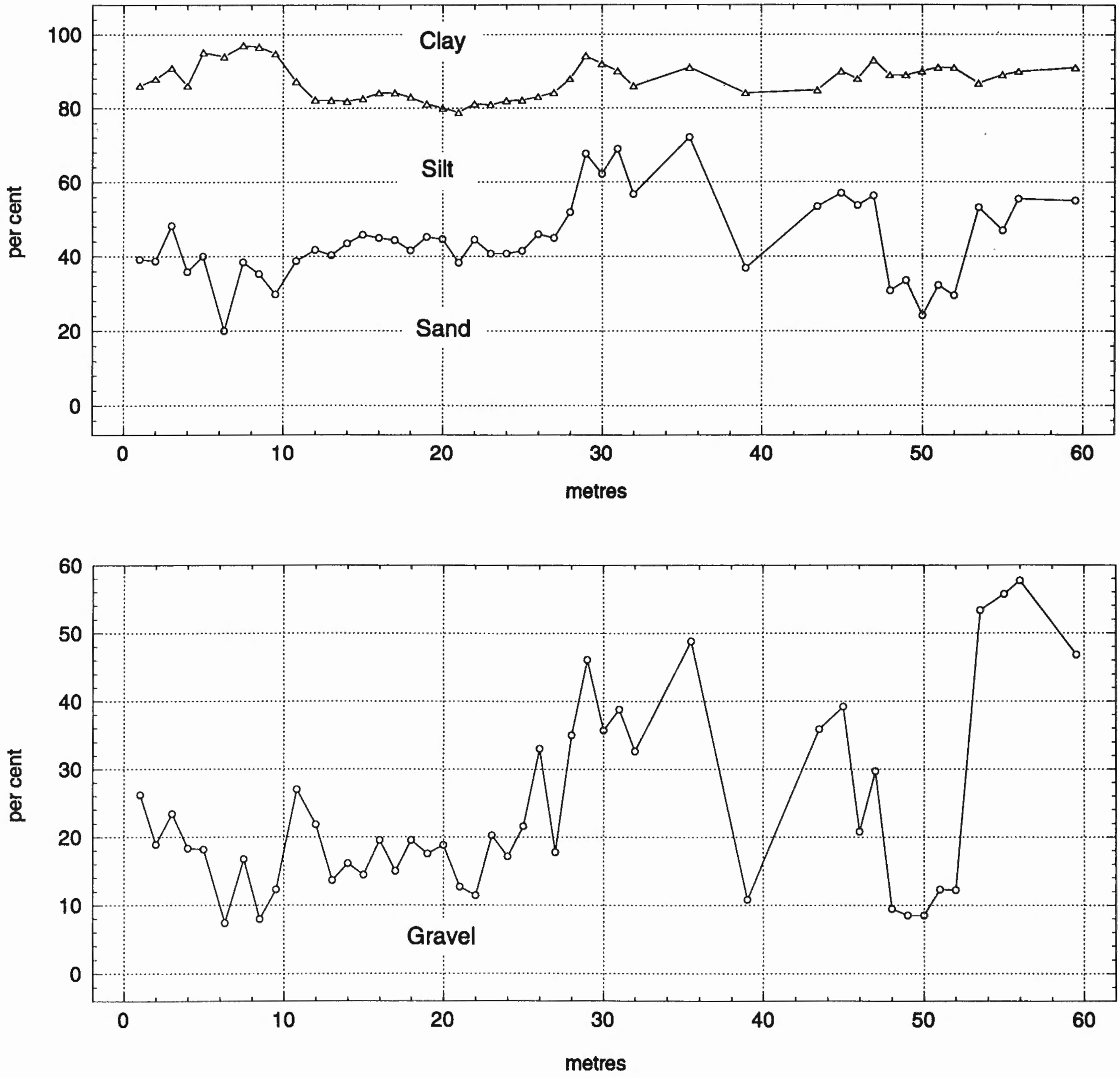
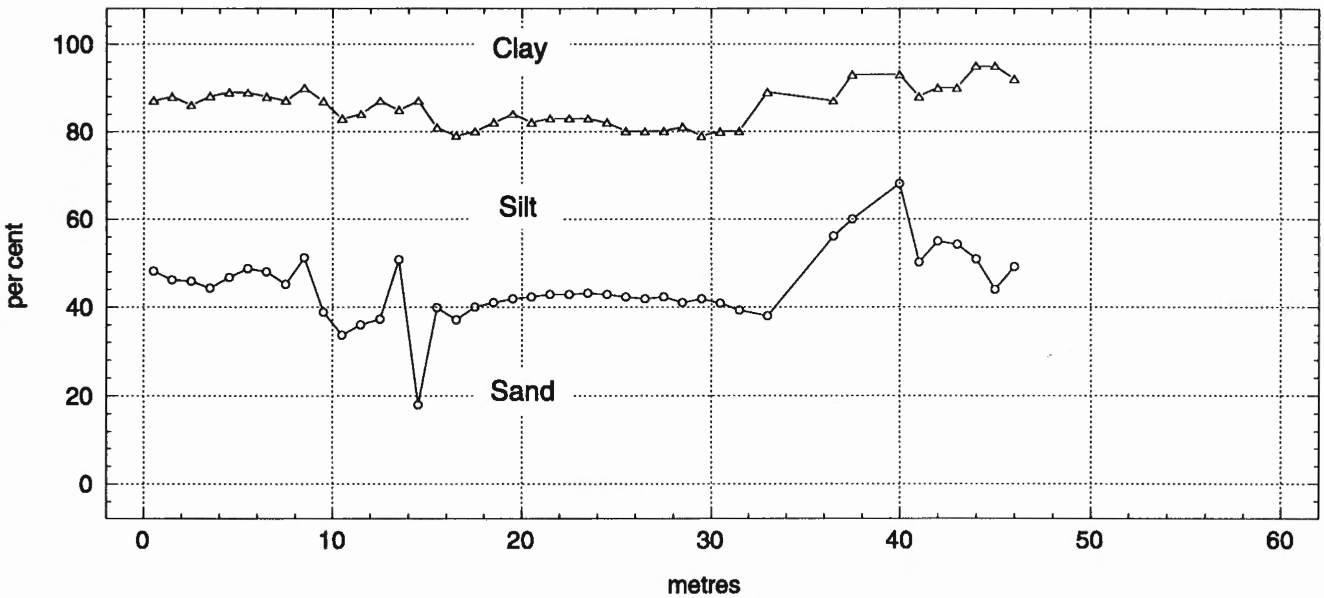


Figure 47. Summary of textural data from hole D.



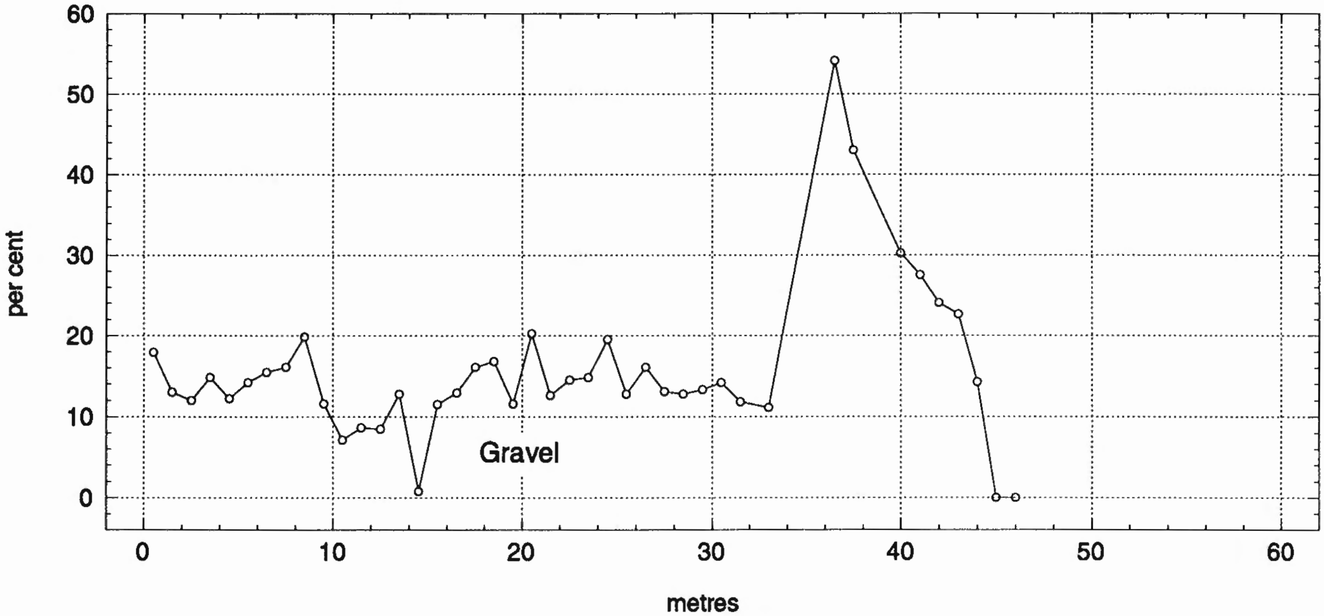


Figure 48. Summary of textural data from hole I.

Sand values show negative correlation with all Chittick carbonate values. Stronger positive correlations are present between silt and Chittick carbonate than clay.

Morphology and extent

Till consisting of thin, locally derived debris is the most common sediment in areas of bedrock-drift complex (map unit 2; 15 to 75% bedrock outcrop). In the northeastern portion of the study area, however, thin, discontinuous exotic debris is present. Surface morphology in these areas is controlled by the underlying bedrock.

In areas of thick till deposits (map unit 3), drift is much thicker and topography is thus drift controlled. Streamlined morphology such as in the Wildgoose Lake area (Fig. 51) correlates strongly with the occurrence of thick, massive, calcareous diamicts. Drumlins up to 1 km in length are scattered across the area, but the principal morphological feature on thick till deposits are flutes about 1 km wide and over 20 km long. Thick, fluted deposits are concentrated in the central part of the study area between Jellicoe and Geraldton, north and south of Wildgoose Lake, as well as between Kenogamisis Lake and Long Lake.

Thick till deposits on the southwest slope of broad topographic highs, hence similar to deposits in the Hemlo-Manitouwadge area (e.g., Geddes and Bajc, 1985a), occur in two areas northwest of Wildgoose Lake. The bedrock obstacles at these two sites are 3 to 5 km wide and 10 to 20 km long. The lee-side till deposits are about 2 km wide and 10 km long.

On a regional scale, thick till in northern Ontario (Fig. 52) has a non-random distribution. The most extensive area where till sufficiently thick to obscure bedrock topography was mapped by Sado and Carswell (1987) is immediately southwest of the Paleozoic carbonate terrane of the Hudson Bay Lowland. Thick till also occurs throughout the Hudson Bay Lowland (McDonald, 1969; Skinner, 1973), but this area was mapped by Sado and Carswell (1987) as having a thick cover of peat. The band of outcropping thick till on the shield parallel to the Paleozoic contact can readily be regarded as a zone in which normal glacial processes transported carbonate debris from the lowland. As discussed by Kaszycki (1987), beyond this zone are a series of zones elongated parallel to ice flow which are connected or nearly connected to the above band of carbonate debris. Four such tongues are recognizable: 1) Pickle Lake in northwestern Ontario, 2) Geraldton, 3) Hemlo-Manitouwadge, and 4) Chapleau. Hudson Bay Lowland debris is documented in this report for the Geraldton area and has been reported for Hemlo by, for example, Geddes (1984a). Other areas of extensive thick till include 1) a zone of late glacial south-southeastward ice flow north of Timmins; 2) southwest of Proterozoic rocks in the Nipigon basin; and 3) the Fort Francis area, where ice flow fanned southeastward from Manitoba Paleozoic terrane (Sado and Carswell, 1987). Hence, in northern Ontario, thick till only occurs where easily eroded Proterozoic and Paleozoic rocks served as the source.

Depositional processes

Nothing observed in the diamict-dominated sequences in the area suggests multiple episodes during which carbonate-rich debris was transported from the Hudson Bay Lowland. No weathering horizons in the drilled sequences are indicated

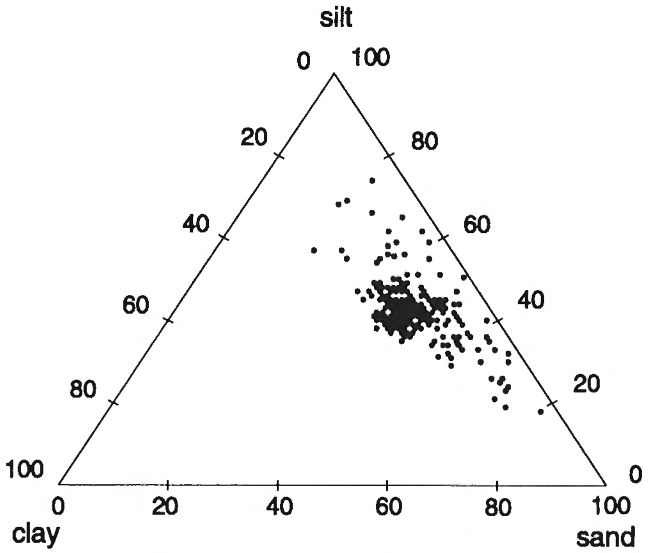


Figure 49. Textural analysis of till from drill holes (<2 μm fraction; n = 302).

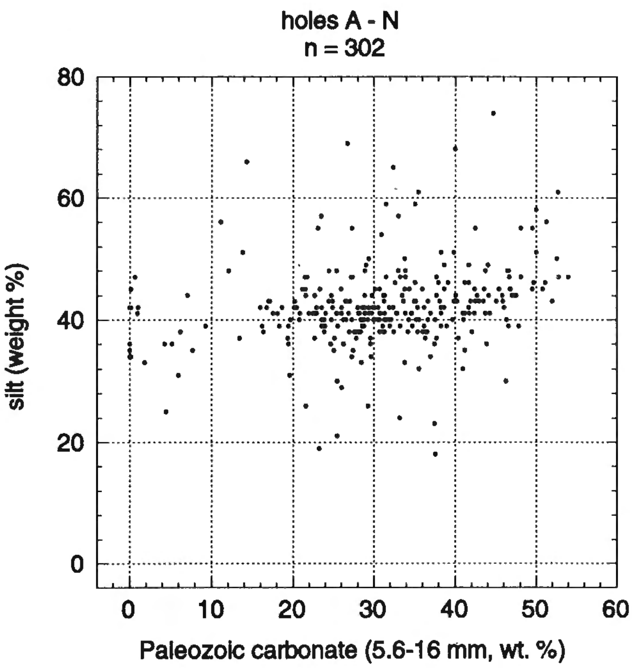


Figure 50. Comparison of texture and provenance data: scatterplot of silt content of the <2 mm fraction and weight per cent carbonate in the pebble (5.6-16 mm) fraction of drill hole samples.

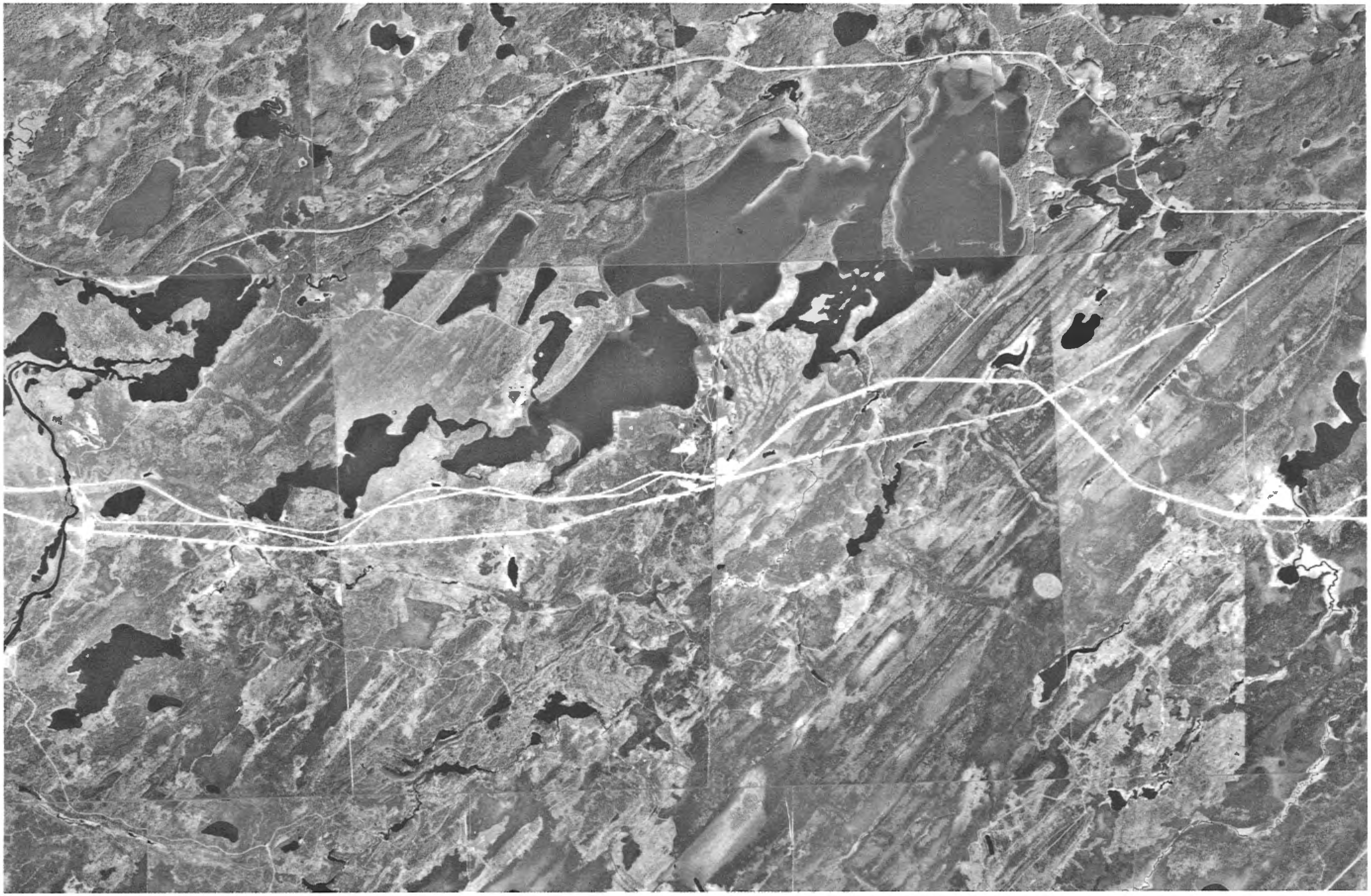


Figure 51. Streamlined thick drift in the Wildgoose Lake area. (North to top; area covers approximately 19 km x 12 km)

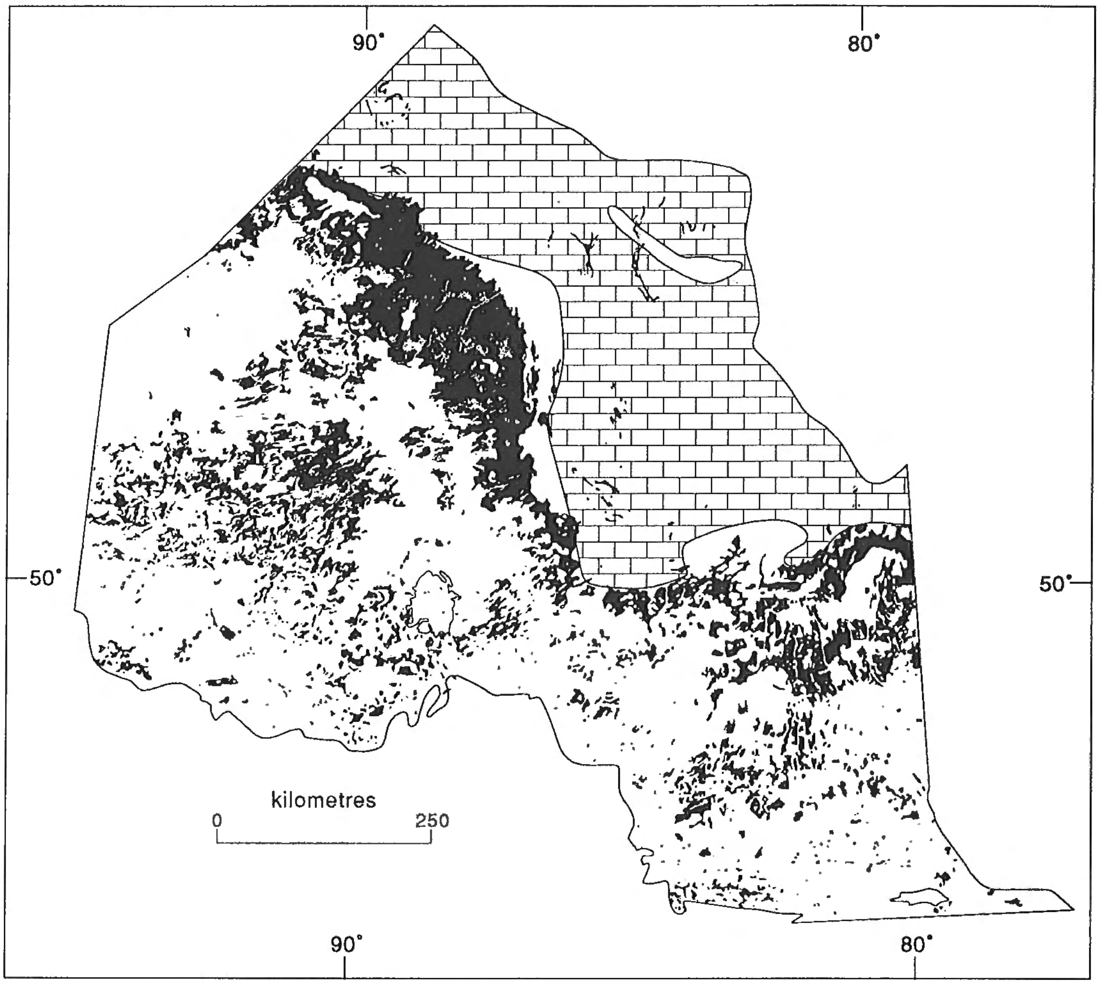


Figure 52. Extent of thick till in northern Ontario: outcrop pattern of till sufficiently thick to mask bedrock topography (black areas) (from Sado and Carswell, 1987). The extent of Paleozoic carbonate rocks is shown as a brick pattern.

either by colour or sulphide preservation data and no buried organic material was encountered. Thin, locally derived diamicts in the Beardmore area may be the chronostratigraphic equivalents of any portion of the thick sequence at Wildgoose Lake. Equivalence with the locally derived debris at the base of the drilled sequence would imply that no sedimentation occurred at Beardmore while thick exotic diamict was being deposited at Wildgoose Lake. On the other hand, thin, locally derived debris at Beardmore may have been transported a short distance and deposited at the same time as calcareous debris was being transported to Wildgoose Lake. It seems likely that some locally derived sediments are remnants of earlier events and others were deposited at the same time as exotic debris elsewhere. Furthermore, the regional extent of thick, calcareous debris indicates a single event in which a clearly defined tongue of debris was transported southwestward.

The stratigraphic successions encountered in drill holes indicate the following sequence of events. Pervasive erosion removed any weathered bedrock, weathered sediments, or organic material which may have been present and left a striated bedrock surface with local relief of over 50 m. The lowermost sediments are locally derived diamicts, but there is no indication that these occurrences are necessarily correlative in terms of time of deposition. Multiple episodes and processes of sedimentation may have been responsible for these deposits, thus simply reflecting the increased probability of local derivation near the bedrock surface. Subsequently, glacial debris derived partially or completely from the Hudson Bay Lowland was deposited in the Wildgoose Lake area. Low areas on the bedrock surface were filled with interbedded, thin units of sand and diamict. At hole D, local debris was mixed with exotic material in this thin unit sequence. Local relief was thus reduced as topographic lows were filled to the level of the surrounding bedrock surface. Thick diamicts were then deposited, raising topography above its previous bedrock-controlled level. At several sites, two thick units, the lower being more compact than the upper, are separated by a thin, soft diamict or laminated silt and clay. Included in these thick, exotic diamicts are zones enriched in granite similar to bedrock north of the belt. Finally, the uppermost sediments were deposited as a discontinuous cover of interbedded sand and thin diamicts, including graded units.

For the purpose of discussion of processes of deposition, diamicts and associated sediments may be grouped as: 1) thin massive diamicts of both local and exotic derivation which were examined in excavation walls, 2) graded diamicts interbedded with thin massive diamicts and sand which were observed in excavations and at the top of drilled sequences, 3) thin diamicts interbedded with sand in drilled bedrock lows, and 4) thick exotic diamicts.

Massive diamicts in surface exposures are generally difficult to interpret conclusively. In many cases, it is sufficient to conclude that the material is probably a basal till (deposited by a subglacial process such as lodgment; Eyles et al., 1982, 1983; Dreimanis, 1989). Fabric and other structural data obtained by Hicock (1988a) indicate shear, hence increasing the certainty with which a subglacial origin may be claimed. The presence of cobbles with horizontally positioned planar, striated facets (Fig. 19; Hicock and Kristjansson, 1989) further increases the likelihood of lodgment sedimentation, given that sliding ice must have been in contact with the sediment as it accumulated. It is hence likely that many to most thin massive diamicts sampled at surface, especially locally derived sediments, are lodgment tills.

At some sections and holes, however, graded diamicts occur at surface. These sediments are interpreted as sediment flows (Lawson, 1979, 1982; Paul, 1983), also referred to as flow tills (Hartshorn, 1958; Boulton, 1968). Normally graded sediments, according to Lawson (1979), indicate high water content and may be capped by laminated silt and sand elutriated from the flow. The most likely source for sediment flows is considered the ice surface. At a roadcut northeast of Geraldton (Fig. 19), cobble and boulder-sized clasts in a graded diamict consist predominantly of angular granitic rocks. The angular nature of this coarse debris is attributed to englacial transport, as suggested by Boulton (1978). Although bedrock at the site is granitic, probable sources for englacial debris of this lithology are bedrock hills northeast of the site. Supraglacial debris is presumably scattered across the area. The distinction between supraglacial and subglacial sediments can only rarely be made, however, due to lack of development of diagnostic morphology and sedimentary structures or simply lack of exposure in, for example, a shovel hole. Speculative distinctions on the basis of provenance, clast roundness, and degree of compaction can be made, but these considerations played no role in sampling.

Interbedded thin diamicts and sand fill bedrock lows in drilled sequences. These sediments are presumably a mix of glaciofluvial sand, subglacial sediment flows, and till. Locally derived debris mixed in this sequence, such as at hole D, may represent erosion from nearby bedrock highs as the low was being filled. Much of this filling took place after the arrival of carbonate debris in the area.

Thin diamicts across the area can thus be explained by what might be regarded as well-known processes. Locally derived, thin lodgment tills are easily attributed to the basal load of the glacier, transported within at most a few metres of the bed (e.g., Dreimanis, 1976; Shaw, 1985). Carbonate-rich till could, according to conventional practice, be assigned to englacial transport, given distance of transport exceeding 100 km and the preservation of soft carbonate clasts. Goldthwait (1971), for example, indicated that less than 0.1% of any clast lithology survives 35 km of basal transport. The process responsible for placing the debris into an englacial position would however, remain enigmatic. Thin diamicts consisting of exotic debris could be attributed to subglacial melt-out from stagnant ice and slumping from the ice surface, producing an assemblage of partially sorted, englacial debris well suited to the term ablation till.

The presence of massive, exotic diamicts up to 25 m thick, however, presents a challenge for which traditional models seem deficient. Deposition by lodgment of basal debris seems contradicted by carbonate clast preservation. Melt-out from stagnant ice would imply thicknesses of and debris concentrations in debris-rich ice well beyond what has been observed in contemporary glaciers in order to produce the documented thickness. Melt-out models also require an ad hoc streamlining event to later modify the depositional surface. Extensive evidence for regional stagnation, as is known where melt-out till has been documented on the prairies (Shaw, 1982), is lacking in northern Ontario. Several issues are thus raised by the thick, massive exotic diamicts: 1) the mechanism by which transport was initiated at the source, 2) the process and/or position in or relative to the ice which permitted transport without comminution, 3) the means by which granites and belt debris were mixed with the exotic debris, 4) the depositional process, and 5) the regional scale processes which produced a radiating, fluted tongue of thick diamicts.

Perhaps the most powerful constraint on the origin of the thick, massive exotic diamicts is their regional distribution in a radiating tongue parallel to southwestward ice flow. Occurrence of thick diamicts in simple tongues of constant width in zones of parallel ice flow could have been attributed to areas of more easily eroded drift or bedrock in the Hudson Bay Lowland, hence increased sediment supply. Radiating patterns, however, indicate that glacial processes were different from the areas between the tongues. Specifically, radiating flow must have been fed by narrow zones of enhanced ice supply, hence ice streams.

Flint (1971) referred to ice streams as a normal feature of ice sheets and defined them as narrow zones within an ice sheet along which flow is much faster than in adjacent broader zones, in many cases because buried valleys are present at depth. The radial till distribution patterns in northern Ontario dictate the former presence of ice streams, using this definition. Radiating ice flow could only have been maintained by a zone of enhanced supply analogous to a valley glacier feeding a piedmont lobe. Radiating glacial ice flow in every case must have had a source in a valley glacier or ice stream, or perhaps something intermediate between these end members. No topographic control or correlation to any topographic feature is apparent, however, for ice streams feeding areas of radiating flow on shield terrane of northern Ontario (Fig. 52). Rivers in the Hudson Bay Lowland to the northeast of Geraldton are narrow notches cut into a flat plain. In contrast, a younger ice stream on Hudson Bay Lowland Paleozoic terrane extending from the Winisk River to the Albany River (Thorleifson, 1989) is in a location clearly defined by a topographic saddle between high ground in the Fawn River area and the Sutton Ridge. The radiating flow of the shield area ice streams could only have been set up in a near marginal setting in late glacial time. At the time of the maximum extent of the ice sheet, ice flow near the centre of the ice mass which was radiating at an angle greater than that due to the circular form of the ice sheet would have no mechanism of dissipation other than an inexplicable convergence following radiation. It could be argued that the fine grained debris reduced bed roughness and produced the radiating ice flow pattern. The ultimate cause of the four plumes would still require explanation. A positive feedback mechanism involving ice streaming, till sedimentation on the shield, and enhanced ice streaming may have been in effect.

It is concluded that thick, massive exotic diamicts occurring in a fluted debris tongue along the axis of a radiating ice flow pattern near Geraldton were deposited at the bed of an ice stream. A debris tongue such as this was referred to as an axial plume by Dyke (1984) and Dyke and Morris (1988), who examined similar deposits in the Arctic.

Processes of sedimentation beneath an ice stream have become the subject of research only recently. A series of conceptual advances based on field work in Antarctica seem likely to be applicable to the Geraldton case. Seismic surveys of the bed of ice stream B in the West Antarctic have indicated a 10 m thick sediment layer whose seismic properties imply a shear strength less than the shear stress exerted by the overriding ice (Alley et al., 1986, 1987a, b). The implied deformation and hence transport of the sediments is analogous to deformation observed in Iceland by Boulton and Jones (1979) and discussed by Boulton (1982, 1987) and Boulton and Hindmarsh (1987). Thick exotic diamicts of the Geraldton area may therefore represent ice stream deposits transported beneath the glacier by shear. Preservation of carbonate clasts could in this context be attributed to protection by the enclosing fine grained deforming matrix.

Transportation without entrainment in the ice provides a mechanism for rapid sedimentation. Models involving freezing of debris into the ice, followed by transport and sedimentation as the debris melted out of the ice are constrained by the heat flow requirements of freezing and melting. As much as 50 m of exotic debris, including 30 m of thick, massive diamicts at Geraldton, would pose immense requirements for heat flow. In contrast, deformable debris dragged from the Hudson Bay Lowland may have been transported very rapidly, without the heat flow requirements of freezing on and melting out. If it is concluded that all of the calcareous deposits postdate the initiation of radiating ice flow, sedimentation rate becomes a crucial issue. As discussed above, radiating ice flow can only be set up in a near-marginal context. The Marquette re-advance which filled the Superior basin at 10 000 BP (Farrand and Drexler, 1985) seems to be represented in the area by rare striations at 190° at Geraldton. Radiating southwestward ice flow at Geraldton was named the Nipigon phase and correlated to the Nipigon moraine by Zoltai (1965b) is dated 9500 BP. Deglaciation of Hudson Bay at or shortly after 8000 BP brackets the episode of radiating ice flow and thick till sedimentation to at most a few centuries.

Exotic diamicts in the Geraldton area also include deposits on the southwest side of major bedrock topographic highs. Hence the presence of obstacles somehow promoted sedimentation of exotic till on their lee-side.

Ice stream transport is considered the mechanism that distributed exotic till derived from the Hudson Bay Lowland. The formation of this debris, however, appears to be due to the erodibility of the soft and jointed Paleozoic and Proterozoic rocks of the Hudson Bay basin. Thick till deposits beyond the apparent limit of transport from the Hudson Bay Lowland are present only in restricted areas. Thick calcareous till in the southwestern corner of northwestern Ontario (Fig. 52), is known to have been derived from Manitoba (Bajc and Gray, 1987). Southwest of Lake Nipigon, thick till mapped by Sado and Carswell (1987) seems likely to have been derived from Proterozoic rocks of the Nipigon basin. A few patches of thick till along the north shore of Lake Huron may be derived from the Proterozoic rocks of that area. It is therefore apparent that extensive areas of thick till in northern Ontario are primarily attributable to Paleozoic or Proterozoic rocks. Archean rocks thus tend not to supply debris sufficient to generate till deposits masking bedrock topography. This is presumably due to the greater hardness and lack of exploitable joints in granites and gneisses. Greenstone belts are either too resistant or are not sufficiently extensive to be an adequate debris supply affecting the distribution of thick till on a regional level. Hence bedrock character governed sediment supply, but glacial processes, specifically ice streaming, governed the configuration of dispersal.

Thick till in the Geraldton area may therefore be attributed to 1) the presence of a sediment source in an up-ice flow direction, and 2) the former presence of an ice stream which transported the debris and produced a radiating, fluted tongue of thick till centred in the Wildgoose Lake area.

In summary, a drill hole transect across fluted thick drift between Jellicoe and Geraldton indicates that a discontinuous cover of graded sediment flow diamicts derived from the ice surface and sand (Fig. 53) overlies as much as 50 m of calcareous silty till in which Paleozoic carbonate and Proterozoic metasediments derived from the Hudson Bay Lowland are more abundant than local debris. At several sites, locally derived debris with little or no exotic material was encountered. Lenses of glaciofluvial sediment occur within the thick diamict sequence. Neither organic material nor weathering horizons were encountered.

Sand and gravel

Sand and gravel deposits occur as eskers and kames formed in contact with glacial ice in conduits and ice-marginal fans, braided subaerial outwash deposited beyond the ice margin

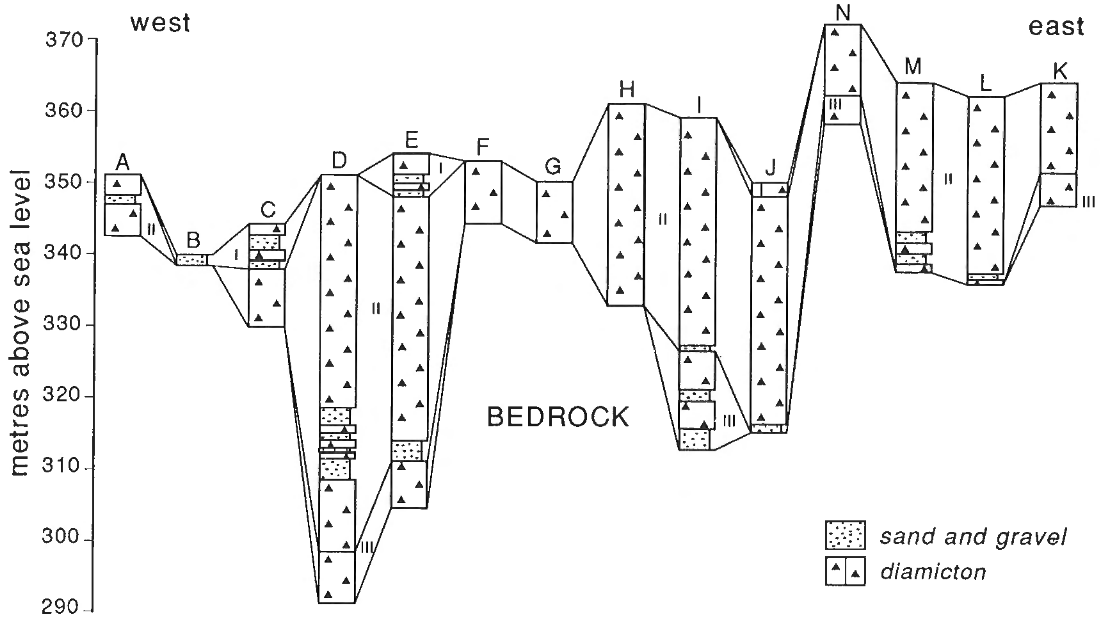


Figure 53. Drill hole stratigraphy; I: discontinuous cover of graded sediment flow diamicts and sand; II: sediments dominated by calcareous silty diamicts; III: locally derived debris. Refer to Figure 11 for drill hole locations.

in subaerial environments, and subaqueous outwash sheet sands deposited by underflow currents below proglacial lake levels.

Sand and gravel in the area represent lag deposits resulting from entrainment of glacial diamicts in meltwater. The silt and clay which must have been removed to produce this coarse sediment was removed from the study area by meltwater, except for minor deposits near Lake Nipigon. Abnormally thick deposits of very calcareous grey clay along the north shore of Lake Superior (e.g., Dell, 1974) presumably in part represent fines transported from the study area. This sediment in the Superior basin has a colour (5Y 4-5/1; Farrand, 1969b) identical to that of unoxidized very calcareous till drilled in the Wildgoose Lake area (5Y 4-5/1).

Ice contact glaciofluvial deposits

Areas of ice contact glaciofluvial deposits (map unit 4) were identified on the basis of gravelly texture and the presence of esker ridges and a complex array of kettle holes and other relief apparent in aerial photographs. Esker ridges and associated deposits are composed of sandy gravel or gravelly sand. Most eskers are cored by massive to crudely-bedded pebble, cobble, and small boulder gravel, grading vertically and laterally to gravelly sand or sand. A complex pattern of small-scale faults was observed in deposits of sand flanking the gravel core of an esker at one site.

The composition of the pebble fraction from esker samples indicates a pattern similar to that of surrounding till deposits (Fig. 35). From the Wildgoose Lake-Geraldton-Longlac area to north of Nakina, eskers contain 30 to 60% carbonate clasts. The carbonate values drop off to 15 to 20% southeast of Beardmore. Northeast of Beardmore, in an area dominated by locally derived till, carbonate content in the eskers falls as low as 1%. As discussed by Pattison (1985) and Heath (1988), the composition of esker gravel therefore implies that transfer of debris to the glaciofluvial system did not involve a significant increase in total distance of transport, the majority of transport having been carried out by glacial processes.

Ice contact glaciofluvial deposits are concentrated in a series of relatively narrow belts oriented parallel to the southwestward final ice flow direction. A single steep-sided sharp-crested esker ridge, marking the position of a subglacial meltwater conduit, is the dominant landform of most of these belts. Esker ridges range up to 30 m in height and may be relatively continuous along their length. For example, an esker ridge southwest of Geraldton, 2 km east of Gamsby Lake, has only minor breaks over a length of 11 km. The esker belts are spaced 5 to 7.5 km apart, implying a well integrated meltwater escape system in the glacier (Banerjee and McDonald, 1975).

Subglacial meltwater conduits trend in the direction of the greatest decrease in the hydraulic gradient, which in general conforms with the direction of slope of the surface of the glacier (Shreve, 1972). This southwest trend is perturbed, however, at sites where the hydraulic gradient increased in proximity to topographic highs on the glacial bed or decreased in topographic lows. Thus, a spatial relationship is apparent between the occurrence of eskers and areas of lower elevations. For example, three parallel esker systems in the Geraldton area, one to the east and two to the west of Kenogamisis Lake, trend southwestward. As the eskers approach a topographic high, however, they converge to form one larger and more continuous esker which crosses a low point in the topographic barrier south and southwest of Finlayson Lake.

Eskers also exhibit shifts from deposition to erosion in response to topography. An esker 8 km northwest of Longlac which trends southwest across an area of low-lying topography merges downflow with a channel eroded across a topographic high. The configuration of the high, which is concave in the upglacier direction, may have prevented divergence of meltwater flow around the obstacle. As a result, potential increased upstream from the bed obstacle and a channel was cut across the topographic high. The meltwater flow was erosional across the barrier and depositional in the area of lower topography.

The belts of glaciofluvial sediment are discontinuous and consist of alternating narrow esker ridges deposited in a subglacial conduit and wide kamiform and kettled terrain deposited in ice marginal fans. For example, 6 km southeast of Jellicoe, a single sharp-crested esker ridge divides to form multiple sharp-crested ridges 200 to 800 m in length. Kettle lakes or boggy depressions up to 750 m long flanking the eskers are attributed to large blocks of stagnant glacier ice. The esker ridges cross a steep northeast-facing slope which marks the ice-contact proximal flank of a fan-shaped sand body deposited at the ice margin. Minor depressions on the fan are attributed to the melting of small remnant blocks of glacier ice. The sediments forming the fan were deposited in a subaerial environment and grade gradually from a proximal sandy gravel to a distal gravelly sand.

Another example of an esker-kame complex is located south of Alfred Lake, northeast of Geraldton. A generally continuous sharp-crested esker ridge approximately 3.5 km long extends most of the length of this complex. The initial ice marginal fan area is composed of multiple coalescent hummocky and lobate sand bodies, within which the main esker ridge is discernible. Numerous kettle holes were also observed. The width of this area decreases in the upstream direction until only the main esker ridge, flanked by large ice contact depressions, is apparent. An area of ice marginal fan deposits and an associated esker constitute a distinct morphological sequence, which is repeated at least six times. The size of esker ridges and associated fans decreases to the northeast. At the extreme upstream end of the complex, only short (200-400 m) ridge segments and irregularly-shaped hummock forms are apparent.

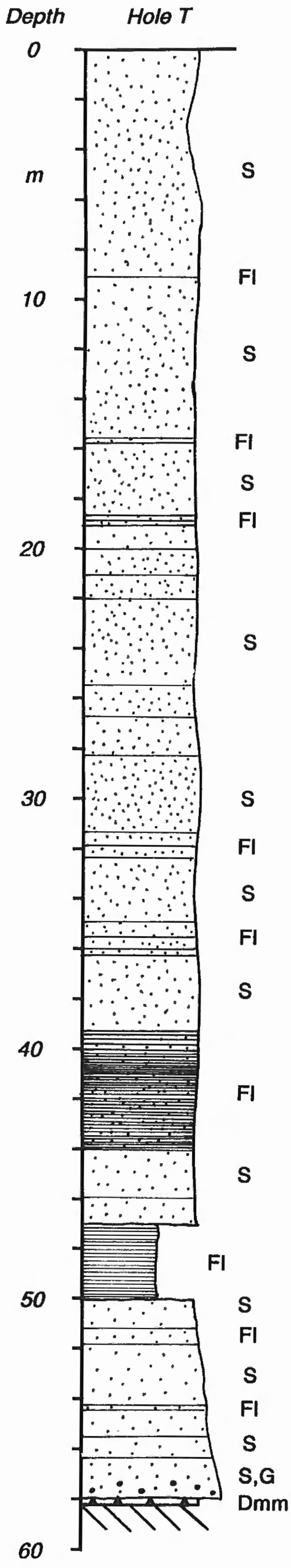
The esker-kame complex in question is situated in a lowland underlain to a large extent by glaciolacustrine sediments and represents deposition in a subaqueous environment at the ice margin. The examination of a number of sand bodies situated within the confines of the glaciolacustrine basin revealed a proximal zone of sandy gravel and gravelly sand, which grades within 100-200 m in the downstream direction to silty fine sand and sandy silt. As discussed by Boulton (1968), meltwater in a subaerial environment maintains competence to transport coarse sediment well beyond the ice margin, but rapid facies transitions result as competence is lost at a subaqueous margin.

A different form of ice contact glaciofluvial belt is present in an elongate basin oriented parallel to the latest direction of glacier flow and occupied by Dumas and Tigerlily lakes, south of Treptow Lake. Linear accumulations of sand and gravel occurring as discontinuous hummocks, sharp-crested esker ridges less then 0.5 km long and more extensive hummocky, kettled and flat-topped deposits extend along the sides as well as across the basin. Intervening depressions at irregular intervals are attributed to large blocks of stagnant glacier ice. Extensive, planar to hummocky kame terraces are associated with high areas of bedrock at the upglacier and downglacier ends of the feature. The esker ridges are not as well developed as the previously described examples, are more discontinuous, and are situated both on the periphery of the basin parallel to glacier flow and across the basin transverse to glacier flow. The character of these deposits is attributed to deposition in an area of stagnant ice. The linear deposits which extend across the basin may represent deposition within a system of transverse crevasses between blocks of stagnant glacier ice and the linear accumulations oriented parallel to the long axis of the basin represent deposition between stagnant glacier ice and the sides of the basin.

Subaerial outwash

Gravelly outwash (map unit 5) deposited in proglacial braided streams, as well as spillway features, were formed in subaerial environments above proglacial lake levels. These deposits are concentrated in the central part of the study area. The ground surface within areas of subaerial outwash is generally planar, with rare to occasional kettle holes. These deposits are proglacial lateral equivalents of ice contact deposits, so planar areas of outwash may be gradational to hummocky and ridged areas of esker and kame deposits. The thickness of outwash deposits is estimated to range from 1 to 10 m. These deposits commonly consist of pebbly, medium- to coarse-grained sand.

Channelized and dissected terrain which occurs to the south and southwest of Wildgoose Lake and Porthos Lake was carved by meltwater episodically released from an ice-marginal lake in the Geraldton area. The size of the channels and their association with boulder lags and coarse grained, glaciofluvial sediments indicates the meltwater flows were vigorous. The orientation of the channels transverse to the southwestward direction of glacier flow suggests westward drainage along the ice margin. In this area, the slope of the ground surface falls toward the ice margin, and periodic spillway activity therefore was focused along rather than away from the ice margin, as it was farther south. Glacier recession and the exposure of land of successively lower elevation along the ice margin resulted in the formation of a series of transverse channels that mark sequential ice marginal positions. The elevation of the channels decreases



northeastward from 1200 ft. (365 m) to 1175 ft. (360 m). A similarly channelized and dissected terrain at about 1150 ft. (350 m) elevation in Croll, Coltham, and McKelvie townships, between Kenogamisis and Long lakes, was formed by later eastward drainage from the Geraldton area.

Subaqueous outwash

Silty, very fine sand and fine sand deposits (map unit 6) occupy broad topographic lows extending from Lake Nipigon to Jellicoe, and northward from this line, as well as in the Geraldton/Longlac area. Excellent exposures of ripple crosslaminated sand are present in sections along Lake Nipigon at, for example, the mouth of the Namewaminikan River. The sediments were cored to bedrock at a site northeast of Poplar Lodge (Fig. 54 and 55). The drilled sequence consists of silty, fine sand interrupted at intervals of a few centimetres to a few metres by a clay layer about 1 cm thick.

These sediments are interpreted as having been deposited in a proglacial lake on the basis of the absence of gravel, presence of a silt component in the sand, and presence of clay laminae. Alternating sand/clay units are considered proximal rhythmites, near-source equivalents of silt/clay varves. Thick, ripple crosslaminated sand dictates deposition from traction in an underflow current.

The behaviour of sediment-laden inflow upon reaching a standing body of water is primarily dependent on the relative density of the river and basin waters (Jopling and Walker, 1968; Gustavson, 1975; Smith et al., 1982). Traction sedimentation well below former lake level indicates that the incoming meltwater had a density higher than the lake water probably due to turbidity, but possibly also due to temperature.

The sediments are classified as glaciofluvial due to their origin as proximal, sandy deposits produced by traction currents emanating from a glaciofluvial environment. Deposition from suspension, which can be considered a lacustrine process, plays a minor role in these sequences. Hence there is a contrast between sandy subaqueous outwash in the study area and varved silt and clay, which may be considered a more typical glaciolacustrine sediment.

Eolian dunes, now completely stabilized by vegetation are common in areas of subaqueous outwash sand. Excellent examples are present northwest and east of Beardmore and in the Geraldton area. These dunes are typically a few hundred metres in length, are oriented generally northwest-southeast, have steep avalanche faces on the northeast side, and consist

Figure 54. Lithofacies profile of thick sorted sediments at hole T, near Beardmore. S: fine to very fine sand; Fl: laminated fines i.e. clay 0.5 to 3 cm thick; S, G: Pebbly sand; Dmm: matrix supported massive diamict, oblique lines: bedrock.

of fine to medium sand, indicating an effective paleo-wind direction from the southwest. These dunes probably formed shortly following deglaciation, after the glacial lakes retreated from the sites, exposing an unvegetated sand sheet to eolian processes.

Subaqueous outwash and other sediments were also identified in Long Lake and beneath Lake Nipigon using subbottom acoustic profiling (Appendix 1). Sediments in the north basin of Long Lake include at least several metres of stratified sediments. Depressions within these sediments are attributed to the melting of buried debris-rich blocks of glacial ice. In the narrows of Long Lake, a discontinuous feature interpreted as an esker is present. Two eskers entering Long Lake were mapped on land in this area and Zoltai (1965a) mapped an esker emerging from the south end of Long Lake. The esker continues into the south basin. In Lake Nipigon, stratified sediments several metres thick extend well offshore.

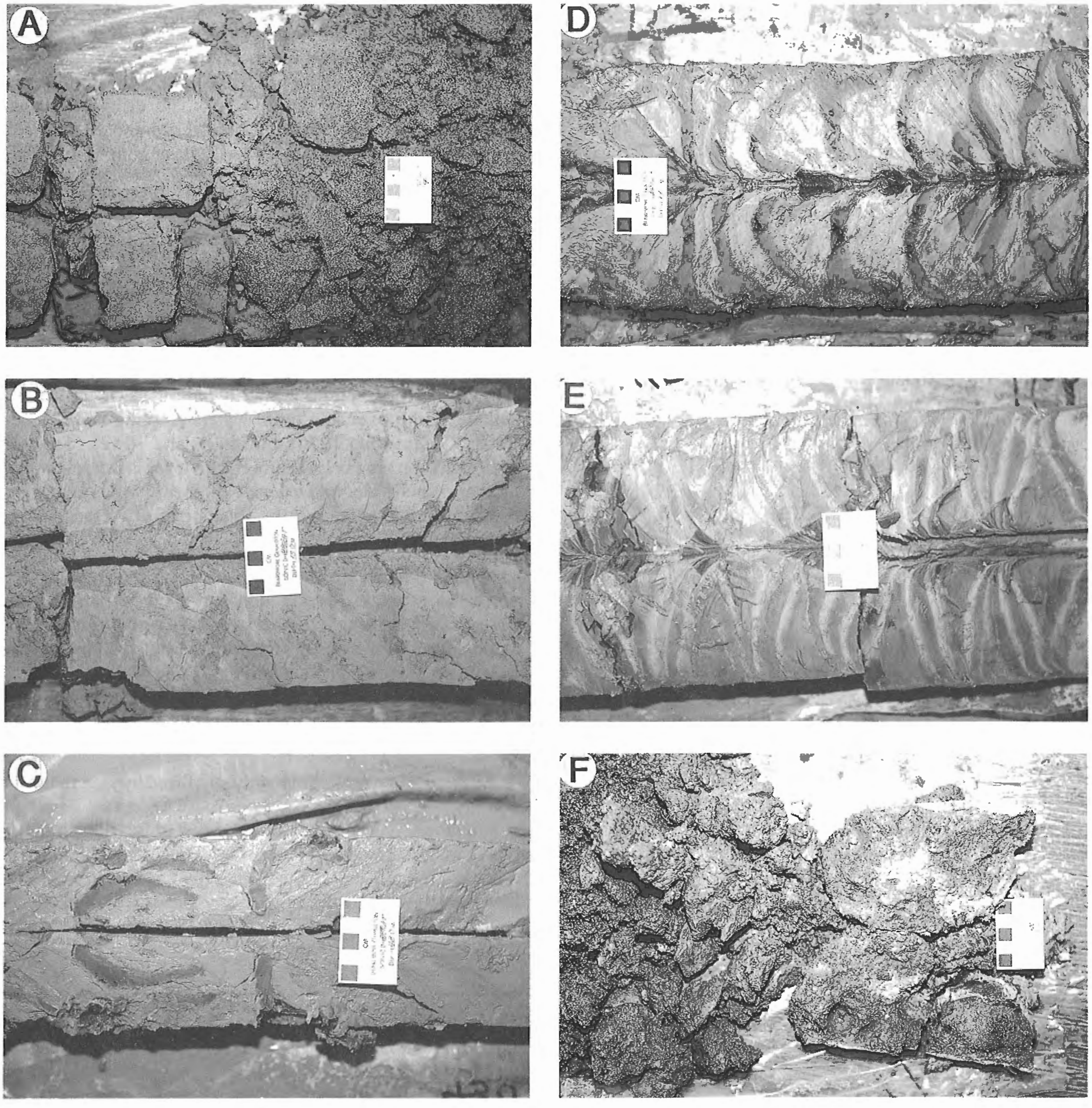


Figure 55. Sediments from hole T. **A**. 5.4 m, GSC 1991-101-K; **B**. 13.0 m, GSC 1991-101-J; **C**. 43.0 m, GSC 1991-101-O; **D**. 47.0 m, GSC 1991-101-S; **E**. 48.0 m, GSC 1991-101-Q; **F**. 58.2 m, GSC 1991-101-R. Scale increments = 1 cm.

Alluvial deposits

Alluvial deposits (map unit 8) composed of silt, sand, gravelly sand, and/or organic material are present in present-day floodplain environments or preserved in the form of early Holocene terraces. Although these deposits are present within and adjacent to all streams and rivers which are not incised, deposits are only mappable in areas of fluvial reworking of glaciofluvial or glaciolacustrine sediment. The boundary between present or earlier postglacial floodplain environments and adjacent glaciofluvial or glaciolacustrine terrain is very often marked by a prominent fluvial scarp. These fluvial systems almost invariably exhibit a meandering channel pattern. Relict channel forms, primarily abandoned meander loops, are common features of defined floodplain settings in the area. Particularly well developed examples of these features occur in alluvial terrain adjacent to the Blackwater River in the Beardmore Township Municipality, in McComber Township, and alongside the Namewaminikan River in Irwin Township.

Organic deposits

Organic deposits (map unit 7) occur throughout the study area as thin discontinuous patches of peat and muck less than 1 m thick. Thicker, more continuous deposits of organic material, 1 to 2 m thick, are present in the vicinity and to the north of Atigogama Lake, to the south of Leduc and Legault townships, to the north of South Beatty Lake, in the vicinity and to the west of the town of Geraldton, in the vicinity and to the north of Kenogamisis Lake, and to the northwest of the town of Longlac. Organic deposits commonly occur within depressions between the crests of flutes on areas of fine grained calcareous till.

Continuous cover of organic material ranges from closed forested to open forested areas. These areas are commonly associated with open bodies of water. Organic deposits form on water-saturated anaerobic substrates, where decreased rates of decomposition result in the accumulation of partially decomposed plant debris. Most peat deposits in the area are authigenic deposits formed in situ. Minor deposits of allogenic peat, which has been eroded and transported to the depositional site may be present. Allogenic peat tends to be finely divided and more decomposed than authigenic peat and, when mixed with varying proportions of inorganic sediment, is referred to as muck.

HISTORICAL GEOLOGY

The landscape of the Beardmore-Geraldton study area is largely erosional. Little stratigraphic information is available from exposures. Thick sequences which were drilled are interpreted as simple, rapidly deposited sediments. An understanding of the Quaternary history of the study area therefore must depend on information from adjacent basins where a more complete stratigraphic record has been preserved. Hudson Bay Lowland riverbank exposures represent the nearest available outcrops of the regional till sequence. The Superior and Nipigon basins received fine grained sediments winnowed by meltwater from the coarse glaciofluvial deposits of the Beardmore-Geraldton region. Superior basin stratigraphy therefore records, to some degree, the influence of meltwater processes in, and fine grained materials from, the Beardmore-Geraldton area.

Advance of the ice sheet

The time at which the Beardmore-Geraldton area was overridden by the advancing Wisconsinan Laurentide Ice Sheet may only be determined by referring to the stratigraphic record of the Hudson Bay Lowland, the edge of which is located 100 km northeast of Geraldton. This is due to the absence of any datable material or other deposits which predate the last glaciation in the study area. In contrast, Wisconsinan tills in the Hudson Bay Lowland overlie exposures of subaerial deposits which were formed immediately preceding the advance of the ice sheet.

McDonald (1969, 1971) and Skinner (1973) conducted reconnaissance examination of Hudson Bay Lowland Quaternary stratigraphy, including tills and an underlying nonglacial sequence of marine sediments, peat, forest litter, and glaciolacustrine sediments. These nonglacial sediments had been examined earlier by Terasmae (1958) and Terasmae and Hughes (1960) and were named the Missinaibi Formation by Skinner (1973). The fossiliferous marine sediments at the base of the Missinaibi sequence were named Bell Sea sediments by Skinner (1973). At their type locality, as well as other occurrences considered correlative, these sediments were attributed to the earliest part of the nonglacial episode (Skinner, 1973) during a period of postglacial isostatic depression similar to that which occurred during the early Holocene. Below the Missinaibi Formation, three till units separated by waterlaid sediments were reported by McDonald (1969, 1971) and Skinner (1973). These pre-Missinaibi tills were attributed to glacial oscillations, probably during the Illinoian. A fourth pre-Missinaibi till was identified by Shilts (1984b). Above the Missinaibi Formation, two and in places three till units, sometimes separated by waterlaid sediments, were attributed to Wisconsinan glaciation by McDonald (1969) and Skinner (1973).

Numerous radiocarbon dates summarized by Dredge and Cowan (1989) indicate that the age of the Missinaibi Formation is greater than 50 000 BP. Stuiver et al. (1978) used isotope enrichment techniques to obtain a radiocarbon age of >72 500 BP (QL-197) for wood from the Missinaibi Formation. These age determinations led to the conclusion that the Missinaibi Formation is equivalent in age with the Sangamonian, or to the early Wisconsinan St. Pierre interstade (Prest, 1970; McDonald, 1971). These episodes of glacial recession have been dated, largely on the basis of correlation to the deep sea oxygen isotope record (Shackleton and Opdyke, 1973), at 130 000 and 80 000 BP, respectively. From this correlation, it was concluded that northern Ontario was not deglaciated during the Middle Wisconsinan, approximately 30 000 to 40 000 BP, as were areas nearer the margin of the glaciated area in North America.

These views were challenged, however, by Shilts (1982b) and Andrews et al. (1983). They reported that isoleucine epimerization ratios from in situ and transported marine shells collected in tills and associated Missinaibi Formation marine and fluvial sediments in the Hudson Bay Lowland cluster into at least four distinct groups, the youngest being of Holocene age and the oldest being derived from Bell Sea sediments. On the basis of thermal history calculations, the amino acid ratios were taken to indicate that great fluctuations in ice extent had caused marine incursions around 35 000 and 75 000 BP. This implied that the most recent ice advance across the Beardmore-Geraldton area may have occurred as recently as about 30 000 BP. Subsequently, Forman et al. (1987) provided support for Early Wisconsinan deglaciation by reporting a thermoluminescence (TL) age of 80 000 BP for marine sediments underlying till on the Severn River. Furthermore, Wyatt (1989), using upgraded laboratory procedures, was able to duplicate the amino acid data presented by Andrews et al. (1983). He reported, however, that shell fragments whose amino acid ratios imply possible Middle Wisconsinan age only occur in tills derived from offshore Hudson Bay and that no separate set of nonglacial sediments are attributable, on the basis of stratigraphic or radiocarbon data, to a separate nonglacial episode of this age. Berger and Nielsen (1990), however, reported a TL age of 40 000 BP for glaciolacustrine sediments which seem to record the end of the nonglacial episode whose initiation was marked by the marine sediments dated by Forman et al. (1987) at 80 000 BP. Subaerial exposure of the region at around 40 000 BP is not supported by radiocarbon dates, although Beukens (1990) has indicated that some of these dates may be misleading. The present state of Hudson Bay

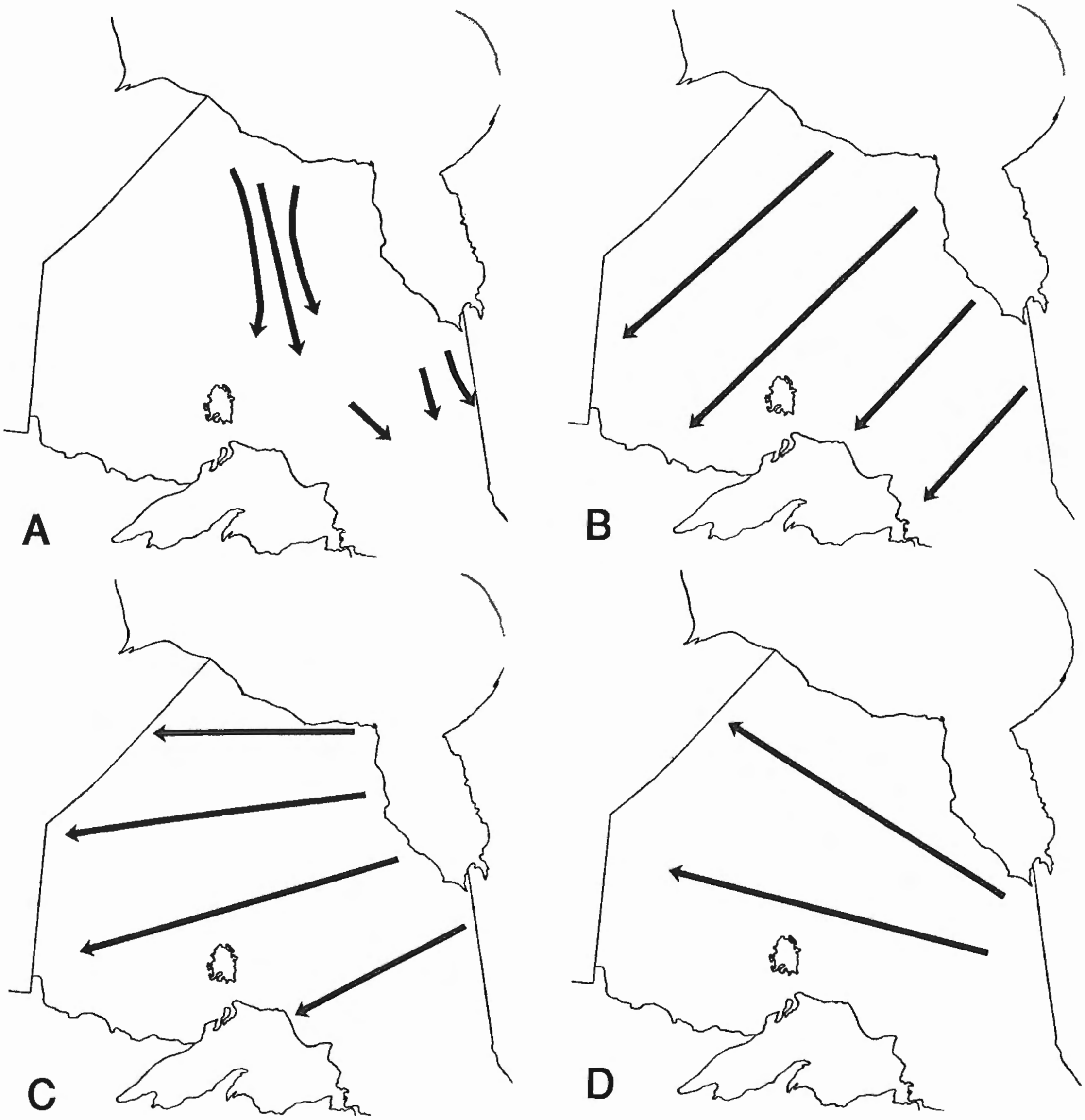


Figure 56. Sequence of regional ice flow patterns from most recent (**A**) to oldest (**D**) (Thorleifson, 1989).

Lowland research therefore implies that the last advance of the Laurentide Ice Sheet over the Beardmore-Geraldton area occurred after oxygen isotope substage 5a, around 70 000 BP or possibly as recently as 40 000 BP.

The possibility of subaerial exposure of the Beardmore-Geraldton area between 11 000 and 10 000 BP, followed by re-advance to the Marquette maximum, was implied by the work of Teller and Last (1981). Their suggestion that the bed of Lake Manitoba was temporarily above the level of Lake Agassiz at this time would require an outlet north of Lake Nipigon to be open. Deglaciation at this latitude would strongly imply deglaciation of the study area, however data from the study area strongly suggest that this did not occur.

Ice flow history

While the region was covered by the Laurentide Ice Sheet, a series of differing ice flow directions caused abrasion of the substrate and dispersal of debris. The sequence of ice flow trends may be summarized as follows (Fig. 56):

A) The most recent ice flow patterns in northern Ontario are localized zones of south-southeastward ice flow in the Winisk-Albany area and in the Abitibi region (Fig. 56). Thorleifson (1989) attributed a single till unit in the former area to an ice stream and not to the flank of the Cochrane lobe (Prest, 1969). In the Abitibi region on the shield south of the Moose River Basin, morphology and the upper tills, Cochrane Till and Matheson Till (Hughes, 1965), were formed by south-southeastward ice flow. These patterns have been attributed to rapid but very erosive adjustments in the disintegrating ice sheet which occurred over a few centuries in very late glacial time (Veillette, 1986, 1989). These zones of ice flow did not affect the Beardmore-Geraldton area.

B) Bell (e.g., 1870) first recognized the dominance of southwestward ice flow in the formation of regional geomorphic features and drift dispersal trends across most of northern Ontario. Southwestward ice flow is recorded by the upper till throughout the Hudson Bay Lowland (Skinner, 1973; Thorleifson, 1989), except in the Winisk-Albany area, where correlative till is the second unit from surface (Thorleifson, 1989). Correlation of Kipling Till of the Moose River Basin (Skinner, 1973), which was deposited primarily by southwestward ice flow, to this array precludes its correlation to the Cochrane Till (Hughes, 1965), which occurs on the shield south of Moose River Basin. Veillette (1986, 1989) indicated that striations predating the final, south-southeastward trend in the Abitibi region record southwestward ice flow preceded by west-southwestward flow. Correlations of these directions, as well as a rarely observed southeast orientation, to subsurface till units were discussed by Bird and Coker (1987), DiLabio et al. (1988), McClenaghan et al. (1988), Steele et al. (1989), and Veillette (1989). Southwestward ice flow in northern Ontario extended into Minnesota and was confluent with the Superior and Michigan lobes. Nearly parallel ice flow over such a large area indicates flow along the flank of a saddle connecting domes east and west of Hudson Bay. The Beardmore-Geraldton area indicates that, when the ice margin retreated north of the Great Lakes, a series of ice streams produced radiating ice flow patterns and thick plumes of till largely derived from the Hudson Bay Lowland. Geomorphic features and drift deposits in the Beardmore-Geraldton seem almost universally to have been produced by this southwestward ice flow.

C) The till which underlies the Kipling Till in the Moose River Basin is the Adam Till (Skinner, 1973). This till overlies the nonglacial Missinaibi Formation and hence probably represents the growth of the ice sheet. The dominant ice flow trend recorded by the Adam Till is west-southwest (Skinner, 1973). This ice flow trend is parallel to old west-southwest striations on the shield south of the Moose River Basin (Veillette, 1986). In the central Hudson Bay Lowland, correlative till deposited by westward ice flow yielded evidence for local southeastward ice flow late in its deposition (Thorleifson, 1989).

D) Striations and roches montonées indicating north-westward ice flow at Big Trout Lake (Tyrrell, 1914) were re-examined and confirmed by Thorleifson (1989), but Tyrrell's model explaining this ice flow pattern was, however, refuted. The upper till of the Winisk-Albany area is present on a portion of the Fawn River. According to Thorleifson (1989), Tyrrell incorrectly interpreted striated boulder pavements at the lower contact of this till as having been formed by north-northwestward ice flow. By combining this orientation with northwest at Big Trout Lake, Tyrrell concluded that an ice sheet dome had been present in the District of Patricia of central northern Ontario. Tyrrell referred to this inferred spreading centre as the Patrician glacier. Re-interpretation of the ice flow direction for the upper till on the Fawn River as south-southeastward rather than north-northwestward forced rejection of Tyrrell's Patrician model. Additional data for southeast-northwest ice flow are, however, available. Prest (1963; Prest et al., 1968) found west-northwest striations over a large area in northern Ontario. Thorleifson (1989) reported an old till unit on the upper Severn River with northwest-southeast fabric and enrichment in erratics derived from the east. Skinner (1973) reported a few observations of west-northwest ice flow in the Moose River Basin, as did Veillette and Pomares (1991) for adjacent Quebec. Boulton and Clark (1990a, b) reported linear features with this orientation in satellite imagery. Taken together, these observations indicate an old west-northwest ice flow pattern which probably predates the Missinaibi Formation.

Scattered evidence for an even older southeastward ice flow has been reported from Manitoba (Nielsen et al., 1986), the central Hudson Bay Lowland (Thorleifson, 1989), the Moose River Basin (Skinner, 1973), and adjacent Quebec (Bouchard and Martineau, 1985; Veillette et al., 1989).

No evidence for ice flow patterns predating southwest-ward trends, including the westward, west- southwestward, west-northwestward, and southeastward ice flow trends discussed above, has been found in the Beardmore-Geraldton area. Remnants of older till units may, however, be present in bedrock lows under thick drift sequences.

The only striations contrasting with radiating southwestward orientations in the Beardmore-Geraldton area are oriented south-southwest. These orientations may be a perturbation of the regional southwest trend related to the Marquette re-advance, which filled the Superior basin around 10 000 BP (Farrand and Drexler, 1985).

Deglaciation

The deglaciation of the Beardmore-Geraldton study area was marked by the deposition of glaciofluvial ice contact, braided stream, and subaqueous outwash sediments. The ice mass wasted back across the study area along a lobate ice front towards the east and northeast. The extreme west and southwest parts of the study area were first to be deglaciated and the extreme northeast part was last.

The absence of end moraines implies deglaciation uninterrupted by pauses. Because the wide portions of esker-kame complexes represent flow expansion and deposition at the ice margin and because the pattern of recurrence of wide-narrow sequences is rhythmic, a model involving the incremental meltback of the ice margin is favoured for the area. Deglaciation occurring in cyclic stages has been described as stagnation zone retreat (e.g., Mulholland, 1982). In this model, the ablating ice mass melts back sequentially by shedding a narrow belt of ice along its margin which has become stagnant due to downwasting to a thickness below which glacier flow is stopped. The active-stagnant ice interface in such a glacier system is thought to have incrementally shifted upglacier. In the process, a narrow belt of stagnant glacier ice, upon and against which glaciofluvial sediments were deposited, was left behind. The diameter of some residual ice depressions ranges up to 750 m and these dimensions may indicate the width of the marginal stagnant zone.

In contrast with the fragmentary record on land, a more continuous stratigraphic record for deglaciation of the region is preserved in the Lake Superior basin, 100 km south of the Beardmore-Geraldton. The stratigraphy of this basin has been determined by coring projects which were initiated in the 1960s. In cores collected offshore in Lake Superior, Farrand (1969a, b) found that mottled red and white Precambrian sandstone and red till are overlain by crudely stratified heavy red clay with laminations of whitish silt and very fine sand, red varves, grey varves, unlaminated grey clay, and finally brown silt and clay. Farrand (1960) found that the grey varves are anomalously thick and extensive along the north shore of the Superior basin. Farrand (1969b) attributed the change from red to grey varves to a change in provenance, from ferruginous Keweenawan rocks of the southwestern Superior basin to light coloured granitic rocks of the Canadian Shield to the northeast. Farrand (1969b) reported that the clay-sized fraction of the red varves contains a higher proportion of calcite than the equivalent fraction of the grey varves. Dell (1972) reported that the grey varves consist of over 92% material under 1 μm in size, but, in contrast with the analysis by Farrand (1969b), Dell stated that the grey clay is highly calcareous. This calcareous grey clay was attributed by Dell (1972) to derivation from the calcareous grey tills of the north shore. Dell (1972) had sampled tills from around the entire Superior basin. Red till was found along the western and southern shores, calcareous grey till along the north shore between the towns of Nipigon and White River, and noncalcareous grey till south of White River. On the basis of her observations on land, Dell (1972) suggested that the contact on the lake bottom between red till to the southwest and grey till to the northeast probably extends from near Sault Ste. Marie to a point between the communities of Thunder Bay and Nipigon. Dell (1972) was unable to detect a difference in grain size between the light coloured and the dark coloured layers of the grey varves, so carbonate dissolution during sedimentation in winter was suggested as the varve-forming process. Mothershill and Fung (1972) confirmed that the grey varves are more carbonate rich than the red varves. They attributed dolomite and calcite concentrated in the light coloured part of the grey varves, however, to precipitation from the epilimnion during summer warming of surface waters. The grey clay showed enrichment in strontium relative to other sediments in the basin (Mothershill and Fung, 1972). Dell (1974) utilized geophysical profiling and long cores to examine what she referred to as the abnormally thick glaciolacustrine sequence of the northern Superior basin. Dell (1974, 1975) found red till on the lake bottom much farther to the northeast than had been anticipated on the basis of her earlier work on land (Dell, 1972). Grey calcareous till was found in the basin, but only within about 50 km of the north shore. The principal deposit in northern Lake Superior are the calcareous grey varves, with a maximum thickness of about 15 m. Nonvarved sediment up to 9 m thick overlying the grey varves was attributed to reworking of glaciolacustrine sediment from the nearshore where truncated sequences had been observed. Dell (1974) and Lineback et al. (1979) identified a particularly distinctive sequence within the varved clays occurring over an area of 4500 km^2 and consisting of 10 to 40 cm of nonvarved, noncalcareous dark grey clay separating overlying and underlying calcareous grey varves. Dell (1974) attributed the end of varve sedimentation in the Superior basin to retreat of the ice beyond the Lake Superior-Hudson Bay drainage divide, well to the north of the basin. After acknowledging that carbonate in Superior basin glaciolacustrine sediment should be considered anomalous, given that the basin is surrounded by noncalcareous Precambrian rocks, Thomas and Dell (1978) stated that the highly calcareous glaciolacustrine sediments of the Superior basin were derived from calcareous tills glacially transported to the vicinity of the basin from the Paleozoic rocks of the Hudson Bay Lowland. Teller (1985), however, suggested that the influx of drainage of surface water from Lake Agassiz into the Nipigon basin around 9500 BP may have played a role in the shift to calcareous grey varves and, furthermore, the end of varve sedimentation may have been related to the diversion of Agassiz drainage from the Great Lakes to Lake Ojibway. Teller and Mahnic (1988) cored a Superior basin rhythmite sequence preserved above present lake level at a site 30 km southwest of the Nipigon moraine near the town of Dorion, between Thunder Bay and Nipigon. The coarse fraction of the lowest varves in this sequence are red, but the clay units in the entire sequence are grey.

Research on glaciolacustrine stratigraphy has also been carried out in the Nipigon basin (Schlosser, 1983; Lemoine, 1989). On the basis of a series of drill holes and sections located along western and northern Lake Nipigon, Lemoine (1989) demonstrated that sediments in the area consist almost entirely of thick, fine to medium quartz-rich sand and grey calcareous silt-clay rhythmites. Whereas a fining upward sequence of rhythmites over sand was encountered west of Lake Nipigon, a drill hole and a section along northern Lake Nipigon encountered as much as over 20 m of sand overlying silt-clay rhythmites. Lemoine (1989) reported carbonate contents of about 40% in the coarse portion of the rhythmites and about 30% in the fine portion. An 11 m sequence of sand located at the mouth of the Namewaminikan River, in the western part of the Beardmore-Geraldton study area, was described by Lemoine (1989). The sequence consists of 1 m of silty very fine grained sand over 1 m of medium- to coarse-grained fossiliferous sand over 9 m of rippled silty very fine grained sand. These sediments were identified as eolian, shoreline, and deltaic, respectively, on the basis of sedimentary structures, paleontology, and context. Shells from this site were radiocarbon dated by Lemoine (1989) at 9760 ± 180 BP (BGS-1150). This date was interpreted by Lemoine to be too old by approximately 1000 years due to incorporation of dissolved Paleozoic carbonate by the organisms. A former shoreline of Lake Nipigon at 272 m was reported for the area west of Beardmore (Lemoine, 1989).

The age of deglaciation of the Superior basin provides a date for the beginning of Superior basin varve records. Farrand (1960) identified a number of sites on land in the western Superior basin where red clay is overlain by till. He suggested that this red clay was deposited in a water body referred to as Lake Keweenaw. The overlying till was correlated with the final ice advance in the basin, an ice mass which was interpreted as not having extended south of the basin. Farrand (1960) correlated the deglaciation of at least part of the Superior basin and the resulting formation of Lake Keweenaw to the Two Creeks interstade, an episode recorded by a forest bed under till in Wisconsin. The Two Creeks forest bed was radiocarbon dated at 11 400 BP at the time, but subsequently an age of 11 850 ± 100 BP (L-607A) was obtained by Broecker and Farrand (1963). Farrand (1960) correlated the till overlying Lake Keweenaw clay, the youngest till in the Superior basin, with the till overlying the Two Creek forest bed. Because no later ice advance was known and because an apparently correlative ice margin southwest of Duluth had been dated at 11 690 ± 370 BP (Y-237) (Flint, 1956), the deglaciation of southwestern Superior basin was estimated to have occurred around 11 000 BP (Farrand, 1960). This conclusion was later challenged by several radiocarbon dates of about 10 000 BP which were obtained from wood and other organic material in till along the southern margin of the Superior basin (Black, 1976). Black could not accept a Laurentide Ice Sheet lobe in Lake Superior at this late date, so he suggested that a local ice cap existed on the land south of the Superior basin at this time. Subsequently, however, more radiocarbon dates and stratigraphic information forced acceptance that a late re-advance, named the Marquette, had filled the Superior basin at about 10 000 BP (Hughes, 1978; Drexler et al., 1983; Clayton, 1984; Farrand and Drexler, 1985; Attig et al., 1985). On the basis of pollen and radiocarbon dates from cores collected in lakes along northeastern Lake Superior, Saarnisto (1974) concluded that the Sault Ste. Marie area of southeastern Lake Superior was deglaciated around 11 000 BP, so the southeastern corner of the basin seems not to have been overridden by the Marquette re-advance. Rapid retreat from the Marquette maximum was indicated by a date of 9500 BP for the Nipigon moraine and what is referred to as the north shore ice margin, along northern Lake Superior (Saarnisto, 1974). All proglacial shorelines and glaciolacustrine sediments overlying till in nearly all of the Superior basin were thus assigned an age of less than 10 000 BP.

The total number of varves in the Superior basin indicates the length of time between deglaciation of the basin and the end of varve sedimentation due to diversion of outwash away from the basin. Farrand (1969a, b) reported that the rhythmite sequence in the Superior basin comprises approximately a 1500 year sequence consisting of about 200 red and 1300 grey varves, hence a 1500 year sequence. About 1600 varves may be inferred from data presented by Teller and Mahnic (1988) for their Dorion core (Fig. 57). These reports are, however, the only sources of information regarding the total number of varves in the basin. On the basis of his estimate for the age of rapid deglaciation of the Superior basin, Farrand (1969b) attributed the 1500 varves in offshore Lake Superior to the period 11 000 to 9500 BP. Using data from cores obtained in small lakes, Saarnisto (1974) suggested deglaciation of the north shore occurred at around 9500 BP and the end of deltaic sedimentation along the north shore at 9000 BP. He therefore suggested that by 9000 BP, the ice margin had retreated north of the Lake Superior-Hudson Bay divide and varve sedimentation had ended. Maher (1977) reviewed deglaciation chronologies by Bryson et al. (1969) which indicated that Lake Superior was deglaciated between 10 500 and 9000 BP, and by Prest (1969) which bracketed Superior basin deglaciation between 10 800 and 10 000 BP, and concluded that varve sedimentation probably proceeded from as early as 11 000 BP and stopped before 9000 BP when the basin was free of glacial ice. For his sites in western Lake Superior, he concluded that massive grey clay was deposited above varves as the ice margin retreated from the Superior north shore to the Superior-Hudson Bay drainage divide during a 500 year period between 9000 and 8500 BP. Similar sediments were interpreted by Dell (1972) to have been reworked from varves in shallow water where truncated sequences had been observed. Palaeomagnetic stratigraphy in the Superior basin was interpreted by Johnson and Fields (1984) using strict application of the date for the end of varve sedimentation of 9500 BP proposed by Farrand (1969b). Acceptance of the Marquette re-advance at 10 000 BP, however, implied that varve sedimentation ended at least 1000 years later than Farrand's estimate. This was subsequently confirmed by Mothershill (1984, 1988), who utilized palaeomagnetic methods to date the uppermost varve in Nipigon Bay, on the north shore of Lake Superior, at 8000 BP. Varve sedimentation ended earlier, however, elsewhere in the Superior basin. For example, Mothershill (1988) reported an age of 8200 BP for the uppermost varve in Thunder Bay and 8700 BP in the southeastern Superior basin. Furthermore, Dell (1972) reported that red varves are restricted to the southern half of the lake and grey varves are missing from sites near the south shore. Hence the total number of varves in the basin is not recorded at any one site. The combination of deglaciation of the Duluth area at 9900 BP (Clayton, 1984), 1600 varves at the north shore Dorion site (Teller and Mahnic, 1988), and the end of varve sedimentation near Dorion in Nipigon Bay at 8000 BP (Mothershill, 1988) leaves only three centuries for the deglaciation of much of the Superior basin. Deglaciation at this rapid rate is compatible, however, with the chronology of Drexler et al. (1983).

Trends in the thickness of varves offer information regarding temporal variation in sediment supply to the basin during deglaciation. Over a total sequence of about 1600 rhythmites in the core recovered at Dorion (Fig. 57) by Teller and Mahnic (1988), rhythmite thickness diminishes from 6 cm immediately following deglaciation to about 0.6 cm at the end of varve sedimentation. Superimposed on this trend are two intervals of thicker rhythmites. Between 300 and 400 rhythmites above the base, thickness increases to as much as 22 cm. Between 1400 and 1500 rhythmites from the base, varves again thicken to about 8 cm. Mothershill (1988) also reported the upper sequence of anomalously thick rhythmites as an abrupt upward thinning from 7 to 3 cm in a core in Nipigon Bay. He counted 238 couplets above the second sequence of thick varves, a number higher than that inferred from the data reported by Teller and Mahnic (1988). In summary, available data indicate that the supply of glaciofluvial sediment to the Superior basin diminished continuously following deglaciation, but was punctuated by two episodes of enhanced supply, one shortly after and one long after deglaciation of the northern basin.

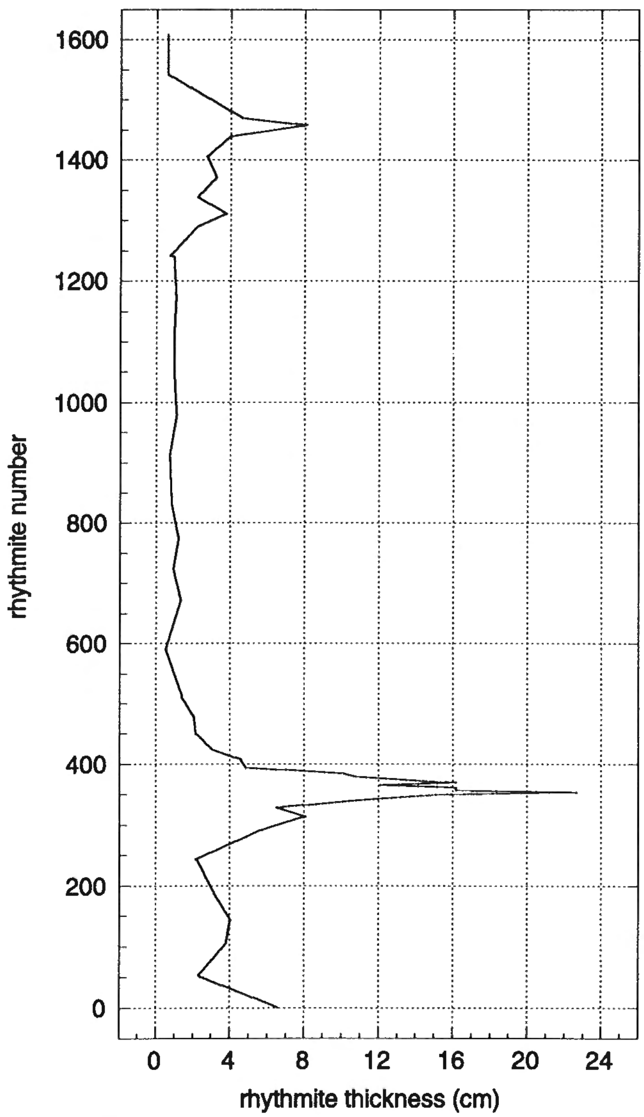


Figure 57. Rhythmite thickness record from the Dorion area, north shore of Lake Superior (Teller and Mahnic, 1988).

Teller and Mahnic (1988) and Mothershill (1988) attributed variation in varve thickness in the northern Superior basin to the influence of outflow from Lake Agassiz, which entered the Nipigon and Superior basins through seventeen different outlets west of Lake Nipigon (Teller and Thorleifson, 1983). Whereas Lake Agassiz outflow would have tapped surface waters probably bearing little sediment, meltwater derived from the ice margin to the northeast must have carried immense quantities of silt and clay winnowed from the voluminous deposits of glaciofluvial sand and gravel across the region. The ice margin must therefore have been the dominant control on clay and silt sedimentation in lakes Nipigon and Superior. Sharpe and Cowan (1990) have suggested that the gravel-dominated moraines of northern Ontario originated during episodes of enhanced glaciofluvial sedimentation. Episodes of enhanced meltwater discharge may have resulted from surges in the ice mass (Kamb et al., 1985). The two sets of thick varves in the Dorion record may therefore correlate to the building of the Nipigon and Nakina moraines, located 30 and 200 km northeast of Dorion, respectively. The intervening record of steady but gradually diminishing glaciofluvial sediment supply implies steady, gradual deglaciation of the Beardmore-Geraldton study area.

Glacial lakes

Whereas topographically higher areas in the southern and north-central parts of the Beardmore-Geraldton map area were not inundated, subaqueous outwash in lower areas between Jellicoe and Lake Nipigon, as well as the Geraldton and Longlac areas, indicates inundation by glacial lakes (Fig. 58). The estimated upper limit of inundation, which rises to the northeast due to postglacial isostatic rebound, varies from 1050 ft. (320 m) at Beardmore to 1150 ft. (350 m) at Longlac. Most of the area within these limits consisted of islands. Currents in these shallow, restricted water bodies were responsible for the lack of varved silt and clay, considered typical of glaciolacustrine environments elsewhere. An upper limit for inundation is indicated by subaerial features such as spillways and braided outwash. A drop in lake level prior to formation of the northernmost two

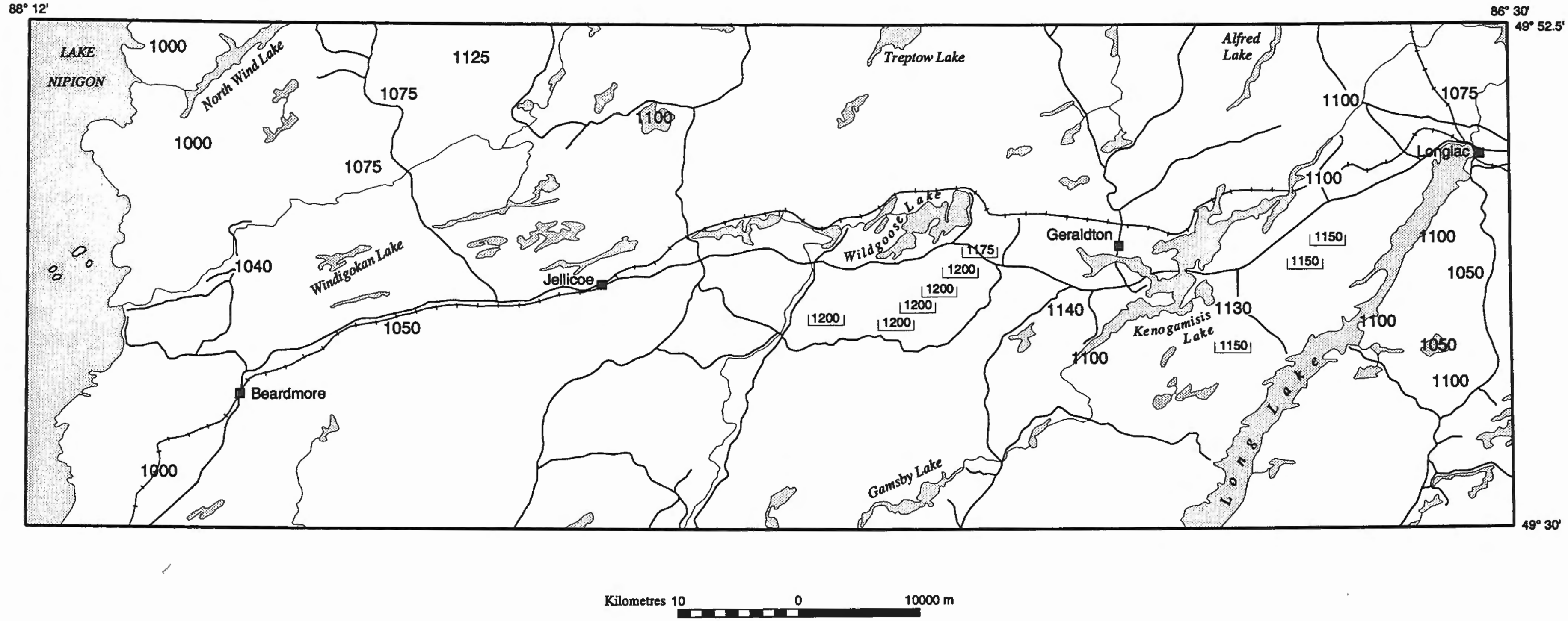


Figure 58. Location of data for proglacial lake levels. Numbers not enclosed by symbols indicate the elevation of silty sand interpreted as subaqeous outwash in feet above sea level. Numbers within symbols indicate the elevation of spillway channels interpreted as having formed in a subaerial environment.

spillway channels in the Wildgoose Lake area is implied by their position below the water level which can be extrapolated from subaqueous outwash to the south (Fig. 59).

Northward extrapolation of the Minong levels of Lake Superior (Fig. 8) indicates that lakes in the Nipigon and Long Lake basins (Fig. 60) were confluent with these levels of Lake Superior.

The proposal by Zoltai (1967a) that a regionally significant spillway extends from Wildgoose Lake to Lake Nipigon was not supported by the present study. Because Zoltai had interpreted the surface of subaqueous fans near Lake Nipigon as the top-sets of Gilbert deltas, he placed the lake limit well below the elevations documented in this report. His observation of stone-free sand in the spillway west of Jellicoe can now be attributed to the sublacustrine origin of the sediments. Spillways do occur at Wildgoose Lake, but these short features are attributed here to drainage of a small lake in the Kenogamisis basin of the Geraldton area (Fig. 60). This lake later drained east to Long Lake, so the Wildgoose Lake spillways could never have acted as an outlet for glacial Lake Nakina (Fig. 7), as envisaged by Zoltai.

According to Farrand (1960), the Minong level of Lake Superior was in contact with the north shore ice margin. During subsequent ice retreat, Minong and lower Superior basin lake levels (Fig. 8) extended inland. Saarnisto (1975) utilized pollen stratigraphy and radiocarbon dates to conclude that, following the establishment of the basin-wide Minong level of Lake Superior at around 9500 BP, high post-Minong levels were maintained around 9000 BP. The Houghton level, representing erosion of the St. Mary's River outlet to its present level, was not established until about 8000 BP. Saarnisto (1975) considered Lake Kelvin in the Nipigon basin and Lake Nakina to have been part of the post-Minong level of Lake Superior. Bajc (1986) carried out investigations along the northeastern shore of Lake Superior which indicated that Lake Superior fell below the Minong I level prior to deglaciation of the Marathon area. Subsequently, according to Bajc (1986), the Minong II and III and the Post-Minong I shorelines formed in the area between about 9500 and 9000 BP. The Dorion shoreline formed shortly after 8300 BP, and a well developed Nipissing terrace formed around 6000 BP.

Postglacial history

The post-Missinaibi tills of the Hudson Bay Lowland are overlain by glaciolacustrine and marine sediments deposited during and after the final deglaciation of the region. Holocene marine sediments were deposited in the Tyrrell Sea (Lee, 1960), which inundated isostatically depressed land around Hudson Bay to altitudes of 150 m (Craig, 1969; Walcott, 1972). Shells from the marine sediments yield radiocarbon ages of 8000 BP (Dyke and Prest, 1987; Dredge and Cowan, 1989). This age implies that there was little time between the end of varve sedimentation in Lake Superior at about 8000 BP (Mothershill, 1988) and the rapid deglaciation of the Hudson Bay Lowland. If Hudson Bay Lowland postglacial shell dates are too old due to incorporation of old carbon, as was suggested for the Nipigon basin by Karrow and Geddes (1987) and Lemoine (1989), the Hudson Bay Lowland marine incursion may not have taken place until several centuries after 8000 BP. This would allow time for ice marginal retreat from the final position which supplied sediment for varve sedimentation in Lake Superior and the subsequent marine incursion.

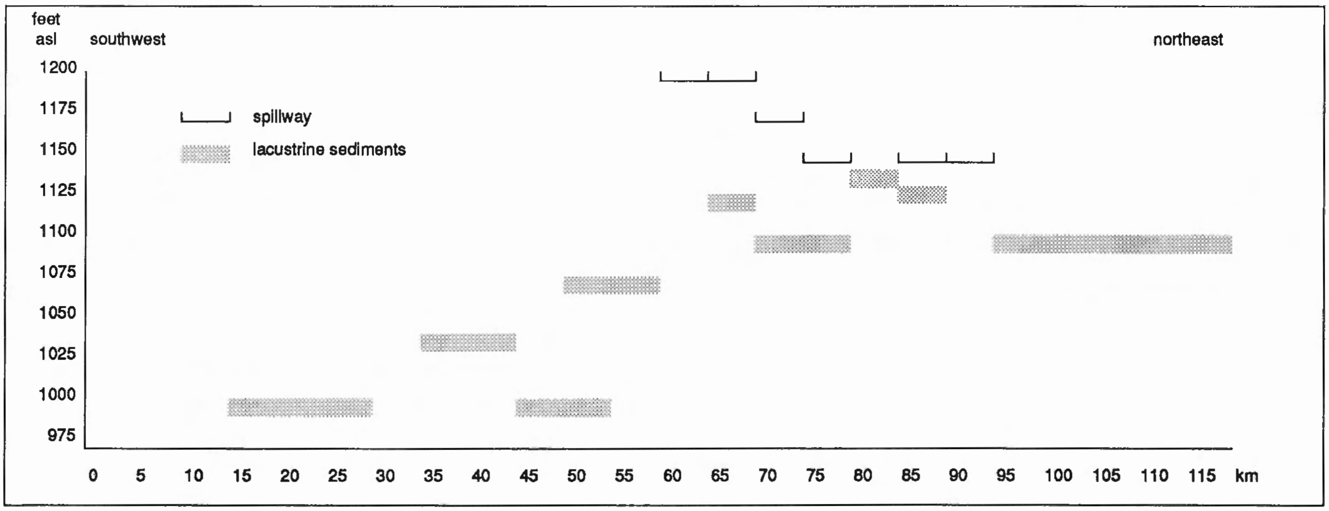


Figure 59. Elevation of proglacial lake level indicators, plotted along a line oriented 30° east of north, perpendicular to regional lines of equal postglacial uplift (Teller and Thorleifson, 1983).

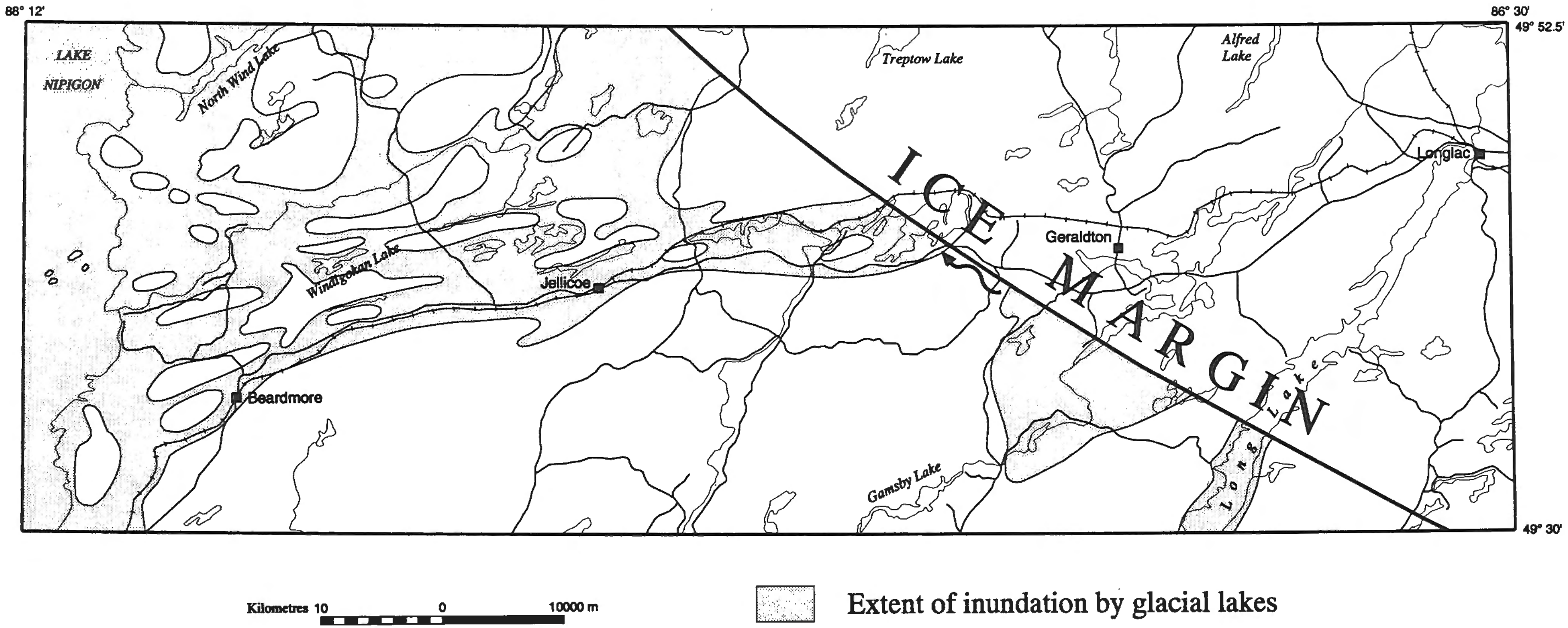


Figure 60. Inferred extent of proglacial lakes during deglaciation (patterned area). Arrow indicates westward drainage of a small lake in the Kenogamisis basin.

Within the study area, the development of extensive areas of organic terrain, the fluvial reworking of glacial deposits and the formation of complexes of dune forms in some areas of glaciolacustrine sand have occurred during postglacial time.

Summary

In summary, data from the Beardmore-Geraldton study area, supplemented by stratigraphic information from the Hudson Bay Lowland and Lake Superior, indicate the following events for the region:

1. Following the most recent interglacial or interstadial episode of subaerial exposure, the Wisconsinan Laurentide ice sheet advanced over the area from the east-northeast.

2. Fragmentary evidence indicates that a series of ice flow patterns affected the region during the final, as well as earlier episodes of ice cover. These old orientations include southeast, west-northwest, and west-southwest. Evidence for these ice flows is found only where features were not destroyed by later southwestward ice flow which affected all of northern Ontario.

3. During the latter part of Late Wisconsinan glaciation, an ice lobe re-advanced and filled the Superior basin around 10 000 BP, scouring the lake bottom to bedrock. Striations in the study area oriented south-southwest may correlate to this event.

4. Dates for events in the Superior basin may be estimated by fixing the uppermost of 1600 varves at Dorion to 8000 BP. If central Lake Superior sites studied by Farrand (1969a, b) were deglaciated around the same time as Dorion, the 300 red varves offshore are equivalent to the lowest 300 at Dorion. Hence this episode of varve sedimentation involving red sediments derived from within the basin may be assigned to the period from 9600 to 9300 BP. Deglaciation of much of the basin after retreat from Duluth at 9900 BP (Clayton, 1984) therefore occurred over about 300 years.

5. At approximately 9300 BP, an ice stream centred on the Geraldton area, and whose position is incompatible with the earlier Marquette event, produced radiating ice flow which extended to the Nipigon moraine and the north shore of Lake Superior. This vigorous ice flow rapidly deposited a plume of thick calcareous till at Geraldton and scoured older drift and the bedrock surface throughout the area. Abnormal rates of glaciofluvial sedimentation which produced the gravel-dominated Nipigon moraine and a ten-fold increase in varve thickness at Dorion (Fig. 57) were maintained at the margin for about one century. Another ice stream was active in the area around Hemlo, Manitouwadge, and Hornepayne, northeast of Lake Superior (Fig. 52). The accompanying influx of exotic calcareous grey clay to Lake Superior produced a transition, over about 100 rhythmites, from red varves to very calcareous grey varves.

6. Glaciofluvial sedimentation rapidly diminished around 9200 BP. A rate of sedimentation compatible with that indicated by pre-Nipigon moraine varves was maintained for the ensuing 900 varve years (Fig. 57). Abnormally thick deposits of grey clay winnowed from the coarse glaciofluvial sediments found on land were deposited in northern Lake Superior. Beardmore-Geraldton was deglaciated during this period of gradual, steady ice retreat and glaciofluvial sedimentation. Opening of a succession of outlets from Lake Agassiz resulted in immense fluctuations in discharge through the Nipigon and Superior basins. This throughflow was probably restricted to surface water due to thermal and turbidity stratification and thus would not have had any effect on sedimentation in Lake Superior. As the ice margin retreated between the Nipigon and Nakina moraines, the level of Lake Superior, including extensions of the lake into the Beardmore and Longlac areas, fell due to outlet downcutting and isostatic rebound.

7. At 1300 varve years following deglaciation of Dorion, hence about 8300 BP, the sedimentation rate in Lake Superior again abruptly increased. This event, which lasted about 200 years until 8100 BP, is correlated with the construction of the gravel-dominated Nakina moraines, which are located north and east of the map area. North of Longlac, the Nakina moraine lies within 2 km of the northeastern corner of the map area (Zoltai, 1965a). During reconnaissance of the Nakina area, crossbedded coarse gravel over 10 m thick and hundreds of metres in lateral extent was observed at the Nakina ice margin in a pit near Cavell. This seems to be the margin associated with an ice stream in the Winisk-Albany area (Thorleifson, 1989). The only esker within the Winisk area ice stream shifts its course from south-southeast to southwest and joins the Nakina ice margin (Prest et al., 1968).

8. Outwash was diverted away from Lake Superior at 8000 BP, presumably due to diversion of meltwater drainage to the Ottawa River. Radiocarbon dates around 8000 BP for the later marine incursion into Hudson Bay must be too old due to incorporation of Paleozoic carbon, perhaps by several centuries.

9. After the retreat of the ice margin, the retreat of Superior basin glacial lakes, and the diversion of outwash to Lake Ojibway and the Ottawa River valley, the Beardmore-Geraldton landscape was only slightly modified by nonglacial processes, including peat accumulation, eolian reworking of sand, and fluvial downcutting or aggradation. Ongoing isostatic rebound presumably has caused regression of Lake pipigon, which has an outlet in the south, and transgression of Long Lake, which had an outlet in the north.

APPLIED GEOLOGY

The Quaternary sediments occurring in the study area are potentially of use in the search for mineralization, must be dealt with in engineering design, and are a resource for granular materials used in construction.

Surficial sediments in the area were examined in detail in order to obtain data of relevance to the use of drift samples in mineral exploration. Mineralogical and geochemical analyses were published by Thorleifson and Kristjansson (1990). These data, which represent an account of background trends across the area, are here summarized and discussed, followed by discussion of the relevance of this information to the conduct of drift prospecting programs.

Indicator minerals

Heavy mineral concentrates

The sample material which was processed for a heavy mineral concentrate yielded an average of 1.3 g of -10 mesh, >3.3 specific gravity nonmagnetic heavy minerals and 0.8 g of magnetic concentrate per kilogram of till.

The nonmagnetic heavy mineral concentrates typically contain about 5% clinopyroxenes and 10% amphiboles, although values for these mineral groups ranged from less than 1% up to 13% and 27%, respectively. Amphiboles and clinopyroxenes were excluded from the calculations of percentages for heavy minerals because the specific gravity of these minerals spans that of methylene iodide. Recovery of these minerals can therefore be influenced by slight changes in technique and heavy liquid density. In surface samples (Fig. 61), the remaining minerals largely consist of epidote, garnet, orthopyroxene, hematite, ilmenite, and titanite. Included in the 'other' category are zircon, leucoxene, goethite, siderite, rutile, chromite, monazite, kyanite, staurolite, and unidentifiable minerals. Unoxidized concentrates from below 7 m in hole D contain, in addition to the suite observed in oxidized samples, between 5 and 80% sulphide minerals consisting almost exclusively of pyrite (Fig. 62). Sulphide mineral abundance at this site abruptly increases at the brown-over-grey colour change at 7 m, at the contact between dominantly exotic and mixed exotic and local debris at 28 m, and at the contact between partially exotic and fully local debris at 54 m.

Sulphide minerals

Sulphide minerals such as pyrite, arsenopyrite, chalcopyrite, sphalerite, pyrrhotite, pentlandite, and galena are significant indicators of mineralization. Pathfinder elements in most cases are metals hosted by sulphides. Sulphide minerals are, however, very susceptible to destruction by weathering in an oxidizing environment and are therefore not found in near-surface horizons of well drained soils (Shilts and Kettles, 1990).

In order to determine how closely presence and state of preservation of sulphide minerals relates to soil colour and depth, nonmagnetic heavy mineral concentrates from near-surface drill hole samples were examined. Sulphide content increases abruptly at the sharp colour change from brownish (2.5Y Munsell hue) down to grey (5Y hue) (Fig. 63). Brownish colour therefore consistently indicates oxidized calcareous material. Sulphide grains are well preserved in underlying unoxidized grey till.

Shifts in sulphide mineral abundance correlate with the concentration of arsenic in this fraction (Fig. 64), indicating that this element occurs primarily within the sulphides. Over 95% of concentrates from 540 surface samples from across the area have arsenic values under 25 ppm, well below virtually all values from below the colour change in drill holes (Fig. 65). Furthermore, surface sample nonmagnetic heavy mineral concentrates examined for visible gold grains lacked a sulphide component. These observations indicate that preserved sulphide mineral grains do not occur in near-surface samples at well drained sites. The few sulphide mineral grains which were encountered in pit samples are strongly tarnished and/or coated with goethite, indicating the grains are oxidized. Also found to be oxidized are grey, locally derived samples which do not show the brown colour which is characteristic of oxidized calcareous till.

Calcareous sediment occurring at a depth of about 0.5 to 1.0 m would be regarded by soil scientists as the C horizon, a mineral horizon comparatively unaffected by pedogenic processes, hence the parent material (Agriculture Canada, 1987). It is here demonstrated, however, that calcareous light brownish grey sediment at a depth of 0.5 to as deep as 7 m is oxidized and hence lacks sulphide minerals. To a geochemist, the horizon very clearly fits the Agriculture Canada (1987) definition of a Bm horizon, a horizon slightly altered by oxidation to give a change in colour. The 2.5Y hue of the near-surface calcareous sediment is presumably related to oxidation, although it is not clear what the primary colour of the sediment was. If it was accepted that the Bm horizon extends to a depth of as much as 7 m, the C horizon would presumably be designated as the material from that depth to bedrock at a depth up to tens of metres. The olive-grey colour of this sulphide-bearing sediment at depth is either primary or it relates to reducing conditions below the water table. A Cg designation, indicating gleying, would seem appropriate because the Agriculture Canada (1987) definition only requires grey colours, or prominent mottling, or both, indicative of permanent or periodic intense reduction. Designation of soil horizons in this manner would, however, conflict with conventional pedological practice in which only the uppermost metre of sediment is examined and slight influences of oxidation are ignored. It is therefore apparent that soil horizon designations defined for the purposes of agriculture may be misleading when used in the context of geochemistry.

Below the depth of sulphide weathering, a background of about 5% sulphide minerals, dominantly pyrite, is common for the nonmagnetic heavy mineral concentrates and indicates that sulphide minerals are or were present in all sediments throughout the area. In sediments sampled in drill holes and believed to be derived from mineralized bedrock, sulphide content in the nonmagnetic heavy mineral fraction reaches values of 80% (Fig. 62) and accompanying arsenic concentrations reach several thousand ppm.

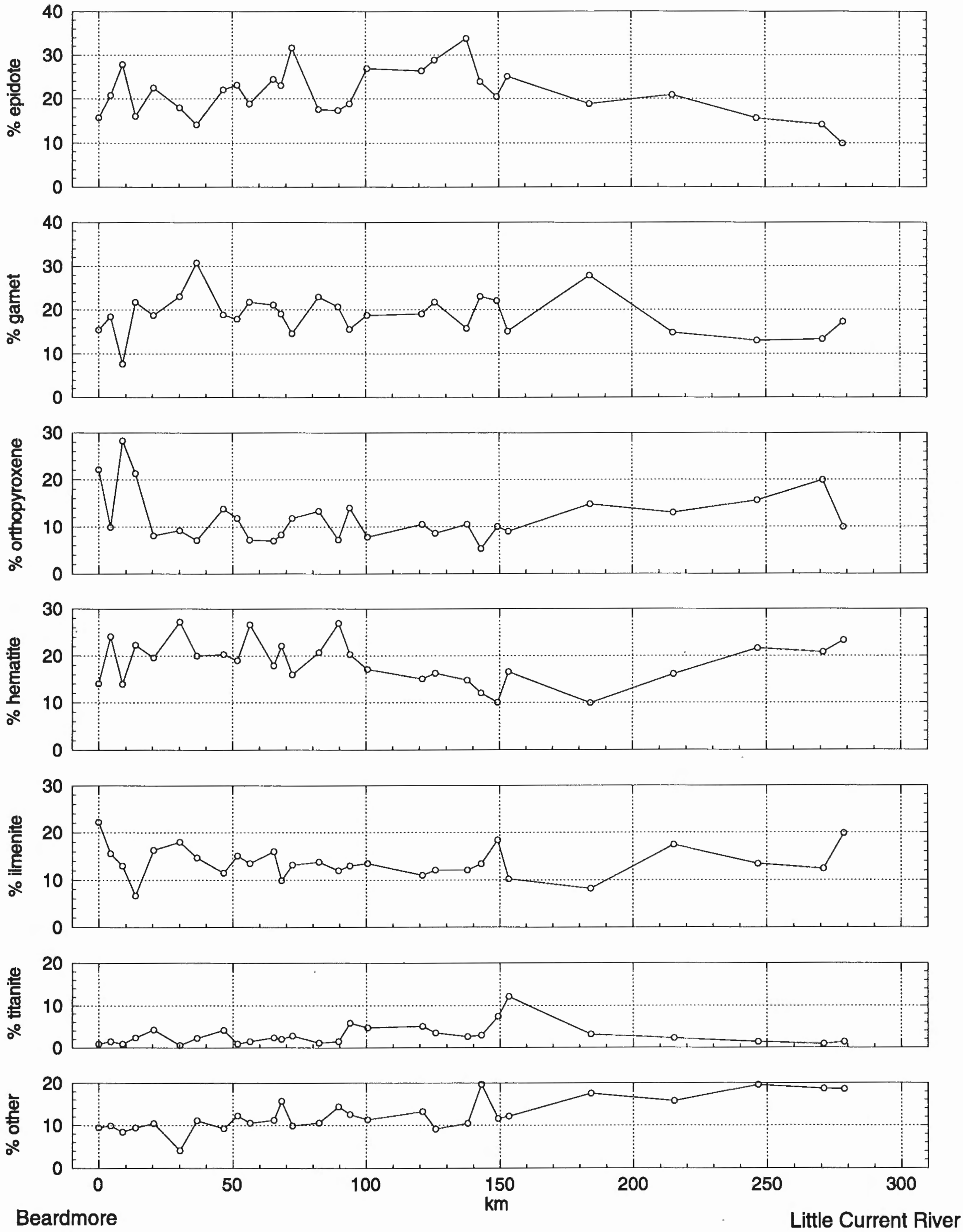


Figure 61. Mineralogy of nonmagnetic heavy mineral concentrates from surface till; (non-clinopyroxene, non-amphibole, 63-250 μm, >3.3 specific gravity). Sites range from Beardmore at 0 km to the Little Current River at 300 km (see Fig. 35 for locations).

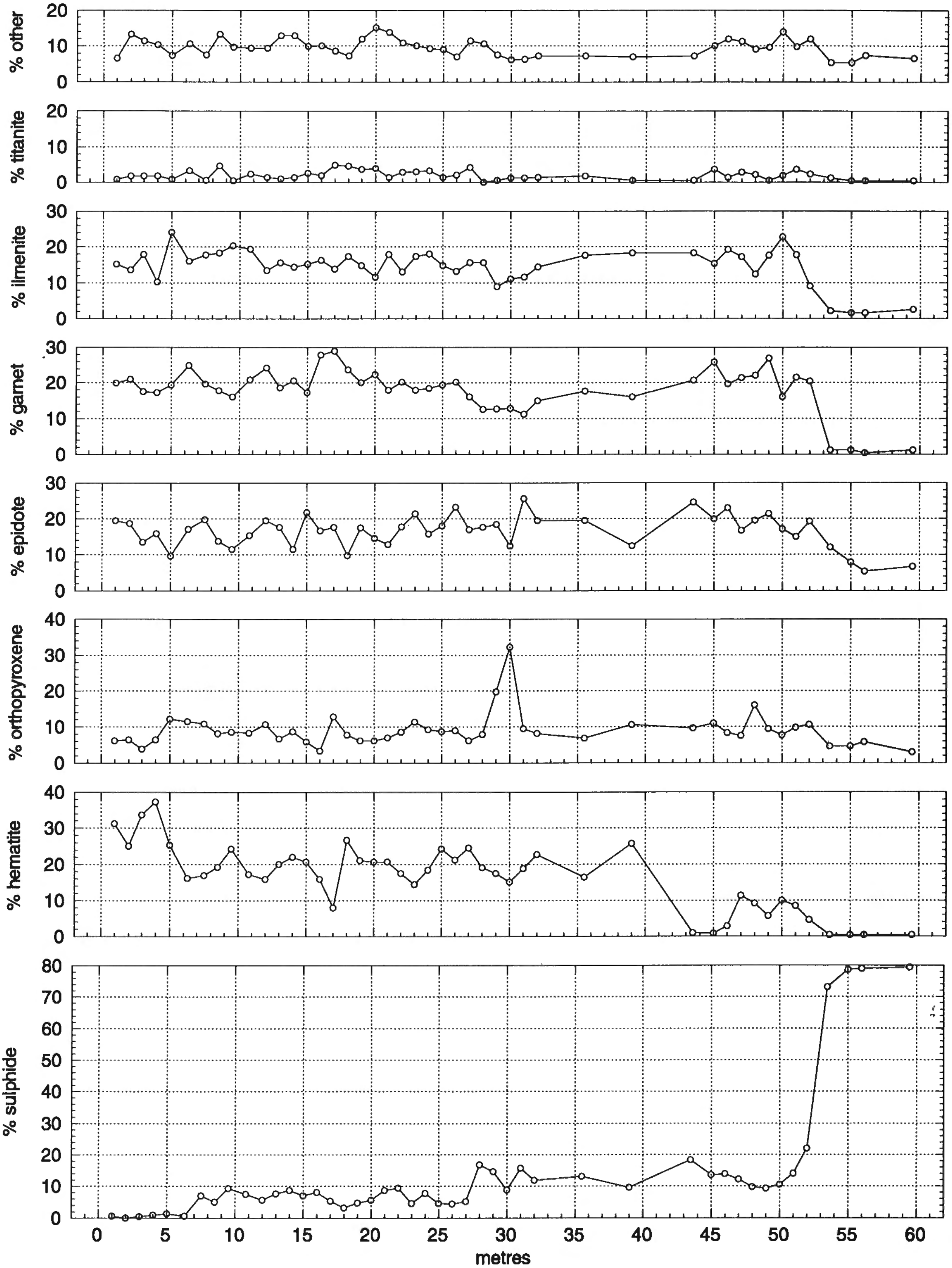


Figure 62. Mineralogy of nonmagnetic concentrates from hole D; (non-clinopyroxene, non-amphibole, 63-250 µm >3.3 specific gravity).

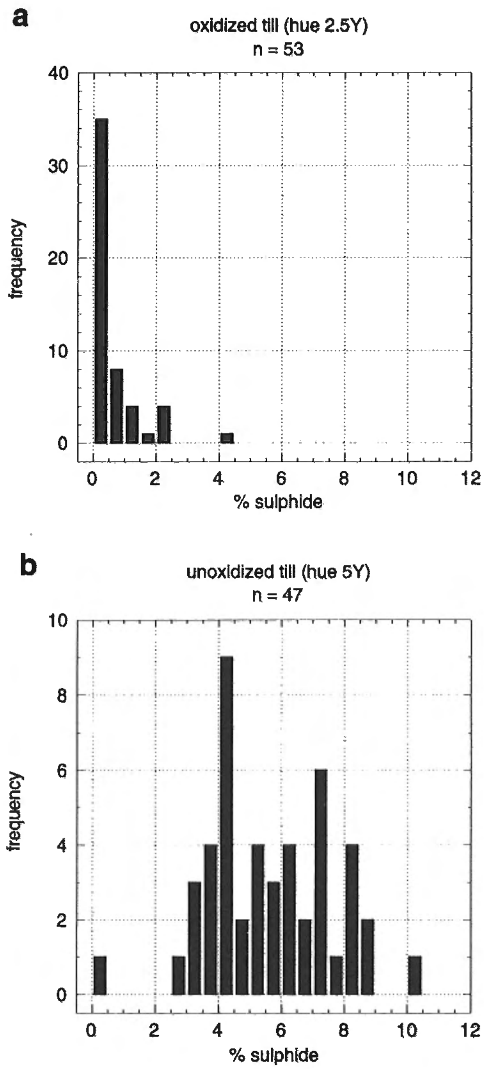


Figure 63. Relationship of sediment colour to sulphide content of nonmagnetic methylene iodide heavy mineral concentrates from **a**) near-surface brown (Munsell hue = 2.5Y) till samples and **b**) grey (Munsell hue = 5Y) till samples from immediately below the abrupt colour change.

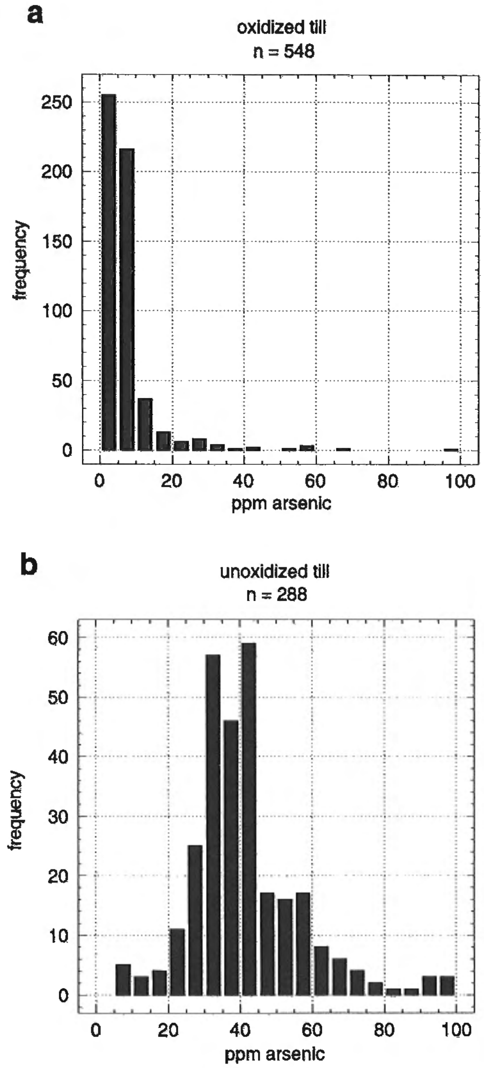


Figure 65. Arsenic as an indicator of sulphide content: arsenic concentration in nonmagnetic, -10 mesh >3.3 specific gravity heavy mineral concentrates. **a**) surface till samples (oxidized); **b**) drill hole till samples from below the abrupt brown/grey colour change (unoxidized). Only values less than 100 ppm are included.

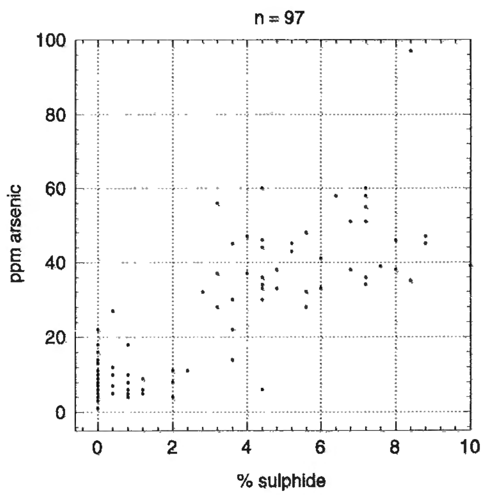


Figure 64. Comparison of arsenic concentration and sulphide content for nonmagnetic methylene iodide heavy mineral concentrates for which sulphide content was determined.

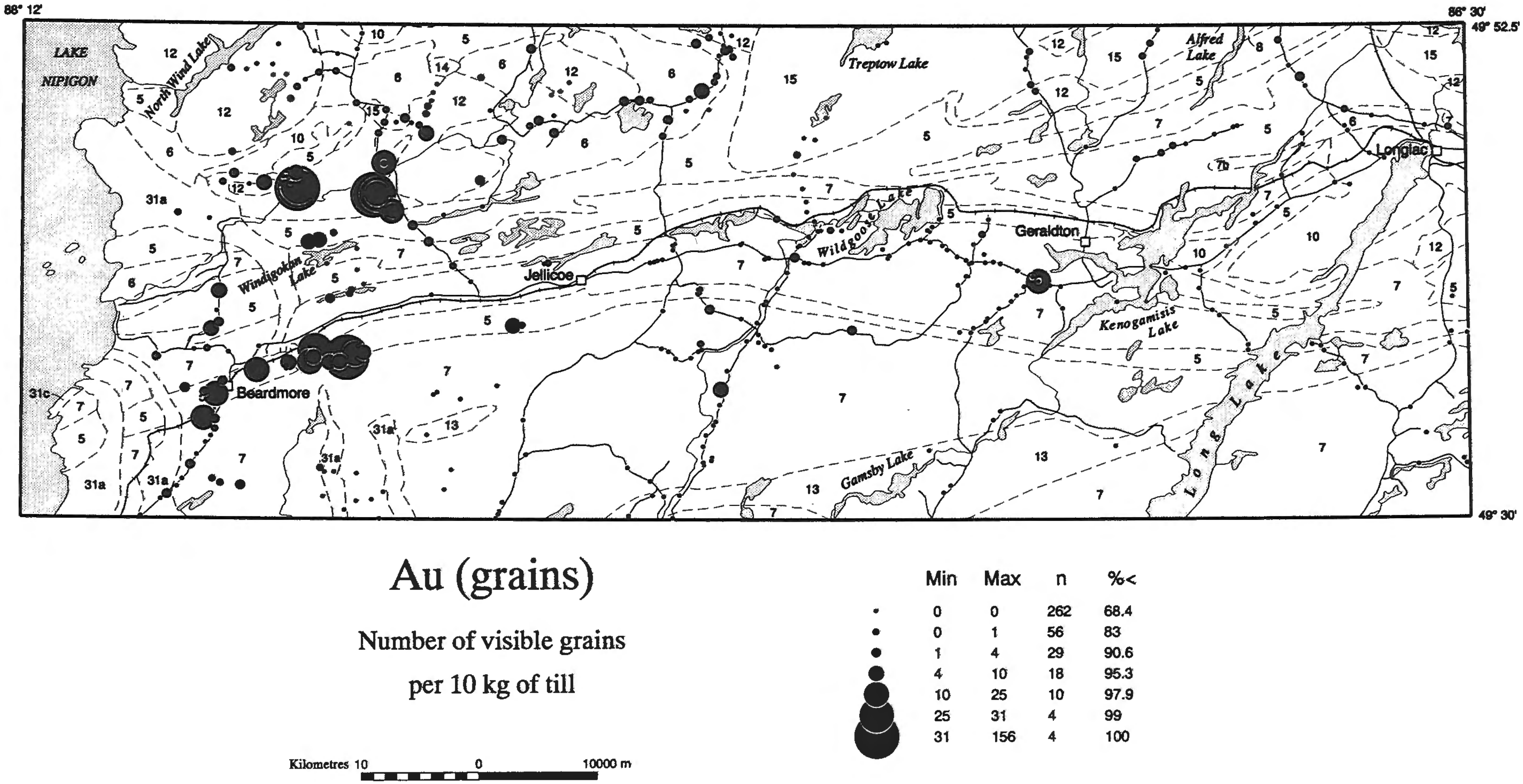


Figure 66. Gold grain abundance in surface till samples.

A total of 29 sand samples from hole T, north of Poplar Lodge near Beardmore, were processed for a heavy mineral concentrate and analyzed chemically. An abrupt increase in arsenic concentration in the nonmagnetic heavy mineral concentrates from about 5 ppm to about 50 ppm at a depth of 20 m (Appendix 2) is attributed to destruction of sulphides by oxidation down to this depth. Greater depth of oxidation, compared to till, is attributed to the higher permeability of sand and a low water table due to a nearby river valley. Furthermore, sand above the shallowest clay unit in hole T at 16 m has at least in part undergone local eolian reworking.

Visible gold grains

Visible gold grains were recovered from till samples collected from throughout the area (Fig. 66). Counts of one or two grains per 10 kg of till were encountered north of known mineralization and in exotic carbonate rich debris. In contrast, surface samples in thin, locally derived debris in the Beardmore area and near the bedrock surface in hole I yielded up to several tens or a few hundred gold grains. One or more grains per 10 kg were observed in 20% of a total of 900 till samples. Ten or more grains were obtained in 2.5% of the samples. This total includes many samples from the Geraldton area which consist of calcareous till derived from the Hudson Bay Lowland. In the locally derived till of the Beardmore area, 49% of all till samples yielded one or more grains, 11% contain ten or more. These counts are similar to gold grain abundance reported for the Fort Frances-Rainy River, Ontario area by Bajc (1988) and for the Black River-Matheson, Ontario area by McClenaghan (1990).

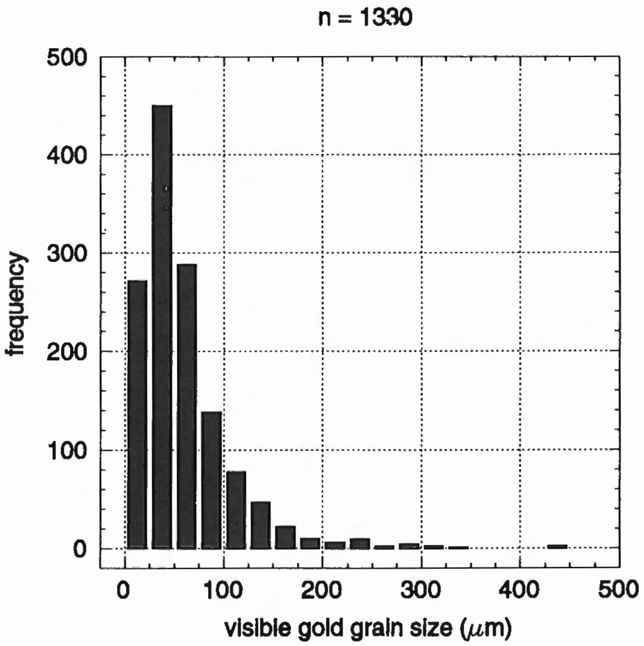


Figure 67. Long axis dimension of visible gold grains from till and esker samples.

Visible gold grains obtained from drift samples collected in the area ranged in long axis dimension from less than 25 μm to a maximum of 450 μm (Fig. 67). Grains smaller than those reported, below the limit of visual analysis between 10 μm and 25 μm, presumably exist. The recorded values average 75 μm. This size range is similar to values reported by Averill (1988), who indicated that 80 to 90% of grains observed in till samples from the shield are between 10 μm and 100 μm. Preferential occurrence of gold in these fractions was also indicated by analyses carried out by DiLabio (1985, 1988).

As has been observed elsewhere (Averill, 1988), grains from dispersal trains have irregular shapes and a nonporous surface (Fig. 68). Grains from samples with background counts in many cases have a rounded, pitted appearance (Fig. 69). Measured gold grains were classified by the staff of Overburden Drilling Management Ltd. as delicate, irregular, or abraded (Averill, 1988). In the study area, samples with no delicate grains are restricted to those with a total number of 10 or fewer grains (Fig. 70). Hence background gold grains were generally described as irregular or abraded. DiLabio (1990a) has developed a similar classification using the terms pristine, modified, and reshaped.

Following morphological analysis, polished sections were made of several visible gold grains coarser than 100 μm which had been removed from selected samples. Examination of these grains using backscatter mode on the SEM revealed compositional zoning (Fig. 71). Fine gold, contrasting with more silver-rich gold, was observed in a few grains as a discontinuous rim or patches in the grain. One grain was found to have a porous internal structure.

Electron microprobe analysis of polished sections of visible gold grains showed compositions similar to results obtained using identical analytical methods for gold from bedrock in the area (Fig. 72). Gold/silver ratios of about 9 to 1 are similar to values for gold in bedrock samples and are comparable to gold/silver ratios in production statistics for area mines (Mason and White, 1986). Several grains from till showed compositions with abnormal concentrations of silver (up to 35%) and mercury (up to 13%).

On the basis of their distribution, shape and composition, visible gold grains in anomalous till samples are attributed to glacial erosion and clastic dispersal from nearby bedrock and not to a chemical mechanism.

Kimberlite indicator minerals

The 0.25 to 2.0 mm fraction of nonmagnetic heavy mineral concentrates was visually examined under a stereoscopic binocular microscope for kimberlite indicator minerals (Fig. 73, 74). Grains tentatively identified as possible pyrope garnet, magnesian ilmenite, or chrome diopside were removed from the concentrate, mounted and polished, and analyzed by electron microprobe (Table 2).

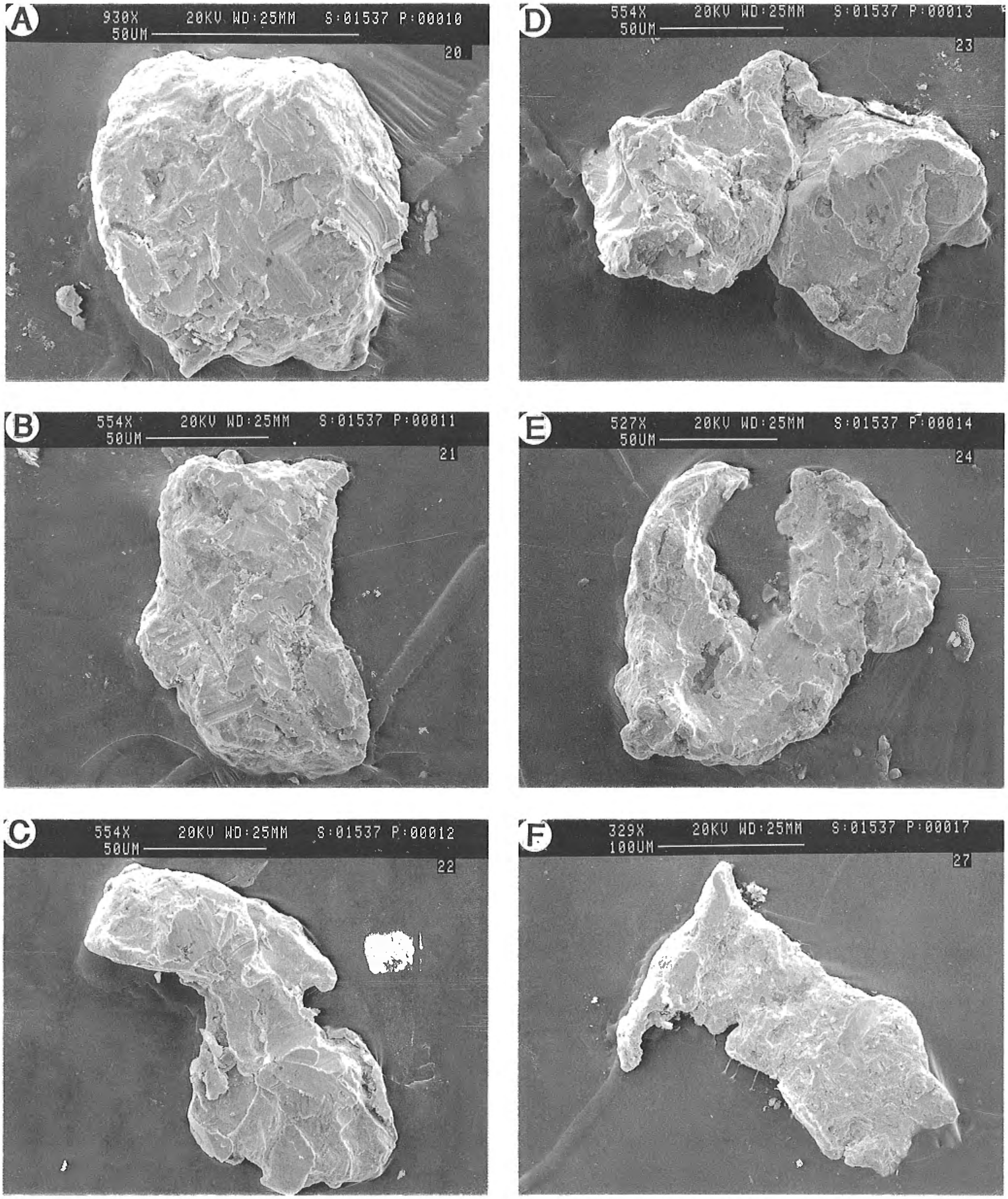


Figure 68. SEM images of gold grains from a dispersal train: Secondary electron images showing surface relief of >100 µm gold grains from sample 608, located 1 km west of the former Quebec Sturgeon Mine, north of Beardmore.

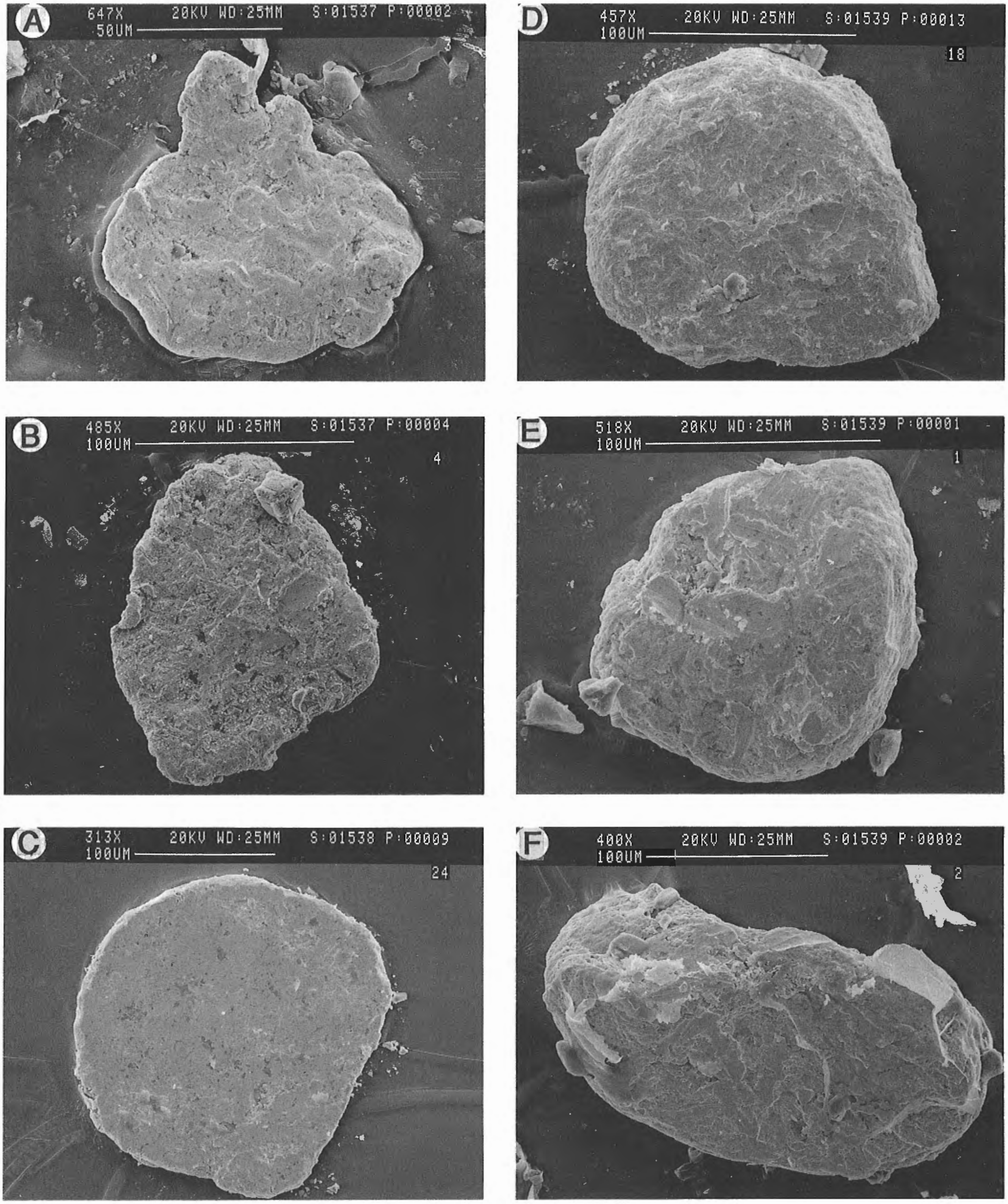


Figure 69. SEM images of background gold grains: Secondary electron images showing surface relief of >100 µm gold grains. Sample numbers: **A**) till sample 018; **B**) till sample 040; **C**) till sample 662; **D**) till sample 1293; **E**) and **F**) esker sample 923.

All pyrope garnets obtained from the study area fall into group nine of the Dawson and Stephens (1975, 1976) classification, referred to as chrome pyrope or G9 garnet (Fig. 75). These calcic chrome pyropes are derived from calcium saturated clinopyroxene-bearing rocks. These minerals typically indicate lherzolite xenoliths, which tend not to be as productive with respect to diamonds as are harzburgite xenoliths in kimberlite, which are indicated by subcalcic G10 garnets (Gurney, 1984; Fipke, 1989). Chromium values in the ilmenites obtained in the area predict good diamond preservation conditions in the source (Fipke, 1989). Chrome diopside, however, shows low chromium content relative to many kimberlites.

Pyrope garnet occurs at a few sites across the area, with a slight concentration northeast of Beardmore (Fig. 76). Magnesian ilmenite is more concentrated near Geraldton, in carbonate-rich debris. Hence more than one source is implied. The few chrome diopside grains which were confirmed are not clustered in a particular area.

Pyrope recovered by Wolfe et al. (1975) from the drift of the Moose River Basin, 400 km east-northeast of Beardmore-Geraldton, has a chemical composition similar to those examined in the present study. A clear contrast is presented, however, by the shape of the garnet grains. In the Moose River Basin, all but one pyrope recovered by Wolfe et al. (1975) are very well rounded. Grains examined in the present study are, in all but one case, angular. Janse et al. (1989) reported the discovery and analysis of alkaline

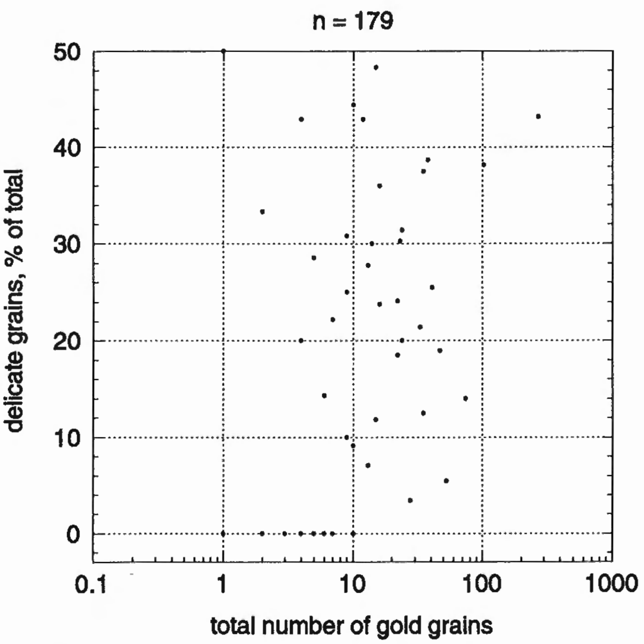


Figure 70. Abundance of delicate gold grains compared to total count.

intrusions located north of Hearst, 250 km east-northeast of the Beardmore-Geraldton study area. Clinopyroxene from their drill core has a similar chromium content, but higher aluminum content than grains from drift of the Beardmore-Geraldton area. Ilmenite analyses reported by these authors show slightly less magnesium, about 7 to 8% MgO, compared to typical values of 11% in the present study. Hence the indicator minerals in the Beardmore-Geraldton area seem not to be derived from these intrusions.

Fluorescent minerals

Nonmagnetic heavy mineral concentrates were examined under short wave ultraviolet light in order to determine the presence and abundance of fluorescent minerals, including the tungsten ore mineral scheelite.

Grains fluorescing yellow, averaging about 2000 grains per 10 g were visually identified as zircon. High zircon counts were obtained northeast of Jellicoe, near Beardmore, and south of Geraldton (Thorleifson and Kristjansson, 1990).

Grains fluorescing blue, as well as a few similar but greenish grains, were identified as scheelite on the basis of visual analysis as well as electron microprobe analysis of six grains. Elevated scheelite counts of a few tens of grains were obtained north of Beardmore and southeast of Geraldton (Thorleifson and Kristjansson, 1990). Samples 700 and 8050, however, contained several thousand scheelite grains, two orders of magnitude more than any other sample. Both samples were obtained on the north side of a pond 0.8 km west of Lordmayor Lake, south of Jellicoe. No mineralization has been reported in this area.

Whereas high zircon counts occur in samples from north of the greenstone belt, scheelite is restricted to sites down-ice from greenstone belt rocks.

Till geochemistry

Although geochemical data obtained for the project are of relevance to considerations of regional and environmental geochemistry, emphasis was placed on the determination of trends in variables commonly utilized in mineral exploration.

Although the C horizon of till deposits, from about 0.5 m to a few metres depth at well drained sites, is oxidized and thus altered by soil-forming processes, this material is generally referred to as glacial sediment rather than soil. Hence the term till is used for these samples, rather than soil. The assessment of methods for soil geochemistry, using the A and B soil horizons, was considered beyond the scope of the project.

Geochemical analysis of crushed bedrock from drill holes produced elemental concentrations very similar to results obtained using the same methods for the <63 μm fraction of till (Thorleifson and Kristjansson, 1990).

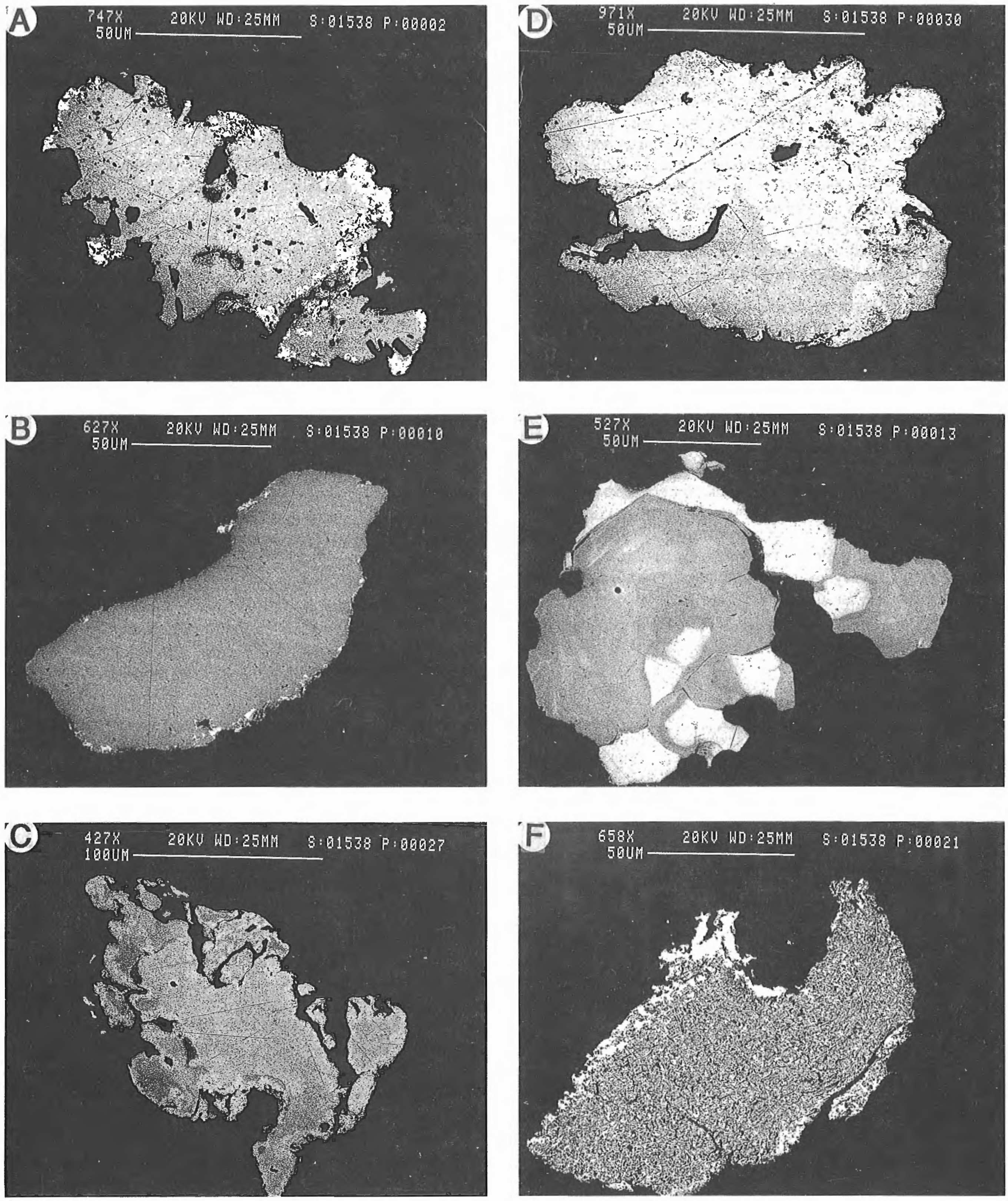


Figure 71. SEM images of gold grain polished sections: backscatter images showing compositional zoning. Light colours indicate higher atomic mass, hence gold of higher fineness. Till sample numbers: **A**) 626; **B**) 635; **C**) 676; **D**) 910 (esker); **E**) 635; **F**) 653.

Table 2. Electron microprobe analysis of kimberlite indicator minerals

Sample #	SiO_2	Al_2O_3	TiO_2	Fe_2O	Cr_2O	MgO	FeO	MnO	CaO	K_2O	Na_2O	NiO	CoO	V_2O_3	Total
	Weight per cent														
	Garnet														
404	42.10	20.71	0.28	0.36	3.18	20.27	7.98	0.44	4.69	0.00					100.01
433	41.49	18.13	0.06	0.00	6.87	19.10	7.16	0.40	6.13	0.00					99.34
436	41.72	19.14	0.40	0.39	4.69	19.95	7.73	0.46	5.03	0.02					99.53
667	41.75	21.04	0.03	0.00	3.35	19.31	8.05	0.59	4.68	0.01					98.81
672	42.35	20.49	0.08	0.00	4.51	19.51	7.32	0.49	4.75	0.01					99.51
676	41.18	17.51	0.53	0.22	6.57	19.69	7.41	0.42	5.30	0.00					98.83
695	42.46	18.92	0.22	0.00	6.21	18.79	7.28	0.46	5.41	0.00					99.75
8012	41.81	18.58	0.14		5.07	19.96	8.20	0.42	5.28						99.46
8034	41.89	19.87	0.05		4.23	20.33	7.99	0.52	4.95						99.82
8041*	42.12	19.50	0.10	0.75	5.03	20.40	6.86	0.38	5.32	0.00					100.46
8041*	42.19	19.75	0.22	0.00	4.66	20.42	7.19	0.37	4.84	0.00					99.64
8043***	41.31	18.83	0.03		5.24	18.37	8.67	0.54	6.43						99.42
8045****	41.55	16.30	0.11		8.30	19.49	7.57	0.47	6.15						99.94
8045****	41.76	18.40	0.27		5.08	21.19	7.48	0.36	4.70						99.24
8149	42.20	20.41	0.03		3.08	20.65	7.73	0.41	5.59						100.10
	Ilmenite														
7	0.03	0.22	53.13	5.79	2.61	12.66	24.63	0.32	0.02			0.13	0.04	0.30	99.88
44	0.00	0.22	52.41	7.01	2.40	11.48	26.07	0.35	0.03			0.15	0.01	0.40	100.53
62	0.04	0.21	51.66	7.39	2.80	10.88	26.53	0.36	0.02			0.12	0.05	0.46	100.52
119	0.02	0.10	52.53	6.84	3.61	12.64	24.08	0.46	0.01			0.21	0.04	0.41	100.95
125	0.00	0.17	51.77	7.30	2.74	10.77	26.76	0.32	0.02			0.16	0.04	0.41	100.46
129	0.02	0.16	51.76	7.77	2.95	10.69	27.00	0.33	0.03			0.13	0.06	0.47	101.37
215	0.05	0.12	49.98	9.87	3.19	10.12	26.28	0.43	0.01			0.12	0.04	0.51	100.72
253	0.00	0.15	50.22	9.07	3.65	10.32	26.14	0.33	0.00			0.14	0.04	0.44	100.50
277	0.00	0.14	50.07	8.96	3.59	9.94	26.78	0.35	0.02			0.11	0.05	0.48	100.49
319	0.00	0.35	54.27	4.67	2.56	12.93	25.27	0.31	0.03			0.14	0.06	0.38	100.97
423	0.47	1.15	50.88	7.77	2.13	11.86	24.61	0.31	0.03			0.14	0.03	0.47	99.85
444	0.05	0.41	54.27	0.25	2.71	10.86	28.98	0.31	0.02			0.20	0.05	0.29	98.40
447	0.03	0.18	52.89	6.94	2.85	12.35	25.06	0.38	0.01			0.14	0.06	0.44	101.33
674	0.03	0.09	49.86	10.47	1.67	8.59	29.09	0.35	0.01			0.05	0.08	0.43	100.72
1063	0.04	0.04	50.53	8.57	3.28	10.43	26.30	0.46	0.02			0.16	0.06	0.47	100.36
1245	0.05	0.33	52.50	6.02	2.85	11.83	25.71	0.29	0.01			0.16	0.05	0.48	100.28
1293	0.01	0.15	50.23	9.05	3.34	9.55	27.47	0.43	0.03			0.16	0.06	0.44	100.92
8041	0.01	0.26	51.20	8.25	2.35	10.49	26.66	0.34	0.03			0.15	0.06	0.49	100.29
8041*	0.01	0.11	49.43	10.13	4.28	10.35	25.07	0.38	0.03			0.17	0.28	0.51	100.75
8041*	0.03	0.28	51.01	8.06	2.34	10.57	26.54	0.35	0.00			0.13	0.04	0.48	99.83
8041*	0.07	0.24	51.26	8.02	2.35	10.68	26.67	0.31	0.01			0.13	0.06	0.47	100.27
8041*	0.00	0.28	50.92	9.01	2.42	11.00	25.55	0.33	0.01			0.10	0.06	0.49	100.17
	Diopside														
65	53.64	1.27	0.04	0.00	1.13	15.93	2.59	0.11	22.70	0.01	0.65				98.07
301	54.01	0.84	0.13	0.00	0.89	17.41	2.96	0.08	22.12	0.01	0.34				98.79
704	53.52	0.99	0.09	0.00	0.50	13.73	5.38	0.25	23.18	0.02	0.70				98.36
1018	54.62	0.92	0.04	0.00	0.52	14.18	4.94	0.18	22.61	0.01	0.50				98.52
1020	53.04	1.00	0.20	0.11	1.36	17.03	3.78	0.10	20.87	0.00	0.57				98.06
1248	53.20	2.10	0.10		0.60	15.90	4.80	0.10	23.50	0.00	0.50				100.30
8042**	54.60	1.10	0.20		1.20	16.60	3.30	0.10	21.00	0.00	1.80				98.10

* grains obtained from a 97 kg supplementary sample.
** no additional grains obtained from a 106 kg supplementary sample.
*** no additional grains obtained from a 106 kg supplementary sample.
**** no additional grains obtained from a 79 kg supplementary sample.

The terms anomaly and anomalous are here used with reference to all data from across the study area, hence varying levels of background are, in general, not taken into account. For the purposes of discussion, the 95th percentile is used a threshold between background and anomalous values.

Quality control

Precision in geochemical analyses carried out for the project was monitored using duplicates and reference materials in all batches (Thorleifson and Kristjansson, 1990). The reference materials used were of mixed origin and result from the accumulation of excess material from laboratory procedures. The materials are not certified, but have been analyzed a sufficient number of times by the specific preparation and analytical methods in question to indicate precision over several months to a few years.

Analysis of duplicates of the <63 µm fraction for gold by fire assay showed acceptable precision above 10 ppb (Fig. 77). Samples were split following preparation of the grain size fraction.

Analysis of <63 and <2 µm fractions by ICP-AES was sufficiently precise for most elements well above the lower detection limits (Fig. 77). Elements occurring at levels near the detection limit, such as arsenic, are not as reproducible.

Bulk till samples weighing about 100 kg were collected from nine sites in the Beardmore area where elevated gold values had previously been obtained. These samples were screened at 6 mm and thoroughly homogenized. Three representative splits weighing 10 kg were submitted for heavy mineral concentration. Gold grain abundance data, corrected for sample weight, and predicted assay in most cases showed two fold variation in values (Table 3), although the order of magnitude was reproduced in every case. Neutron activation analysis of these concentrates were similarly to less variable. Replicate fire assay analyses of the <63 µm fraction ranged from highly variable for sample 8008 to highly precise for sample 8010. Good precision for the latter sample is attributed to an abnormally high gold concentration of 700 ppb in the <2 µm clay fraction (Thorleifson and Kristjansson, 1990). Precision for this sample was better within batches than between batches. In summary, results for replicate gold analyses indicate acceptable to excellent reproducibility for most analyses.

Contamination of sediment by human activity is suspected for at least one site. Sample 140 (Thorleifson and Kristjansson, 1990), located a few hundred metres from the former Magnet mine, shows an anomalous gold concentration in the <63 µm fraction, despite a high carbonate content. The nonmagnetic heavy mineral concentrate from this sample was not anomalous with respect to gold.

Tungsten carbide contamination derived from the sonic drill bit is the probable cause for very high tungsten and cobalt values in several magnetic heavy mineral concentrates from drill hole samples (Fig. 78).

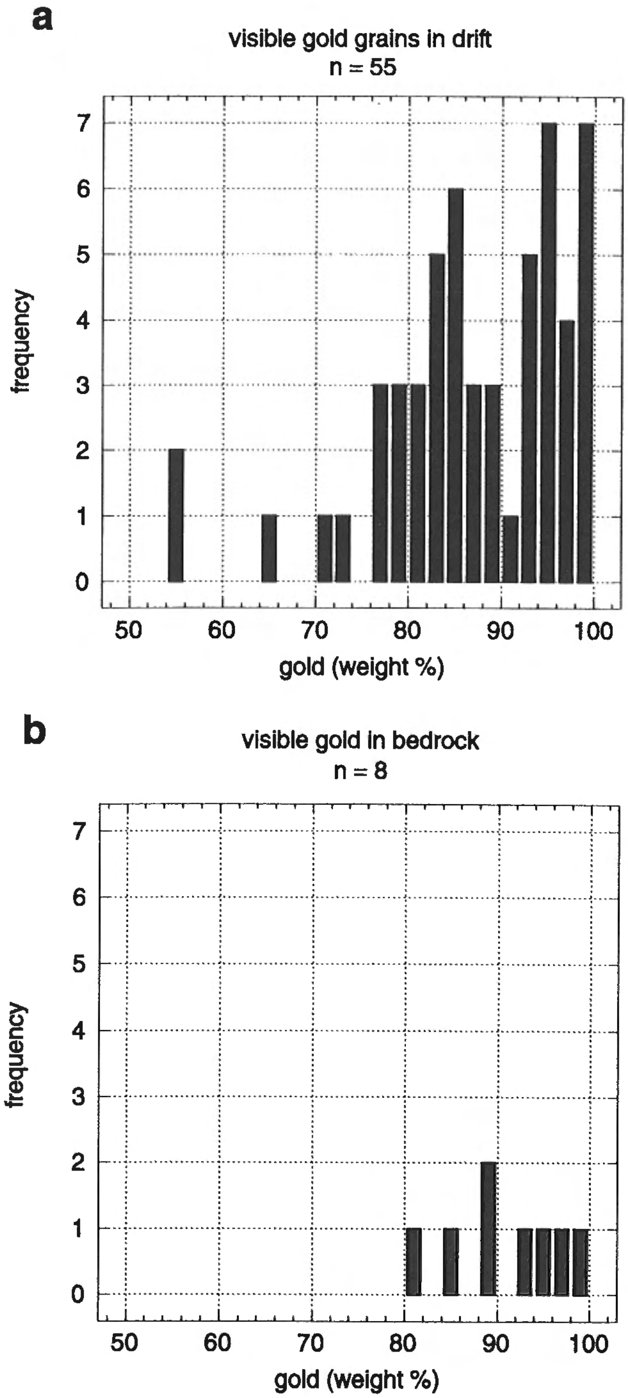


Figure 72. Composition of **a**) visible gold grains from till and esker samples and **b**) gold in bedrock.

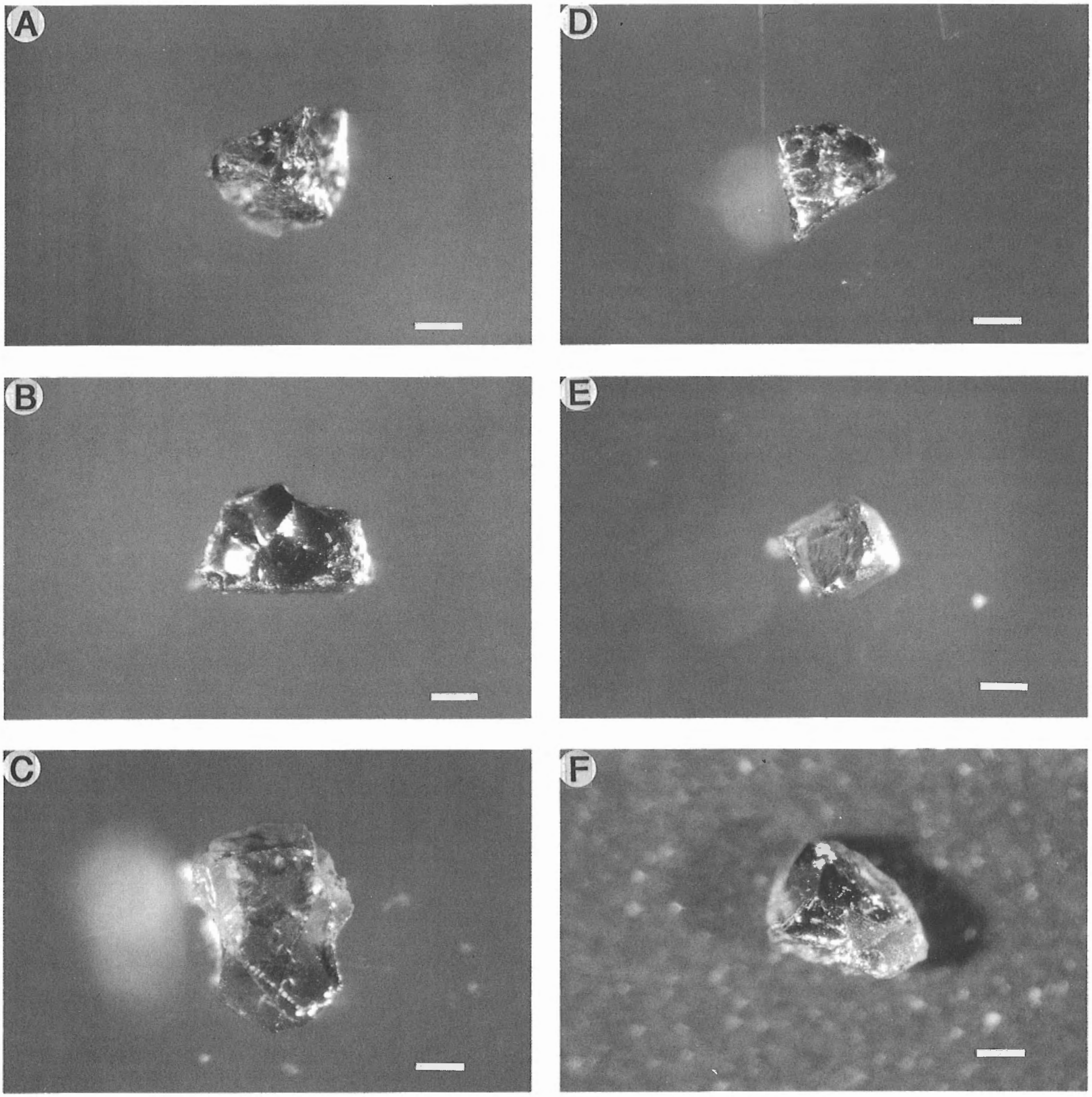


Figure 73. Kimberlite indicator minerals I. Scale bar = 0.25 mm. Chrome pyrope: **A**) till sample 433 (GSC 205458-H); **B**) till sample 436 (GSC 205458-E); **C**) till sample 667 (GSC 205458-B); **D**) till sample 676 (GSC 205458-D); **E**) till sample 695 (GSC 205458-C); **F**) till sample 8043 (GSC 205458-J).

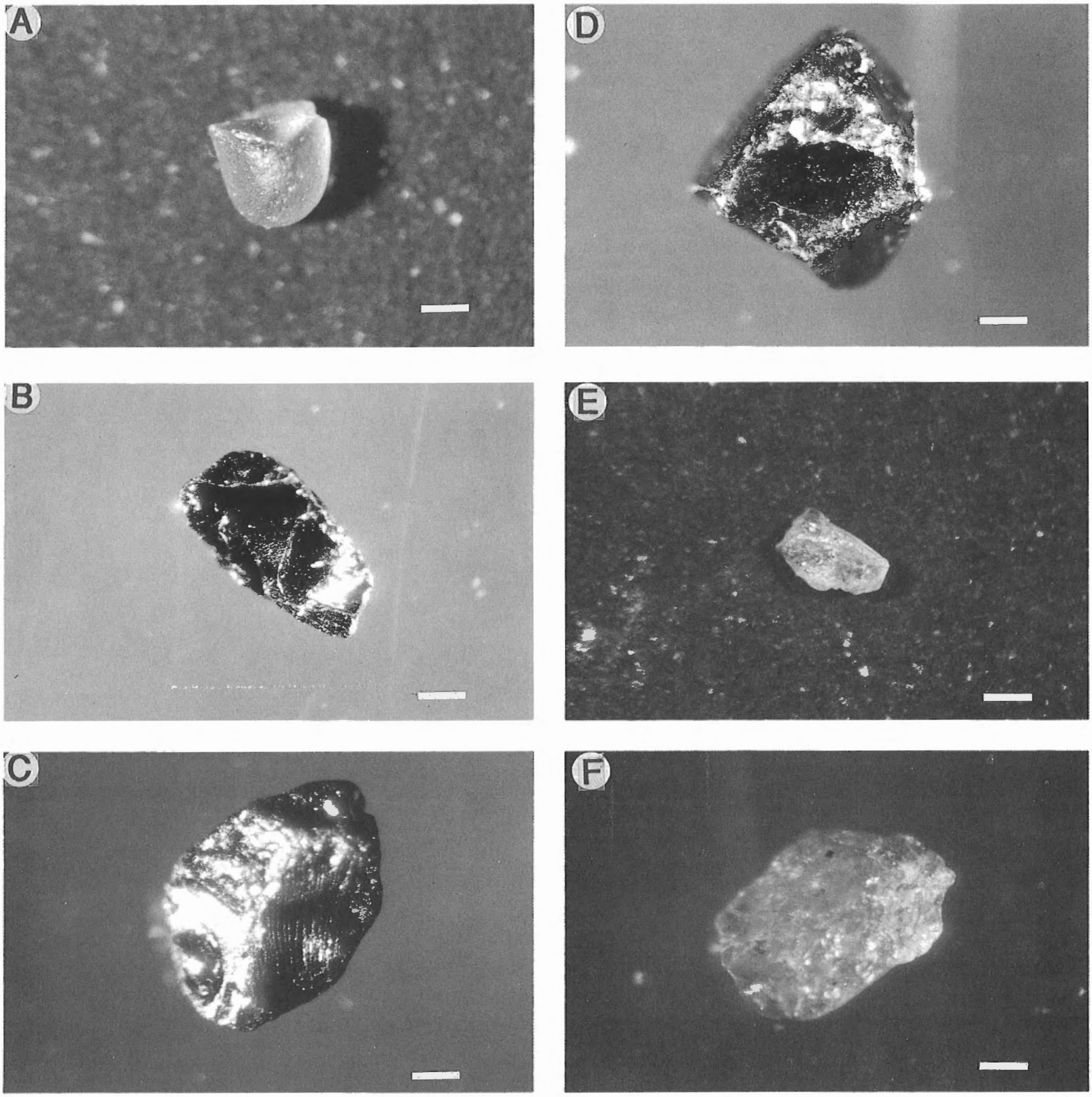


Figure 74. Kimberlite indicator minerals II. Scale bar = 0.25 mm. Chrome pyrope: **A**) till sample 8149 (GSC 205458-I); Magnesian ilmenite: **B**) till sample 277 (GSC 205458-F); **C**) till sample 319 (GSC 205458-M); **D**) till sample 447 (GSC 205458-L); Chrome diopside: **E**) till sample 65 (GSC 205458-G); **F**) till sample 301 (GSC 205458-K).

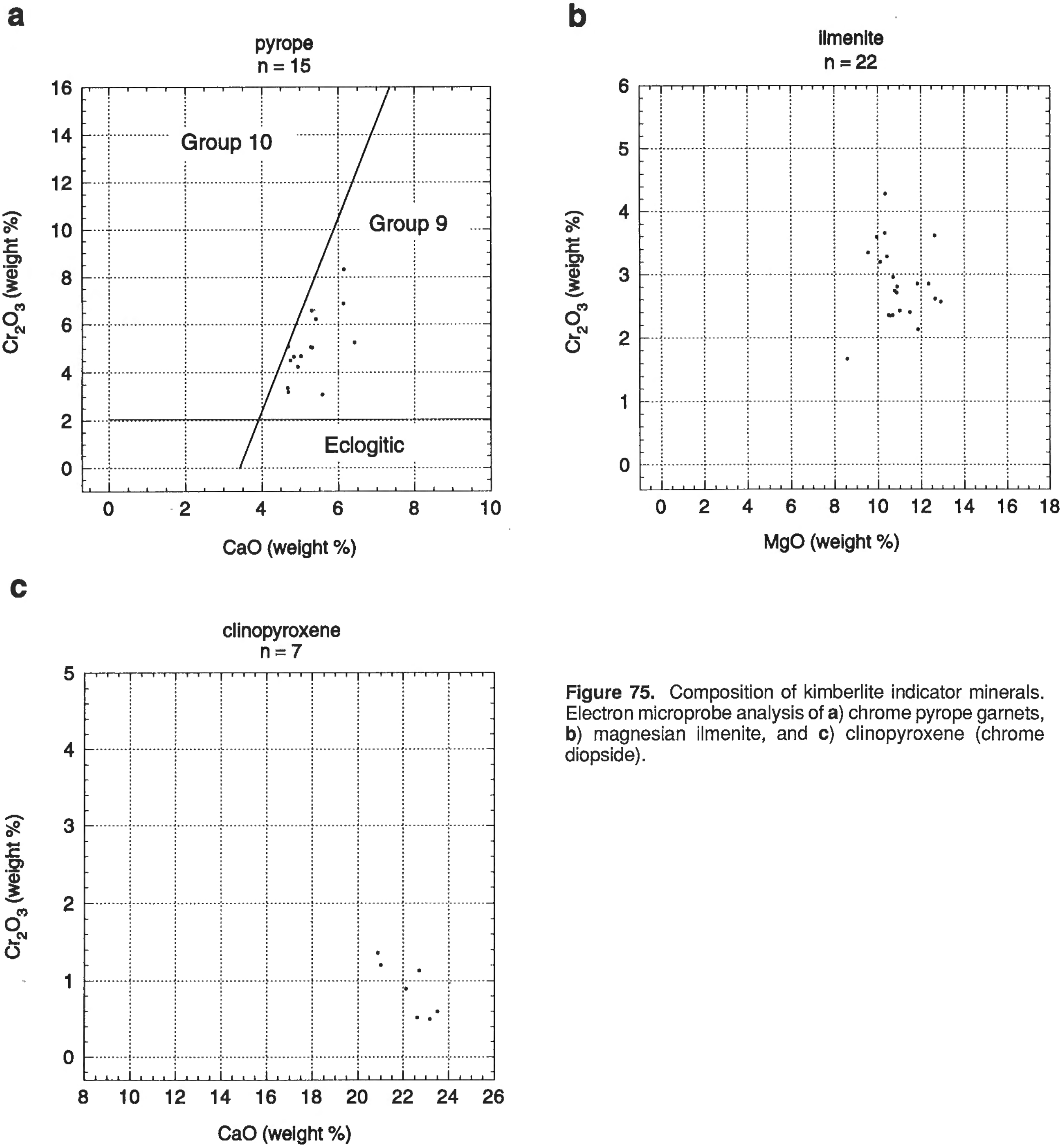


Figure 75. Composition of kimberlite indicator minerals. Electron microprobe analysis of **a**) chrome pyrope garnets, **b**) magnesian ilmenite, and **c**) clinopyroxene (chrome diopside).

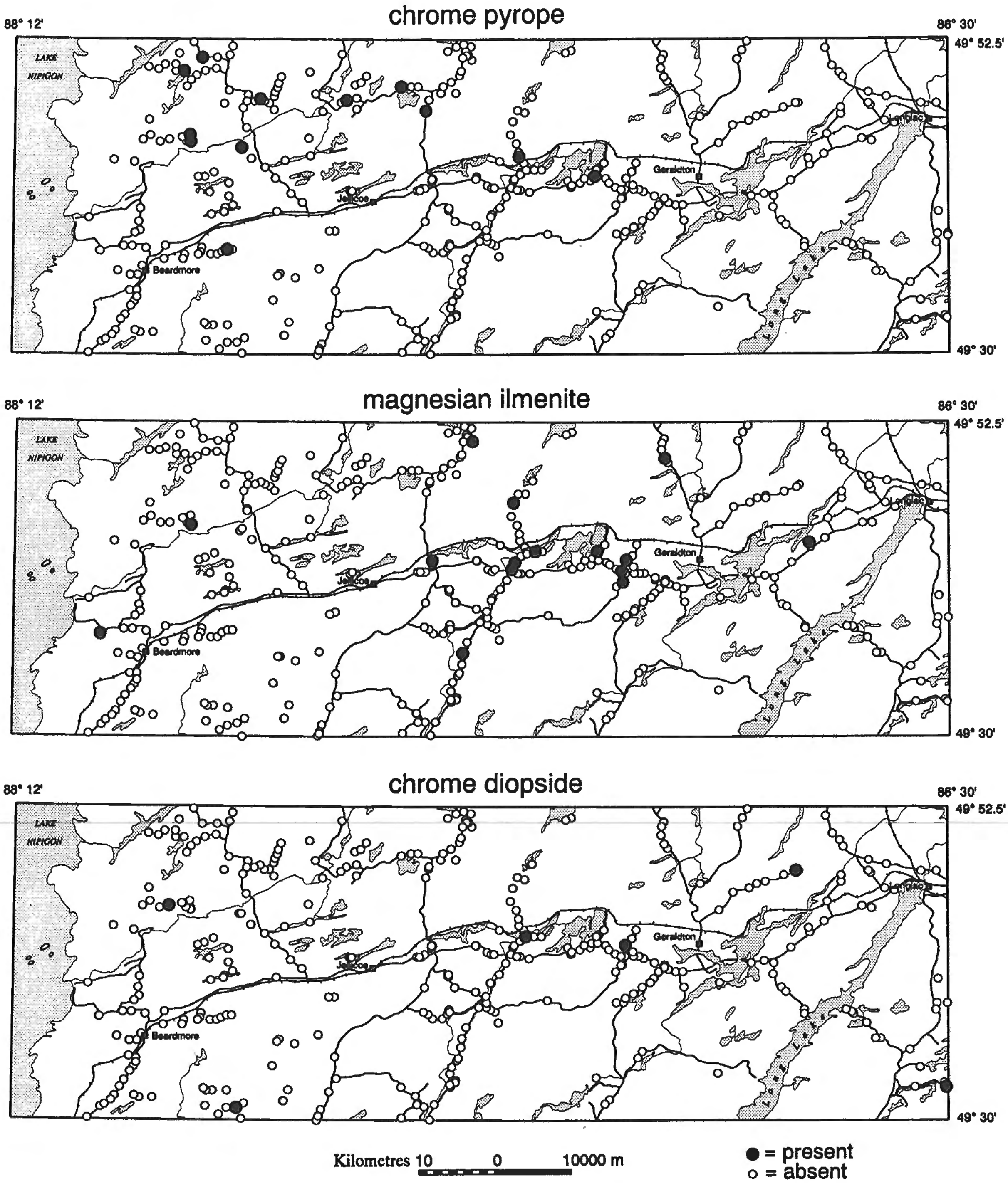


Figure 76. Location of kimberlite indicator mineral occurrences.

Table 3. Replicate gold analyses

Sample number:								
8008	8010	8040	8041	8042	8043	8044	8045	8046
Three 10 kg splits from 100 kg homogenized bulk samples:								
Gold grains / 10 kg								
36	5	446	37	4	6	31	94	13
16	2	214	70	6	7	39	88	13
22	6	313	52	10	16	34	54	7
Predicted assay, ppb								
1982	114	6250	975	778	5750	199	1147	86
1040	36	26393	1228	1397	179	435	1048	90
569	449	13258	1221	155	748	939	857	36
INAA analysis of heavy mineral concentrate, ppb								
1590	60	9080	3030	632	2190	530	1044	225
716	100	11100	996	665	110	772	845	280
709	430	8400	1800	100	604	721	978	280
Ten gram splits of $<63\mu m$ fraction, fire assay, ppb								
Batch 1:								
2	170	193	49	2	3	24	38	48
<1	182	163	54	1	4	20	33	7
1	174	205	27	3	11	49	33	13
1	176	185	41	2	4	70	45	24
14	188	163	17	4	11	33	51	20
2	158	262	22	9	8	19	46	10
7	168	200	30	6	9	24	21	27
<1	168	188	24	6	9	26	45	18
2	166	147	19	3	7	20	29	77
46	183	201	24	4	4	23	50	47
13	170	264	16	3	4	164	15	20
<1	188	177	21	10	6	27	32	19
2	166	254	29	5	2	45	22	13
5	171	313	30	4	3	33	85	11
5	171	197	24	2	3	32	30	23
1	174	187	24	24	4	12	41	11
<1	143	151	13	2	2	34	18	10
1	165	185	28	4	3	29	149	21
2	194	181	26	3	3	31	48	39
84	174	158	41	4	2	35	95	17
<1	170	144	93	10	3	23	32	12
86	165	151	31	5	6	15	32	12
19	168	143	26	3	2	23	28	30
1	170	208	23	5	5	26	22	6
39	166	167	20	9	2	24	22	14
<1	170	181	44	6	10	53	96	10
<1	175	174	23	5	6	48	47	16
1	161	152	28	2	2	19	12	9
185	167	118	24	11	3	25	24	7
1	173	124	21	6	3	39	46	26
Batch 2:								
3	200	162	71	4	19	31	55	40
3	214	228	21	4	8	96	48	13
1	219	197	22	4	53	28	33	53
Batch 3:								
2	213	195	37	9	4	45	33	19
2	201	119	57	6	7	38	48	12
2	234	251	28	10	5	69	24	37

Geochemical data obtained from the <2 µm fraction were inspected to check for values indicative of errors in sample preparation. Careless decantation following low RPM centrifugation meant to bring >2 µm material out of suspension may result in the introduction of coarse material into the suspension which is subsequently subjected to high RPM centrifugation. Because the <2 µm fraction is dominated by aluminosilicates, aluminum values were checked for anomalously low values. Fifteen samples with partial leach aluminum contents of less than 1% in the <2 µm fraction, as well as 15 samples with aluminum concentrations over 5%, were resubmitted for preparation. Subsequent ICP analysis indicated much higher values for aluminum and other elements for samples anomalously low on the first run, but comparable values for samples which showed high aluminum on the first run. It was therefore concluded that <2 µm preparations with anomalously low aluminum content should be regarded as suspect preparations.

Inspection of the aluminum content in the <63 µm and <2 µm fractions of all samples indicates that flawed preparations of the <2 µm fraction were not a pervasive problem. About 5% of all <2 µm samples showed aluminum contents below 1%, a value typical of the <63 µm fraction. Hence the few anomalous samples which happen to occur within this group may show metal levels which are suppressed by silt. This conclusion was regarded with concern, but the results of <2 µm analyses are nevertheless considered adequate to indicate regional trends. A problem such as this may be less severe than variability in <63 µm analyses caused by the natural variability in silt content of the <63 µm fraction.

Precious metals

Geochemical analysis of soil and drift samples for gold has been discussed by authors such as Gleeson et al. (1984), DiLabio (1985), Sopuck et al. (1986), Bloom and Steele (1989), Gleeson et al. (1989), Campbell and Schreiner (1989), and McClenaghan (1990).

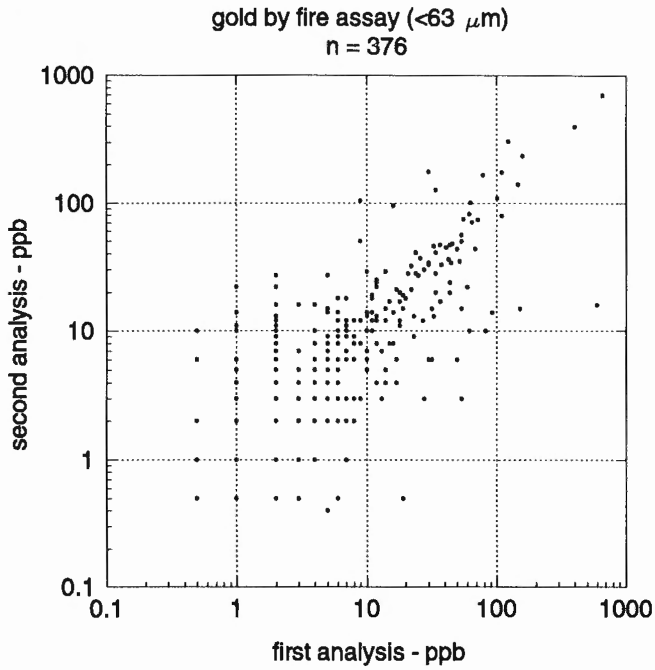
Values for the 95th percentile of the gold measurements are 8 gold grains per 10 kg of till, 900 ppb in the nonmagnetic heavy mineral concentrate, and 18 ppb in the <63 µm fraction.

Gold concentrations in nonmagnetic heavy mineral concentrates reach values of several thousand parts per billion and are correlated with the number of gold grains observed during processing of the concentrate (Fig. 79). Ten gold grains per 10 kg correspond to about 1000 ppb in nonmagnetic heavy mineral concentrate, 100 grains are equivalent to about 10 000 ppb.

Gold concentrations in nonmagnetic heavy mineral concentrates are also correlated with the assay predicted on the basis of number and size of the gold grains (Fig. 79). Hence no abnormal, nonvisible gold was detected in this fraction. Several predicted values on this plot were based on samples which were not panned and hence are based on one or two grains recognized on the shaking table. More gold might have been found if these samples had been panned. Samples plotted as 1 ppb predicted are those for which no gold grains were seen on the shaking table and were therefore not panned.

The few samples from which visible gold was removed for SEM and microprobe analysis were excluded from these plots.

a



b

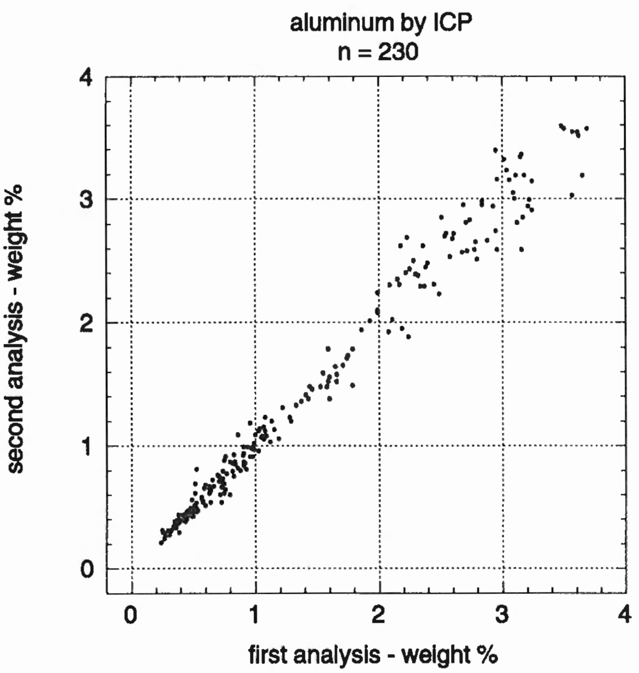


Figure 77. Precision of geochemical analyses were tested using duplicate analyses, **a)** analysis of gold by fire assay of 10 to 30 g of <0.063 mm fraction of till, **b)** analysis of aluminum in <0.002 and <0.063 mm fractions of till by nitric/aqua regia/ICP-AES.

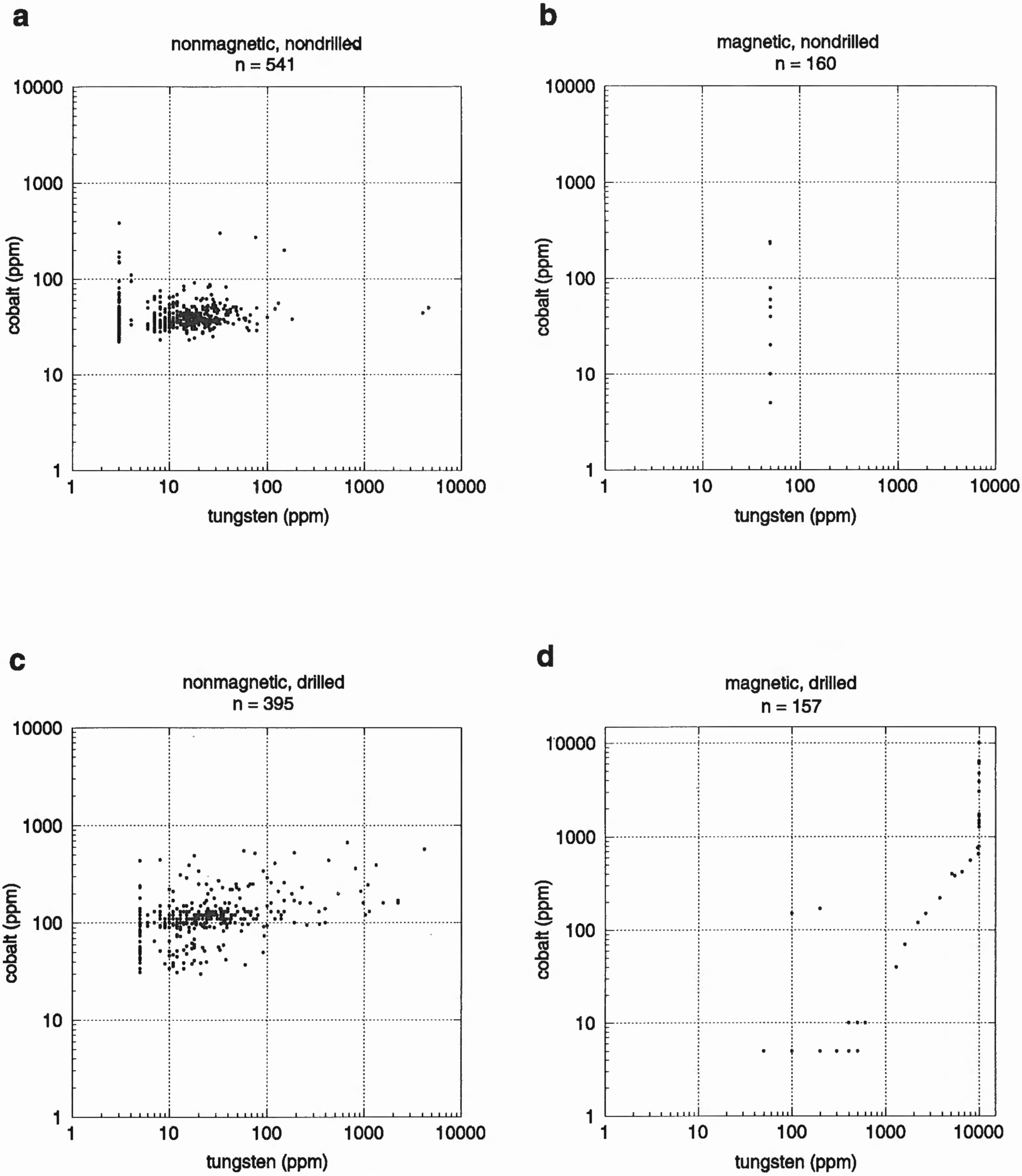


Figure 78. Tungsten carbide bit contamination in drill hole magnetic concentrates indicated by tungsten and cobalt analyses.

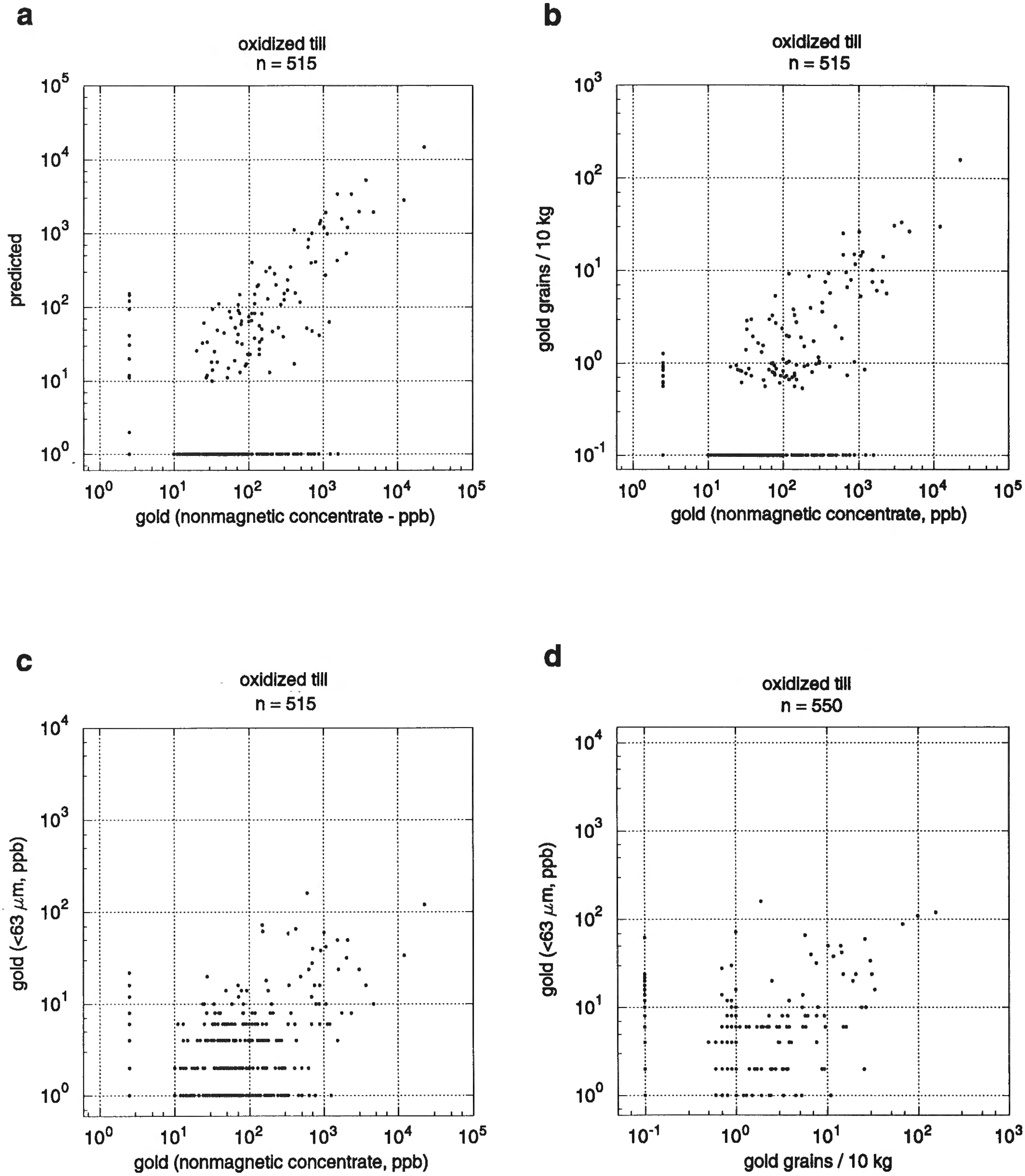


Figure 79. Comparison of gold analyses, oxidized surface till samples.

The geographical pattern of gold values in surface till sample nonmagnetic heavy mineral concentrates (Fig. 80) is similar to the map pattern for gold grain abundance data (Fig. 66). The ranking of sites is somewhat different between the two methods. Several sites give high background values for geochemical analysis, but no accompanying gold grain count. The dominant control on gold concentration in surface till within the greenstone belt is the provenance of the debris. Analyses of very calcareous till in the Geraldton area show no manifestation of known gold mineralization. Thin, locally derived till in the Beardmore area produced a much higher gold background due to the derivation of this till from mineralized greenstone belt rocks.

Comparison of gold grain counts and gold analyses of nonmagnetic heavy mineral concentrates with fire assay results from the <63 μm fraction (Fig. 79) indicate several unexpectedly high values in the fine grained sediment. Very few samples which gave background values in the fines are anomalous in the concentrate. About half of the samples which are anomalous in the fines also gave anomalous values in the concentrates. Some of the samples with elevated gold values in the fines but background values in the concentrate may contain high concentrations of gold in fine grained sediments such as clay, but many others in this group are probably examples of the nugget effect. The map pattern for analysis of gold in the <63 μm fraction by fire assay (Fig. 81) mimics the pattern for gold grain counts and neutron activation analysis of the nonmagnetic heavy mineral concentrate, but the pattern is less variable and the distribution of elevated values is broader. A few areas of clustered elevated values in the <63 μm fraction which are not apparent in the gold grain and concentrate data are present.

The concentration of gold in the <2 μm fraction of samples in most cases earlier found to be anomalous with respect to gold in other fractions was determined. Several centrifuge runs were required to obtain more than 5 g of clay. Results indicate that gold concentration is higher in the clay fraction for 60% of the samples (Fig. 82). In contrast, as discussed below, base metals are almost universally much higher in the clay fraction (Shilts, 1984a).

Magnetic heavy mineral concentrates from the Beardmore area and two drill holes were analyzed for gold. Several values exceeding the detection limit ranged from a few tens to a few hundred ppb (Thorleifson and Kristjansson, 1990). The magnetic fraction from sulphide-rich till overlying bedrock at hole E has consistently elevated gold values ranging from 20 to 60 ppb.

Elements commonly associated with gold, such as arsenic and antimony (Table 4; Fig. 83), show correlation with high gold values in several samples, but several cases of high gold values not accompanied by anomalies in these pathfinder elements are present. Arsenic in the <2 μm and <63 μm fractions is elevated in gold-bearing samples from the southernmost portion of the Beardmore-Geraldton belt (Fig. 84), whereas copper shows a stronger association with gold mineralization in felsic volcanic terrrane north of Beardmore (Fig. 85). In unoxidized nonmagnetic heavy mineral concentrates, arsenic values of as much as 10 000 ppm, in cases associated with gold anomalies, were encountered (Appendix 2). Antimony anomalies in oxidized nonmagnetic heavy mineral concentrates occur in the area between Beardmore and Windigokan Lake which presumably represents an area of Sb-bearing mineralization (Fig. 86). This Sb pattern was also detected by analysis of the <2 μm fraction, but the <63 μm did not reveal the pattern at the detection limit used.

Comparison of gold results and carbonate content, as an indicator of provenance (Fig. 87), indicates that anomalies are present in both calcareous and noncalcareous till. In surface samples, values of several thousand parts per billion in the nonmagnetic heavy mineral concentrate are only present in noncalcareous till, but values over 1000 ppb are also present in very calcareous till. In till from drill holes, there is little difference in the occurrence of anomalies. Hence, elevated gold values may be encountered in calcareous till, presumably due to mixing of mineralized debris into exotic calcareous material.

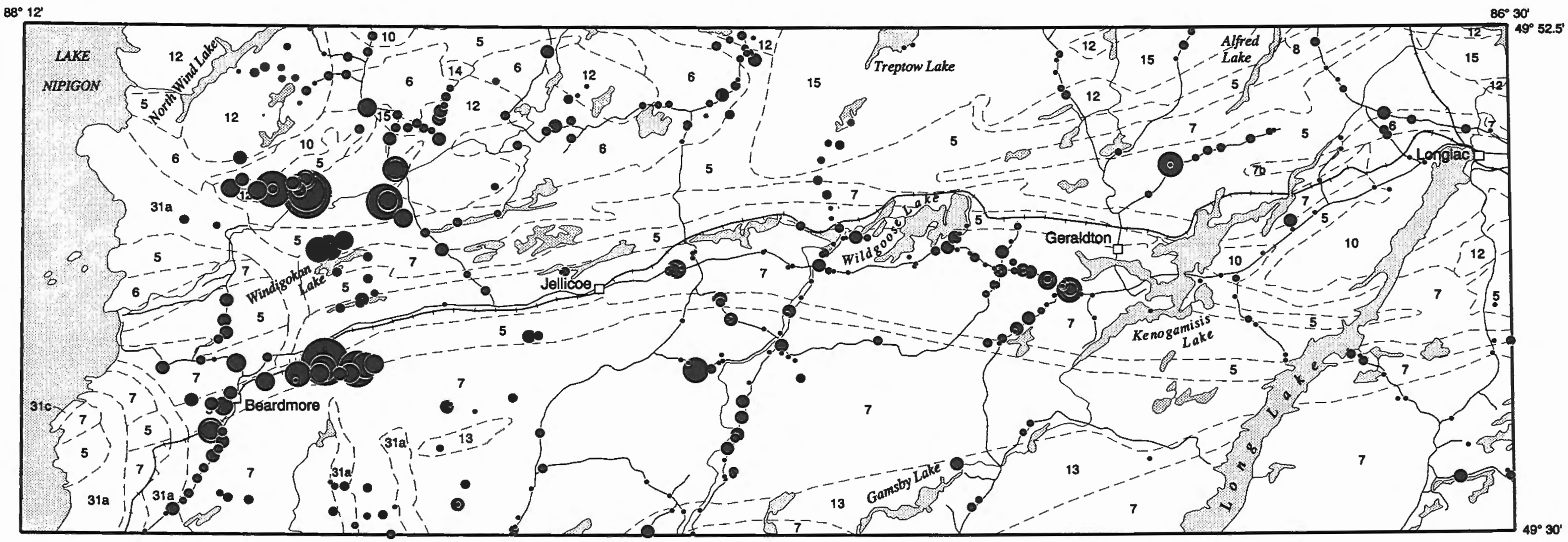
The <63 μm fraction and the magnetic heavy mineral concentrates from the Beardmore area and two drill holes were analyzed for platinum and palladium. Palladium in the <63 μm fraction is slightly elevated in the area of diabase outcrop north of Beardmore. Elevated palladium values from the Longlac area were attributed to analytical problems by Thorleifson and Kristjansson (1990). Platinum in the <63 μm fraction shows scattered values slightly above the detection limit, with a group of elevated values between Jellicoe and Wildgoose Lake (Thorleifson and Kristjansson, 1990). A cluster of elevated chromium values in the <63 μm fraction were also encountered in this area. Platinum exceeded the detection limit in only two out of over 240 magnetic concentrates. The detection limit was exceeded more frequently by palladium, including a value of 190 ppb from a sample overlying bedrock at hole E.

A cluster of three silver anomalies in the <2 μm fraction were obtained near Windigokan Lake. The <63 μm fraction failed to detect this pattern.

Base metals

The principal data source regarding base metals in this project is the geochemistry of the fine grained fractions from till. Metals liberated from sulphides by oxidation may be detectable in the fine fractions (Shilts, 1984a). Only limited data for base metals in sulphide-bearing nonmagnetic heavy mineral concentrates from unoxidized samples are available because no destructive chemical analyses, which are required for satisfactory base metal analysis, were done.

The <63 μm fraction represents metal-rich clay variably diluted by relatively sterile silt (Fig. 88; Shilts, 1984a). Concentrations for base metals reported by Thorleifson and Kristjansson (1990) are consistently higher in the clay, but are correlated in the <63 μm and <2 μm fractions (Fig. 89).



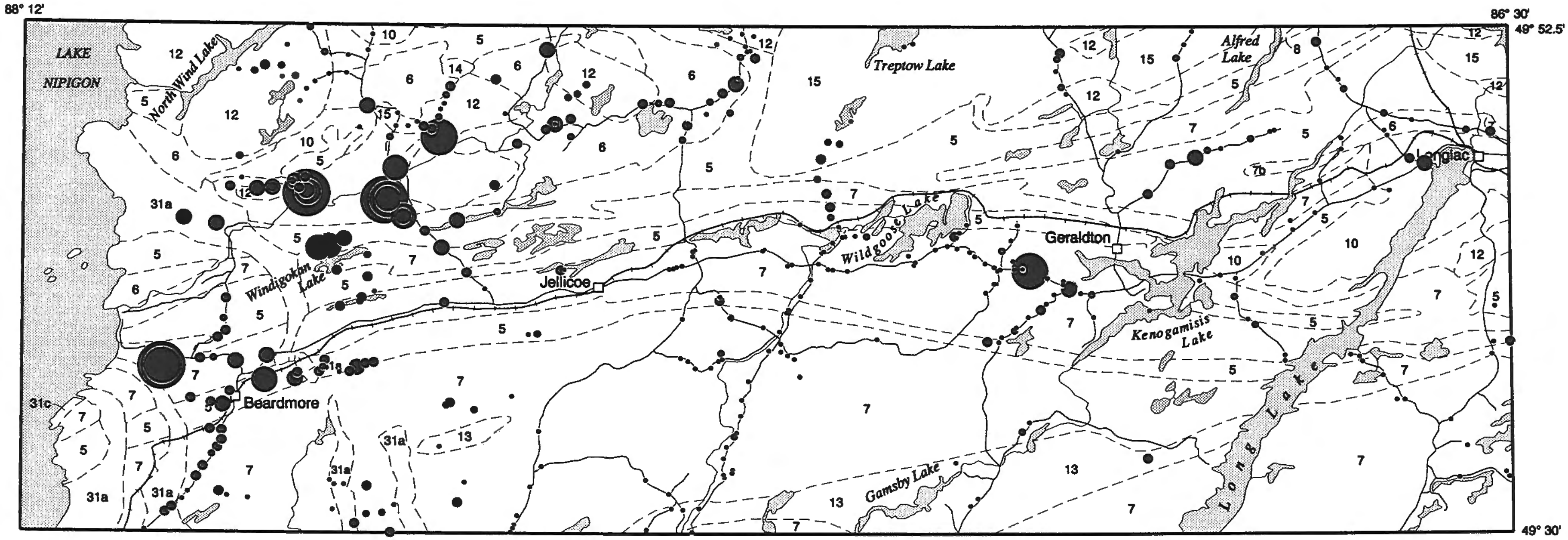
Au (ppb)

INAA analysis of nonmagnetic heavy mineral fraction of till

Min	Max	n	%<
3	3	134	35
3	38	59	50.4
38	130	95	75.2
130	599	57	90.1
599	1070	19	95
1070	2110	11	97.9
2110	3730	4	99
3730	22500	4	100

Kilometres 10 0 10000 m

Figure 80. Gold in nonmagnetic heavy mineral concentrates from surface till samples. For bedrock geology see Figure 3.



Au (ppb)

Fire assay analysis <63 μm fraction of till

Min	Max	n	%<
1	2	219	57.2
2	5	54	71.3
5	11	70	89.6
11	28	24	95.8
28	50	8	97.9
50	72	4	99
72	160	4	100

Kilometres 10 0 10000 m

Figure 81. Gold in the <63 μm fraction of surface till samples. For bedrock geology see Figure 3.

Table 4. Oxidized Till; n = 469

Correlation Matrix						Gold H	Gold <63μm	Gold Grains	Predicted Assay
Gold, Nonmagnetic Heavy Mineral Concentrate (H)						1.00	0.51	0.92	0.91
Gold, <63 μm						0.51	1.00	0.54	0.48
Visible Gold Grains per 10 kg						0.92	0.54	1.00	0.94
Predicted Heavy Mineral Assay						0.91	0.48	0.94	1.00
Correlation Matrix	**AuH**	**Au <63**	**AsH**	**CoH**	**CrH**	**NiH**	**SbH**	**WH**	
Gold, Heavy Minerals (H)	1.00	0.51	0.43	0.08	-0.06	-0.02	0.17	0.00	
Gold, <63 μm	0.51	1.00	0.23	0.10	-0.15	0.05	0.44	0.01	
Arsenic, Heavy Minerals	0.43	0.23	1.00	0.10	-0.03	-0.02	0.32	-0.03	
Cobalt, Heavy Minerals	0.08	0.10	0.10	1.00	0.02	0.53	0.15	0.02	
Chromium, Heavy Minerals	-0.06	-0.15	-0.03	0.02	1.00	-0.28	0.06	-0.06	
Nickel, Heavy Minerals	-0.02	0.05	-0.02	0.53	-0.28	1.00	-0.05	0.00	
Antimony, Heavy Minerals	0.17	0.44	0.32	0.15	0.06	-0.05	1.00	0.06	
Tungsten, Heavy Minerals	0.00	0.01	-0.03	0.02	-0.06	0.00	0.06	1.00	
Correlation Matrix	**AuH**	**Au <63**	**As <63**	**Co <63**	**Cr <63**	**Cu <63**	**Ni <63**	**Sb <63**	**Zn <63**
Gold, Heavy Minerals (H)	1.00	0.51	0.23	0.16	0.11	0.19	0.18	-0.04	0.05
Gold, <63 μm	0.51	1.00	0.19	0.18	0.08	0.31	0.19	-0.08	0.13
Arsenic, <63 μm	0.23	0.19	1.00	0.59	0.40	0.39	0.50	-0.02	0.10
Cobalt, <63 μm	0.16	0.18	0.59	1.00	0.70	0.71	0.86	-0.00	0.23
Chromium, <63 μm	0.11	0.08	0.40	0.70	1.00	0.39	0.86	-0.04	0.18
Copper, <63 μm	0.19	0.31	0.39	0.71	0.39	1.00	0.66	-0.08	0.49
Nickel, <63 μm	0.18	0.19	0.50	0.86	0.86	0.66	1.00	-0.12	0.24
Antimony, <63 μm	-0.04	-0.08	-0.02	-0.00	-0.04	-0.08	-0.12	1.00	-0.04
Zinc, <63 μm	0.05	0.13	0.10	0.23	0.18	0.49	0.24	-0.04	1.00
Correlation Matrix	**AuH**	**Au <63**	**As <2**	**Co <2**	**Cr <2**	**Cu <2**	**Ni <2**	**Sb <2**	**Zn <2**
Gold, Heavy Minerals (H)	1.00	0.51	0.17	0.19	0.10	0.25	0.10	0.09	0.04
Gold, <63 μm	0.51	1.00	0.18	0.23	0.08	0.37	0.11	0.20	0.12
Arsenic, <2 μm	0.17	0.18	1.00	0.67	0.42	0.46	0.47	0.54	0.10
Cobalt, <2 μm	0.19	0.23	0.67	1.00	0.66	0.66	0.84	0.47	0.26
Chromium, <2 μm	0.10	0.08	0.42	0.66	1.00	0.44	0.80	0.35	0.26
Copper, <2 μm	0.25	0.37	0.46	0.66	0.44	1.00	0.63	0.35	0.41
Nickel, <2 μm	0.10	0.11	0.47	0.84	0.80	0.63	1.00	0.32	0.35
Antimony, <2 μm	0.09	0.20	0.54	0.47	0.35	0.35	0.32	1.00	0.09
Zinc, <2 μm	0.04	0.12	0.10	0.26	0.26	0.41	0.35	0.09	1.00

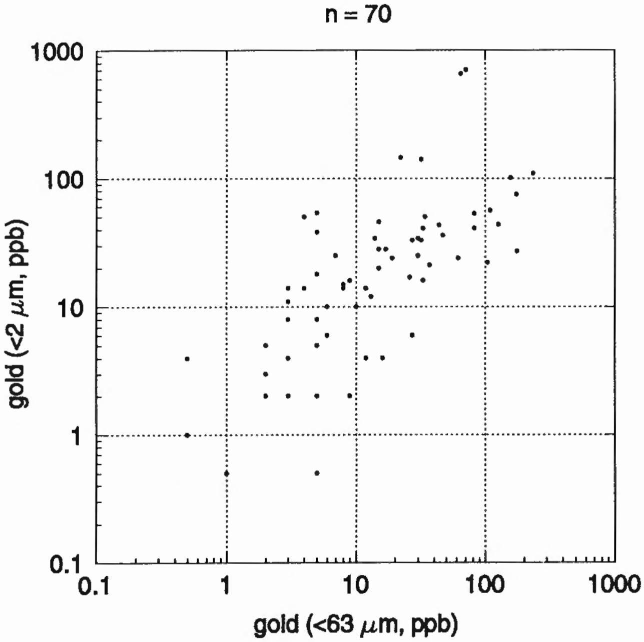
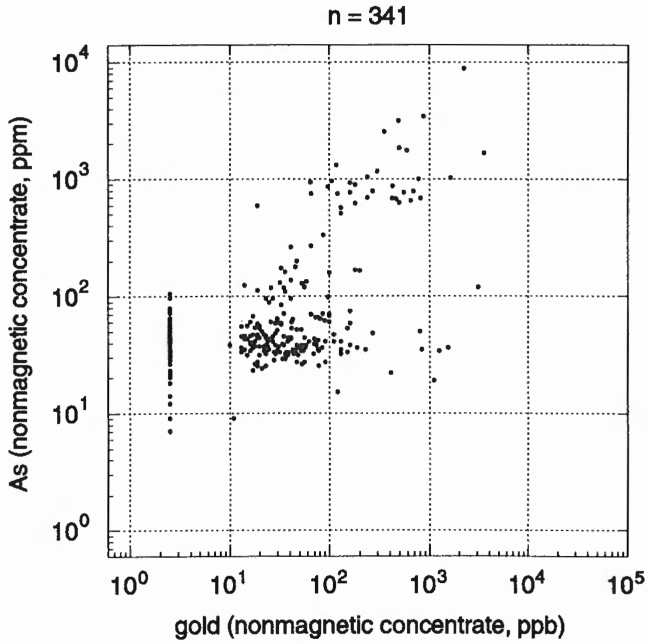


Figure 82. Comparison of gold in <63 µm and <2 µm fraction.

a



b

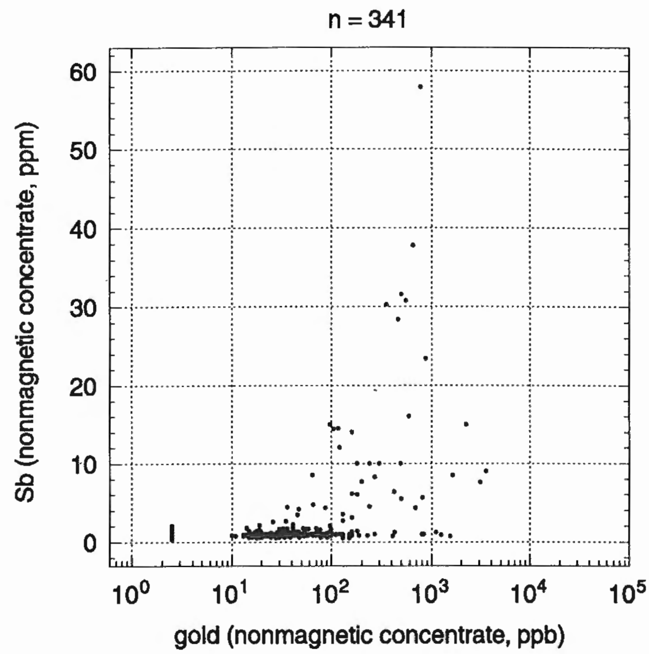
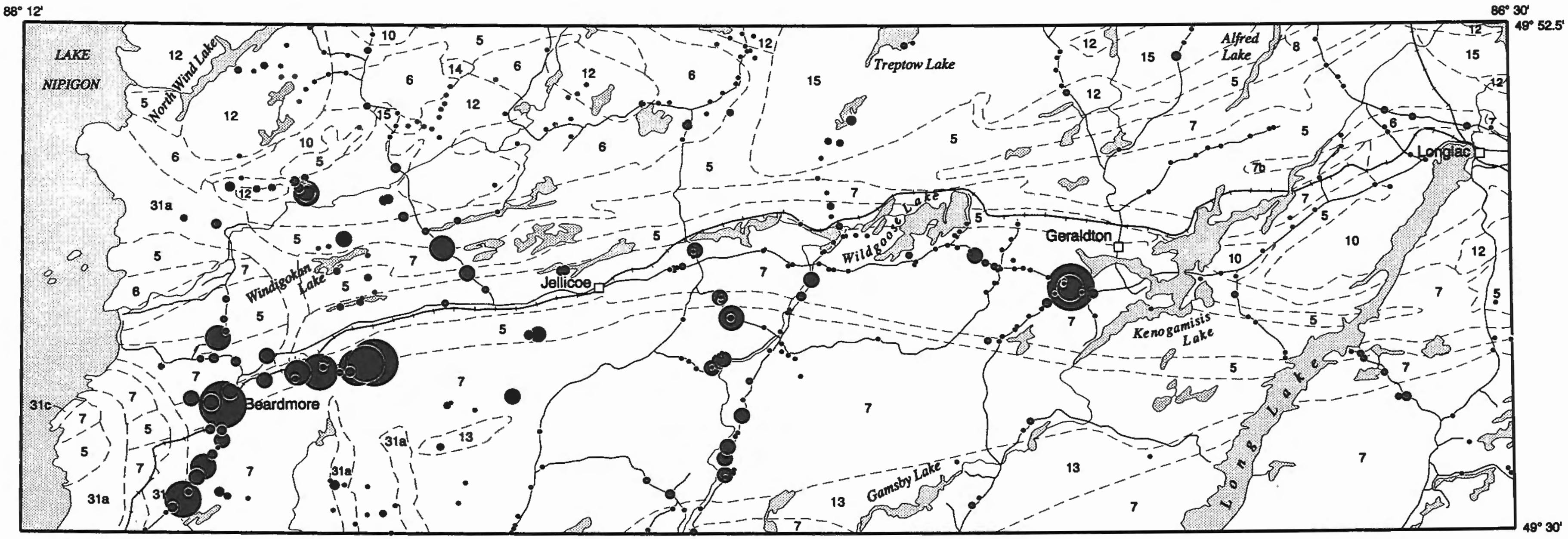


Figure 83. Elements associated with gold: scatterplot of **a**) arsenic and **b**) antimony against gold concentration in nonmagnetic heavy mineral concentrates from unoxidized drill hole till samples.



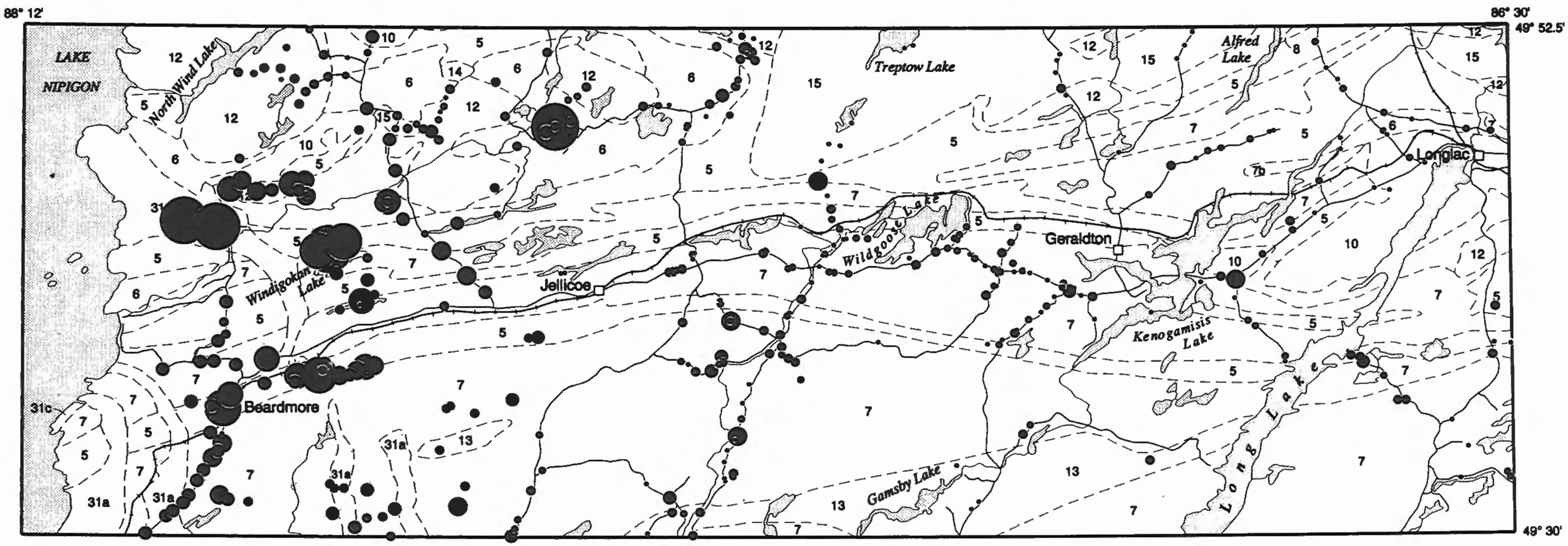
As (ppm)

Nitric/aqua regia preparation and ICP/AES analysis of the <63 μm fraction of till

Min	Max	n	%<
3	3	254	66.3
3	5	59	81.7
5	10	30	89.6
10	20	25	96.1
20	35	8	98.2
35	50	4	99.2
50	85	3	100

Kilometres 10 0 10000 m

Figure 84. Arsenic in <63 μm fraction of surface till samples. For bedrock geology see Figure 3.



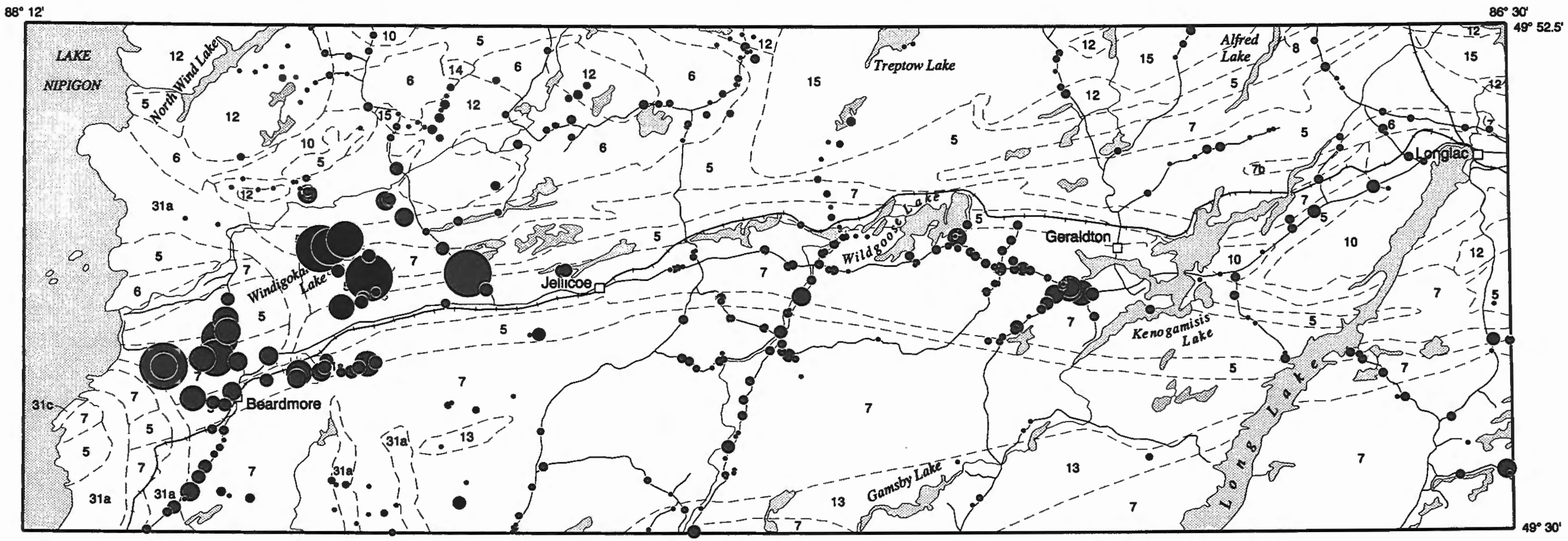
Cu (ppm)

Nitric/aqua regia preparation and ICP/AES analysis of the <63 μm fraction of till

Kilometres 10 0 10000 m

Min	Max	n	%<
1	8	103	26.9
8	12	89	50.1
12	23	97	75.5
23	48	56	90.1
48	78	21	95.6
78	118	9	97.9
118	162	4	99
162	252	4	100

Figure 85. Copper in <63 μm fraction of surface till samples. For bedrock geology see Figure 3.



Sb (ppm)

INAA analysis of nonmagnetic heavy mineral fraction of till

Min	Max	n	%<
0.1	.4	125	32.6
.4	.5	95	57.4
.5	.7	90	80.9
.7	1.1	38	90.9
1.1	1.6	16	95
1.6	2.2	11	97.9
2.2	2.7	4	99
2.7	6.9	4	100

Kilometres 10 0 10000 m

Figure 86. Antimony in nonmagnetic heavy mineral concentrates from surface till samples. For bedrock geology see Figure 3.

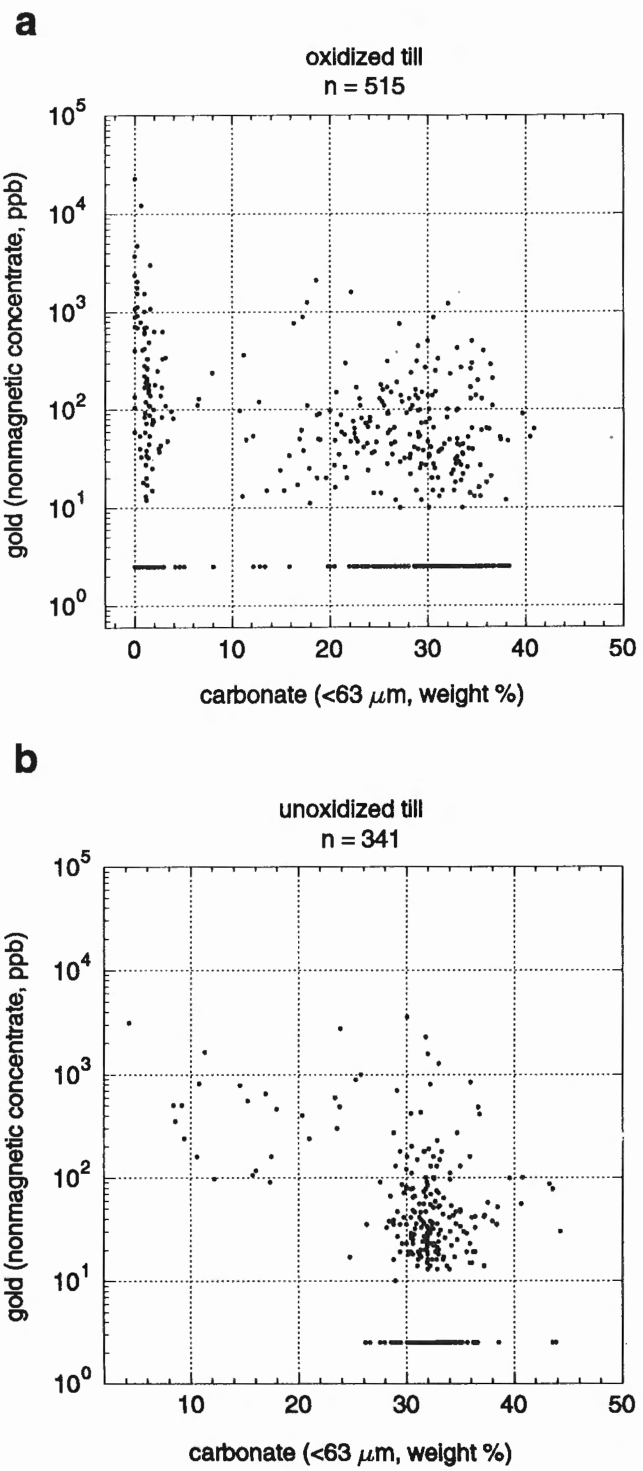


Figure 87. Comparison of gold concentration and carbonate content; gold in nonmagnetic heavy mineral concentrate, Chittick analysis for total carbonate in <63 μm fraction.

Hence, for most elements, patterns apparent in the clay data are reliably reproduced by the <63 μm fraction. The additional expense and quality control problems associated with the clay fraction are therefore commonly not justified. For some elements by the methods used, including antimony, bismuth, gallium, and thallium, the clay produced geologically meaningful patterns which were not indicated by the <63 μm fraction. The reverse is true for beryllium, for which a more meaningful pattern was produced by the <63 μm fraction. In general, trace elements consistently exhibit higher to much higher concentrations in the clay fraction for both oxidized and unoxidized samples (Fig. 89). For arsenic and copper, however, the two fractions give similar concentrations in unoxidized till (Thorleifson and Kristjansson, 1990).

Diabase outcrops in the area north of Beardmore appear to be the source for elevated concentrations of cobalt and nickel in oxidized nonmagnetic heavy mineral concentrates and the fine fractions, copper and vanadium in the fine fractions, and aluminum, magnesium, nickel, vanadium, and zinc in the magnetic heavy mineral concentrate.

Nickel data for unoxidized and oxidized till samples (Fig. 90) indicate: 1) similar concentrations for unoxidized and oxidized till, hence a probable lack of sulphide-hosted nickel in the unoxidized drill hole samples, 2) slight enrichment in the oxidized <63 μm fractions, relative to unoxidized <63 μm data, 3) much higher values in the oxidized <2 μm fractions, compared to unoxidized <2 μm or <63 μm fractions, hence implying the former existence of sulphide-hosted nickel in surface samples.

As an example of base metal concentrations, nickel in the <2 μm fraction (Fig. 91) only shows strong anomalies in noncalcareous oxidized till. Calcareous samples do include outliers which may represent significant anomalies diluted by exotic material. In drill hole samples, noncalcareous samples are consistently enriched in nickel.

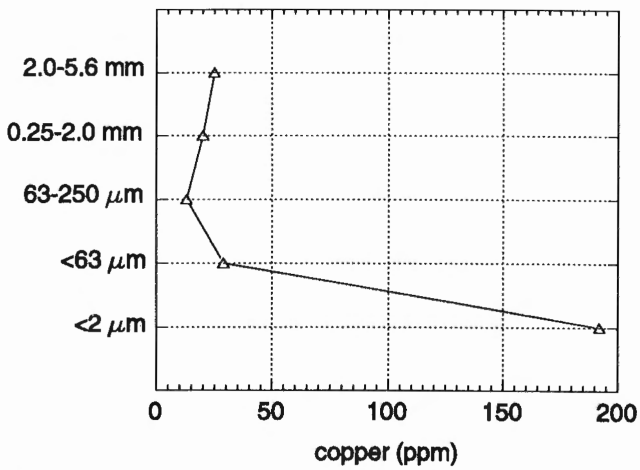


Figure 88. Relationship of copper concentration to grain size.

Background counts of a few tens of scheelite grains in 10 g of -10 mesh nonmagnetic methylene iodide heavy minerals correspond to a few tens of parts per million tungsten in the same fraction. Counts of 13 000 and 19 000 grains from till samples collected south of Jellicoe resulted in analyses of about 4000 and 5000 ppm W, respectively. The <2 µm and <63 µm fractions from these samples failed to detect this tungsten anomaly.

Comparison of partial (nitric/aqua regia) and total (perchloric-nitric-hydrofluoric) extractions from grain size fractions ranging from clay to coarse sand indicates a relationship apparently dependent on mineralogy of the material (Fig. 92). Total extraction yields much higher values for aluminum, for example, except in the case of clay fraction samples (>3% partial Al), which approach a 1:1 relationship. As another example, the majority of samples show no difference in magnesium concentration, but samples derived from diabase (cluster of 1% partial and high total) contain a significant magnesium host which appears not to be attacked by a partial extraction. Copper and chromium show no difference between partial and total methods for nearly all samples. In summary, higher concentrations were obtained after a total leach for Al, Ba, K, Na, Sr, Ti, and V, whereas other elements showed no significant difference between partial and total (Thorleifson and Kristjansson, 1990).

Other elements

Rare-earth elements in oxidized heavy mineral concentrates show patterns of elevated values south of Wildgoose Lake (Thorleifson and Kristjansson, 1990).

Some elements, such as potassium and barium in the fine fractions, are at their highest concentrations over the Quetico metasediments, south of the greenstone belt (Fig. 93).

Geochemical trends in thick till

Drill hole logs were plotted with data for concentration of locally derived debris and data for arsenic and gold in the nonmagnetic heavy mineral concentrate, as examples of geochemical data (Appendix 2). The concentration of locally derived debris shown in the appendix was obtained by deducting six-tenths of the weight per cent carbonate from the weight per cent metasedimentary and metavolcanic rocks, as discussed above. Geochemical trends in thick till may be classified as four groups.

In holes A, C, F, G, H, L, P, and S (Appendix 2), there is no geochemical manifestation of mineralization, even at the bedrock surface.

In holes J, M, and Q, carbonate-dominated till extends to the bedrock surface, but elevated trace element levels are slightly apparent in the few samples closest to bedrock.

At hole K, carbonate rich sediments below 6 m contain much more local debris than most other very calcareous sediments in the region. Strong arsenic and gold values

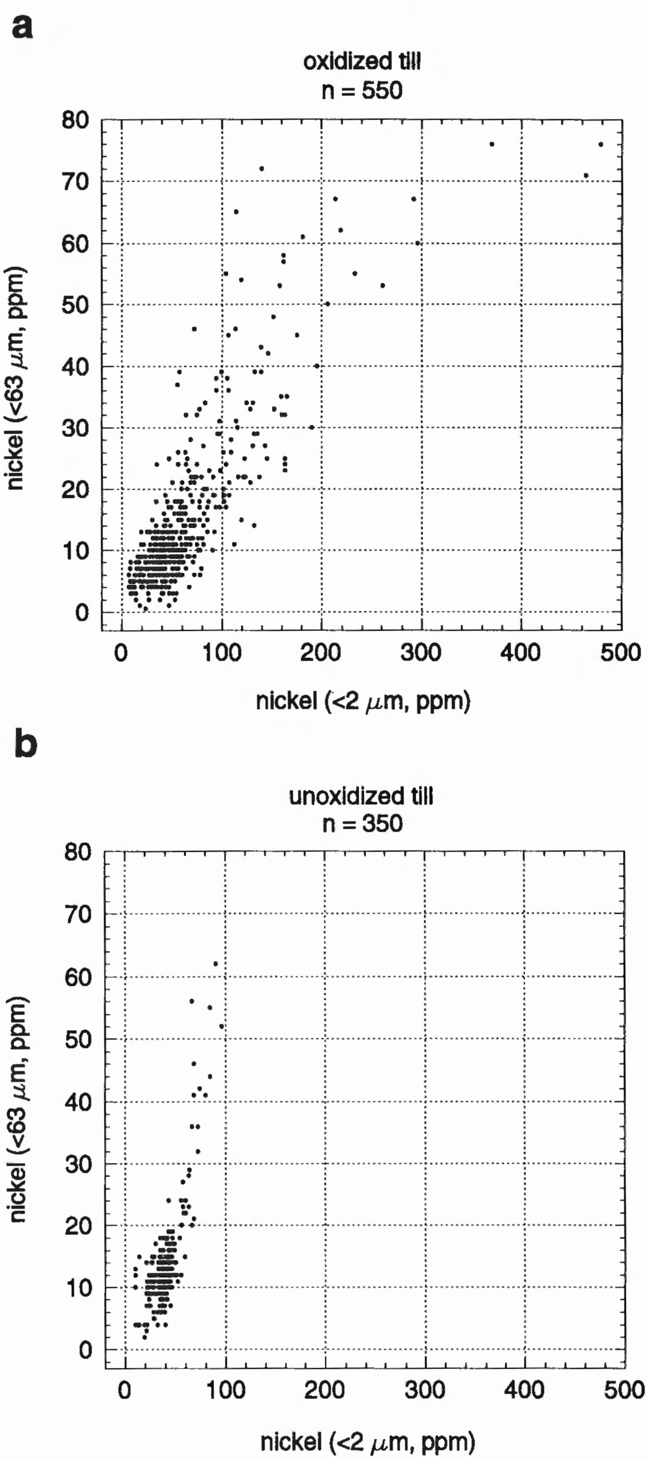


Figure 89. Comparison of nickel in <63 µm and <2 µm fractions; **a**) oxidized surface till samples, **b**) unoxidized drill hole till samples.

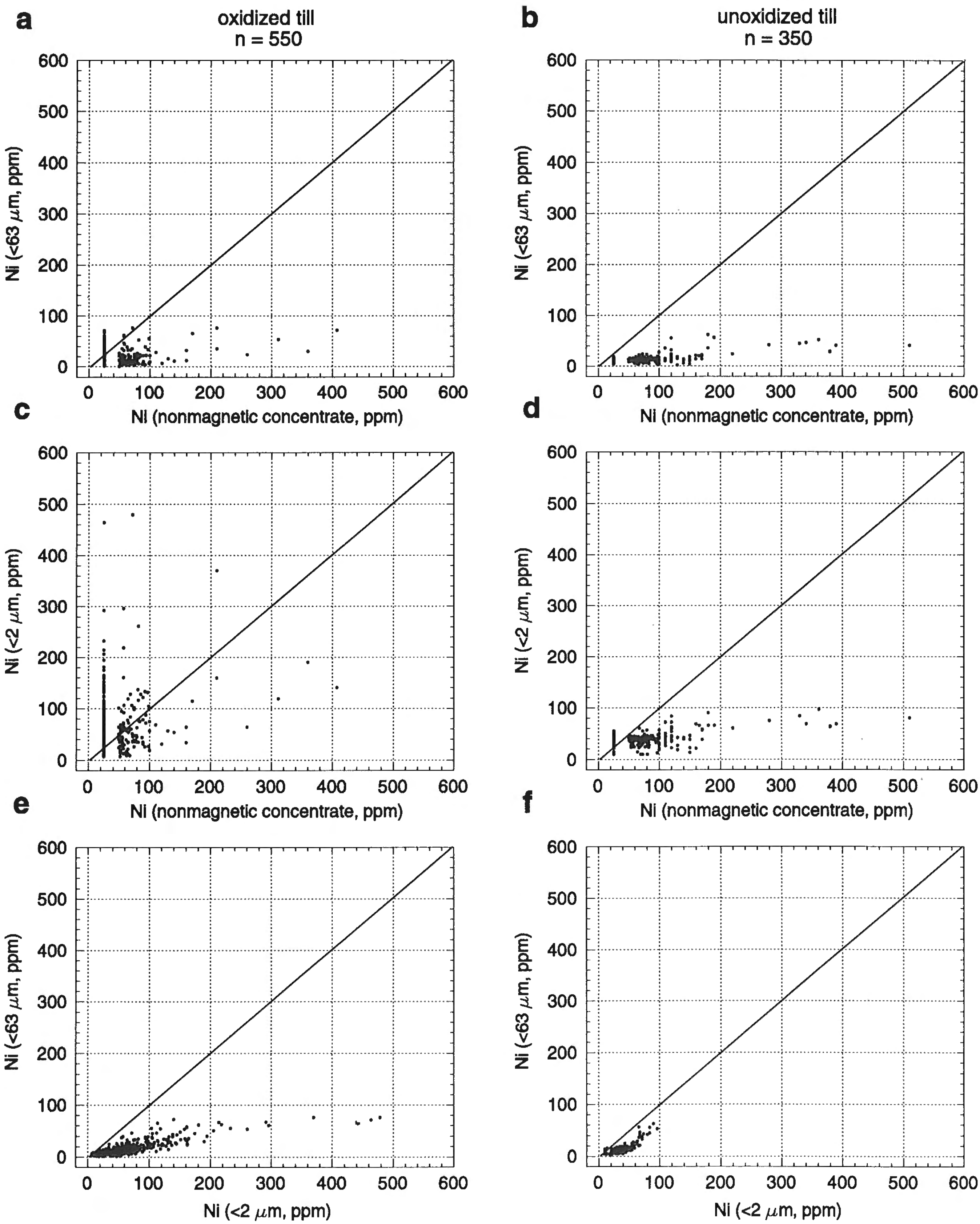


Figure 90. Comparison of nickel in oxidized and unoxidized till.

correlate with this local debris mixed into carbonate-rich sediment. The sample which yielded the highest arsenic and gold values contains 16% carbonate in the pebbles.

The fourth group of drill holes includes those with a lower till unit consisting entirely of, or dominated by, material derived from within the belt. This material yielded sulphide-rich nonmagnetic heavy mineral concentrates with very high values for mineralization-related elements. Geochemical data from hole D indicate that elevated arsenic values are present where local debris is mixed with calcareous sediment between 30 and 40 m as well as in 8 m of local debris over bedrock. High arsenic values in this case are not accompanied by elevated gold. At hole E, a similar order of magnitude increase in arsenic concentration is accompanied by elevated gold values. Provenance and geochemical data from hole I indicate locally derived debris rich in arsenic and gold separated from the bedrock surface by 2 m of sand. No zone of elevated local debris content mixed with very calcareous sediments similar to the trend in hole D was observed at holes E and I. At hole N, mineralized debris is mixed with 7 m of dominantly exotic till overlying bedrock. At hole O, arsenic reaches a value two orders of magnitude above the background for unoxidized till 9 m above bedrock. Gold data in this hole includes two anomalies, 5 m and 9 m above bedrock. In hole R, a gradual rise in local debris concentration is present, unlike abrupt transitions elsewhere. Elevated arsenic values were obtained from calcareous till at this site.

Drift prospecting

On the basis of information obtained for this regional survey, the following recommendations may be made regarding the use of drift prospecting in mineral exploration programs in the area:

1. Drift prospecting in areas of thin, locally derived till: In areas of thin locally derived till, such as the Beardmore area, surface till sampling, as well as other methods such as vegetation and soil sampling, are likely to produce useful data. Low cost methods such as panning in the field (Hirvas and Nenonen, 1990) would be appropriate in this area.

2. Drift prospecting in areas of thin exotic till: Mixing occurs between calcareous exotic debris and local greenstone belt debris. Hence the rejection of till due simply to a calcareous matrix is not justified. Degree of local derivation may be assessed by inspection of the pebble fraction of till. The potential usefulness of till does, however, diminish rapidly with increasing carbonate content. Hence surface till sampling may, in many cases, be an inappropriate method in large areas where exotic drift lacking an admixed local component blankets the surface.

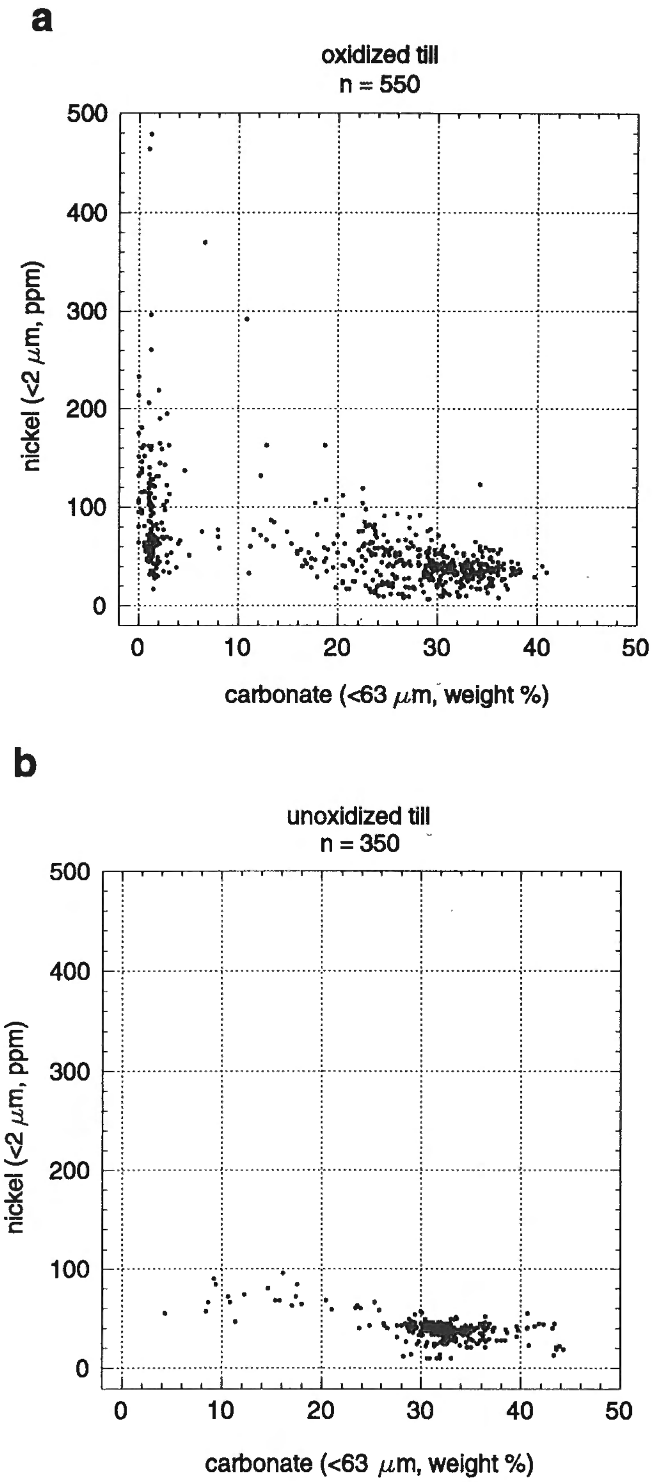


Figure 91. Comparison of nickel concentration and carbonate content; **a**) oxidized surface till samples, **b**) unoxidized drill hole till samples.

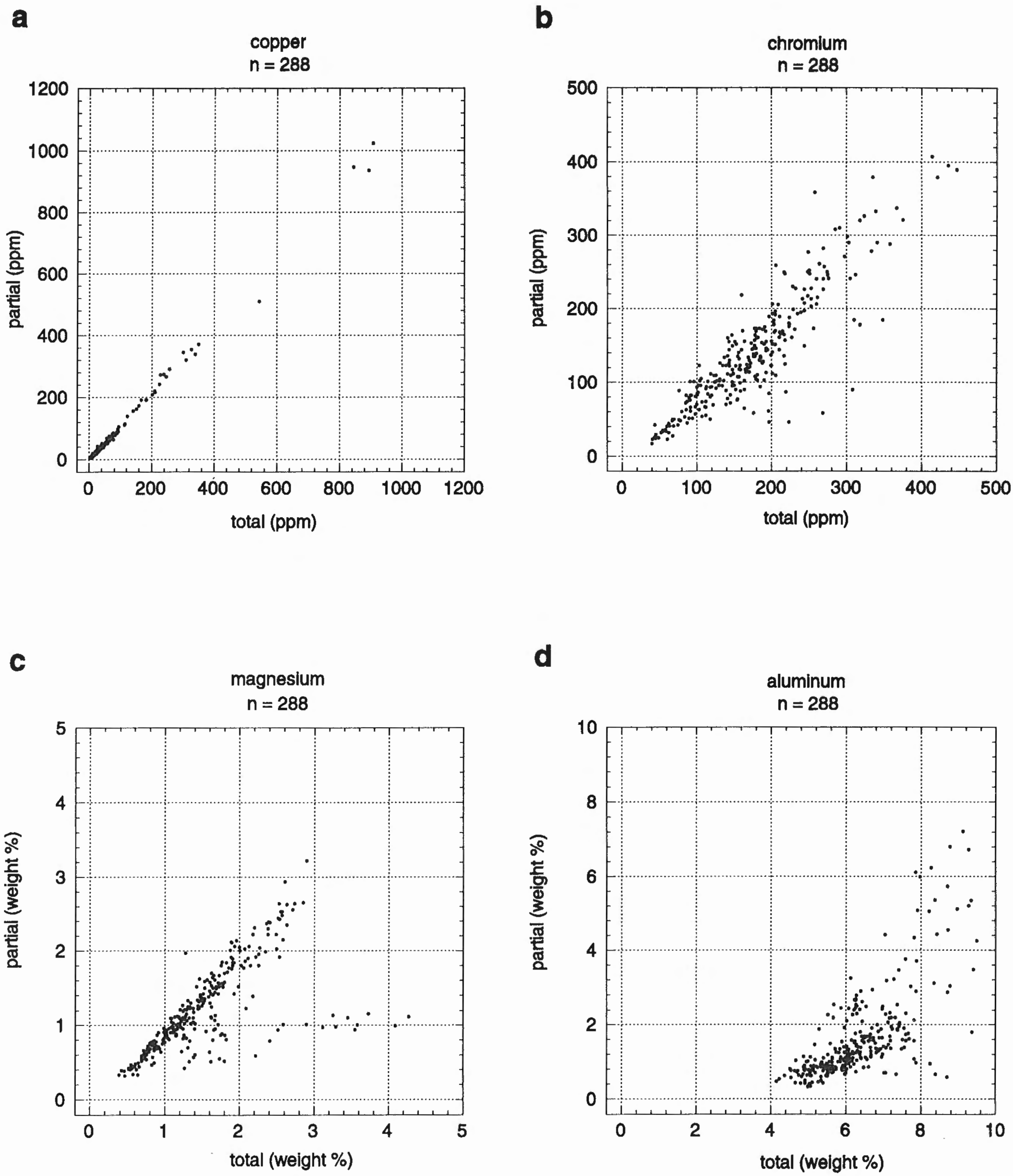
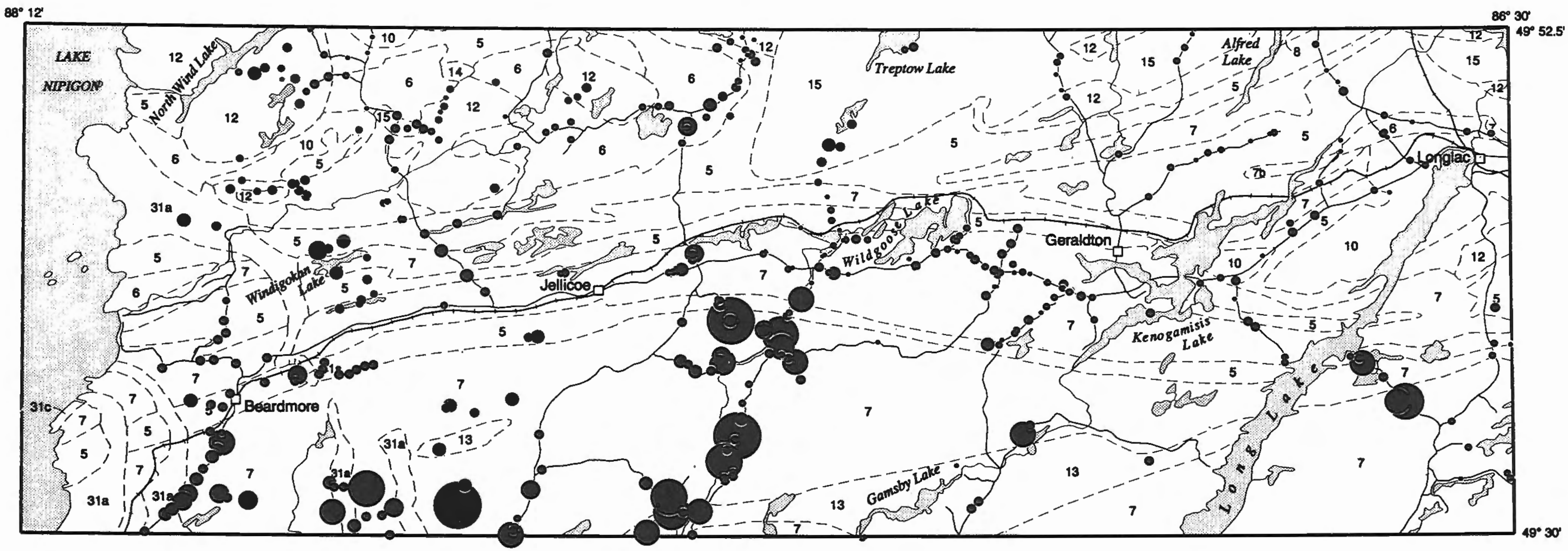


Figure 92. Comparison of partial (nitric/aqua regia) and total (perchloric-nitric-hydrofluoric) extractions for grain size fractions ranging from clay to coarse sand.



Ba (ppm)

Nitric/aqua regia preparation and ICP/AES analysis of the <63 μm fraction of till

Kilometres 10 0 10000 m

Min	Max	n	%<
10	15	59	15.4
15	20	119	46.5
20	40	138	82.5
40	50	32	90.9
50	60	13	94.3
60	70	12	97.4
70	100	6	99
100	240	4	100

Figure 93. Barium in <63 μm fraction of surface till samples. For bedrock geology see Figure 3.

3. Drift prospecting in areas of thick till: Surface till sampling is an inappropriate method in areas where thick drift is known or implied by lack of bedrock outcrop. Drift prospecting in these areas, if used, should be restricted to overburden drilling. The present study indicates that, in general, locally derived till will only be intersected at about one third of all drill holes. Useful data might be obtained at a few additional sites from carbonate-rich till into which local debris has been mixed. Most anomalies will be encountered within 10 m of the bedrock surface. Seismic reflection surveys were marginally successful in thick till due to uncertain identification of the bedrock surface, but useful information was obtained.

4. Choice of analytical fraction: Till collected at about 0.8 m to as much as 7 m depth from over 500 well-drained sites lacks a preserved sulphide component and is hence oxidized. The principal geochemical media for these samples are the fine grained fractions. The <63 µm fraction is readily obtainable and provides useful data for precious and base metals. The <2 µm fraction, where most of the metals in fine grained sediments reside, is more sensitive for detecting base metals and will detect patterns missed by the <63 µm fraction. The clay fraction is, however, more expensive to recover, its recovery is more prone to error, and it is not practical to recover a quantity sufficient for the analysis of precious metals. Furthermore, there has been no demonstration that the clay fraction is appropriate for precious metal analysis. Nonmagnetic heavy mineral concentrates from oxidized samples, including surface till samples and sand from eskers, are not an appropriate medium for base metal exploration due to their lack of a sulphide component. This fraction is appropriate, however, for the analysis of resistate-hosted elements such as gold in native gold and tungsten in scheelite, provided a large sample is collected.

   The principal geochemical medium for unoxidized till is the sulphide-bearing nonmagnetic heavy mineral concentrate obtained from a sample weighing several kilograms. All unoxidized concentrates, which were recovered from grey samples below an abrupt brown-over-grey colour change at a few metres depth in drill holes, contain unaltered sulphides. The fine grained fractions from these samples may be analyzed in order to test for material not detected by the concentrate, such as extremely fine gold.

5. Distance and direction of glacial transport: Although dispersal trains were not mapped by detailed sampling during this study, inspection of geochemical maps (Thorleifson and Kristjansson, 1990) indicates that elevated elemental concentrations attributable to mineralization are only detectable within a few hundred metres to a few kilometres from the probable source. The apparent contradiction with long distance transport of Paleozoic carbonate implies that mineralized debris transported by rapidly flowing ice is too dilute to be detectable beyond a few kilometres from source.

   Because surface features throughout the area indicate that southwestward ice flow was strongly erosive, it is likely that all detectable mineralized debris has been dispersed in this direction. It is possible, however, that till deep in drill holes may have been transported by an older ice flow, possibly more westward or even southeastward.

6. Exploration for kimberlite: Large drift samples, mineral grain selection by experienced technicians, and electron microprobe analysis of all selected grains are required for successful drift prospecting for kimberlite. The 12 kg till samples used for a heavy mineral concentrate in this study were marginally adequate for any useful information to be obtained.

Environmental geochemistry

Geochemical data compiled by Thorleifson and Kristjansson (1990) are potentially of use: 1) in the assessment of background elemental concentrations against which future measurements may be compared, and 2) in the evaluation of the regional concentrations of possibly deleterious elements.

Engineering geology

Terrain conditions

The significance to engineering and planning of the terrain units found within the study area was discussed in the reports of the Northern Ontario Engineering Geology Terrain Study (NOEGTS) (Mollard and Mollard, 1981; Gartner, 1979a, b). Bedrock plateaus, knobs and ridges in the area, according to these authors, have poor sand and gravel or groundwater resource potential, offer excellent foundation conditions but present construction activity with difficulties involving blasting as well as steep, irregular, and complex slopes, and have little potential for waste disposal. Thin sandy till has poor sand and gravel or groundwater resource potential, excellent foundation conditions but fair to good earth moving conditions, and fair to good waste disposal potential. Thick silty till, compared to thin sandy till, has slightly higher groundwater potential, more favourable excavation and grading characteristics, with the exception of handling problems in wet weather, better potential for septic systems, and excellent potential, where thickness is sufficient, for sewage lagoons. Glaciofluvial deposits have fair to excellent sand and gravel potential, with the best aggregate resources in eskers, fair to good groundwater potential, good construction conditions, and only fair potential for waste disposal. Sandy glaciofluvial deposits are less favourable than other glaciofluvial deposits regarding resource potential and construction conditions, but are more favourable than gravelly deposits for septic systems. Glaciolacustrine silt and clay, which is rare in the Beardmore-Geraldton map area, have poor resource potential, poor to fair construction conditions, and poor to fair waste disposal potential, with the exception of good potential for lagoons. Organic terrain should be avoided for human activity due to poor sand and gravel or groundwater potential, very poor to poor construction conditions, and very poor potential for waste disposal. Eolian sand dunes present special characteristics regarding wind erosion, material properties, and slope stability.

The installation of a shaft collar in thick till similar to the deposits near Geraldton was described by Winship and Martin (1989).

Aggregate resources

The planning and development of municipal works and mining operations requires knowledge of, and access to, the aggregate resources of the area. Within areas of glaciofluvial ice contact (unit 4) and subaerial outwash sediments (unit 5), the potential for discovering substantial sand and gravel deposits is high.

In the central and eastern parts of the Beardmore-Geraldton area, gravel deposits exhibit high percentages of Paleozoic sedimentary rocks. The presence of deleterious rock types, such as chert of Paleozoic age, and the potential for silica-alkali reactivity problems relative to the manufacture of concrete products must be considered.

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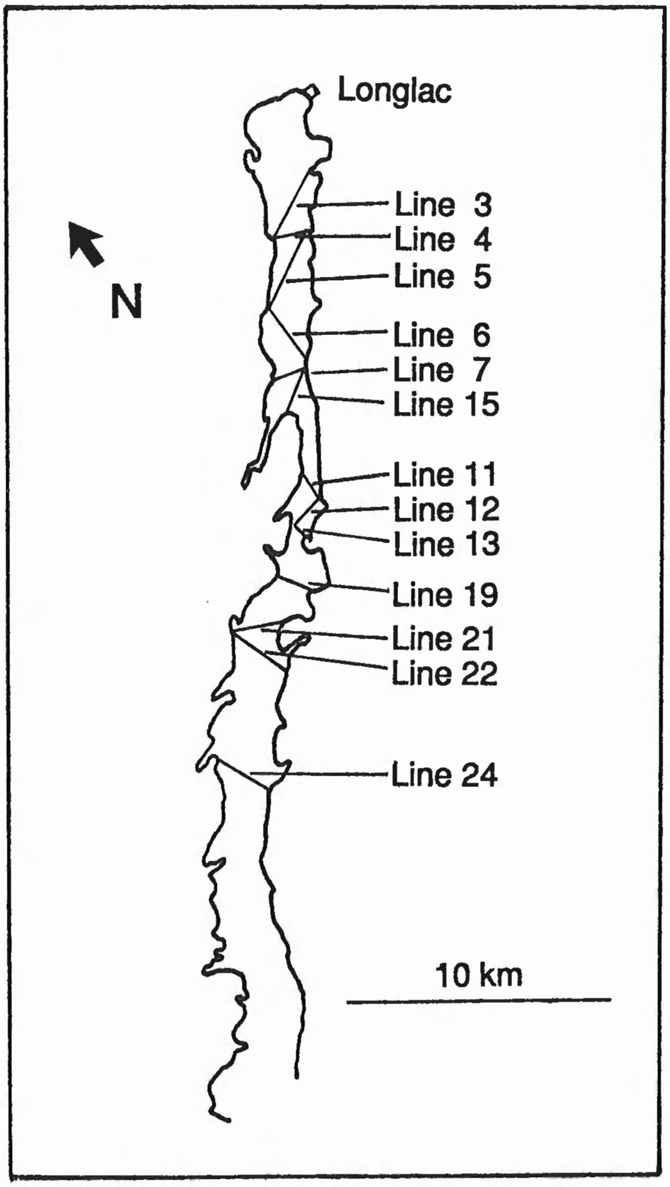
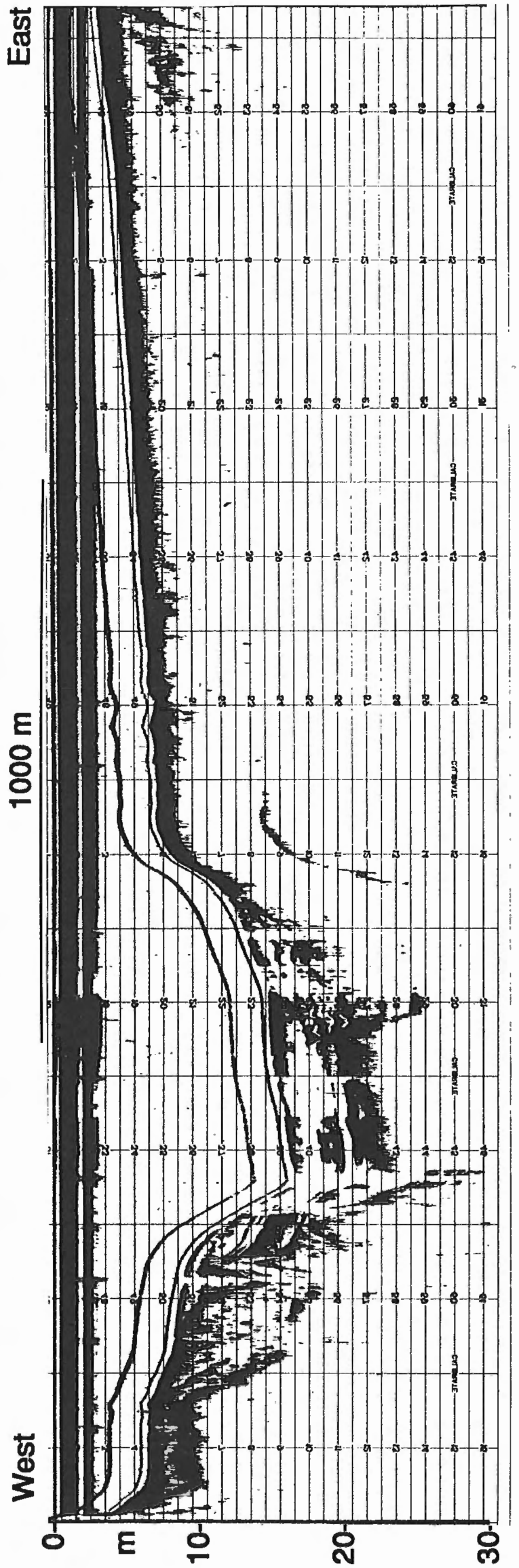
APPENDIX 1
Subbottom profiles from Long Lake and Lake Nipigon

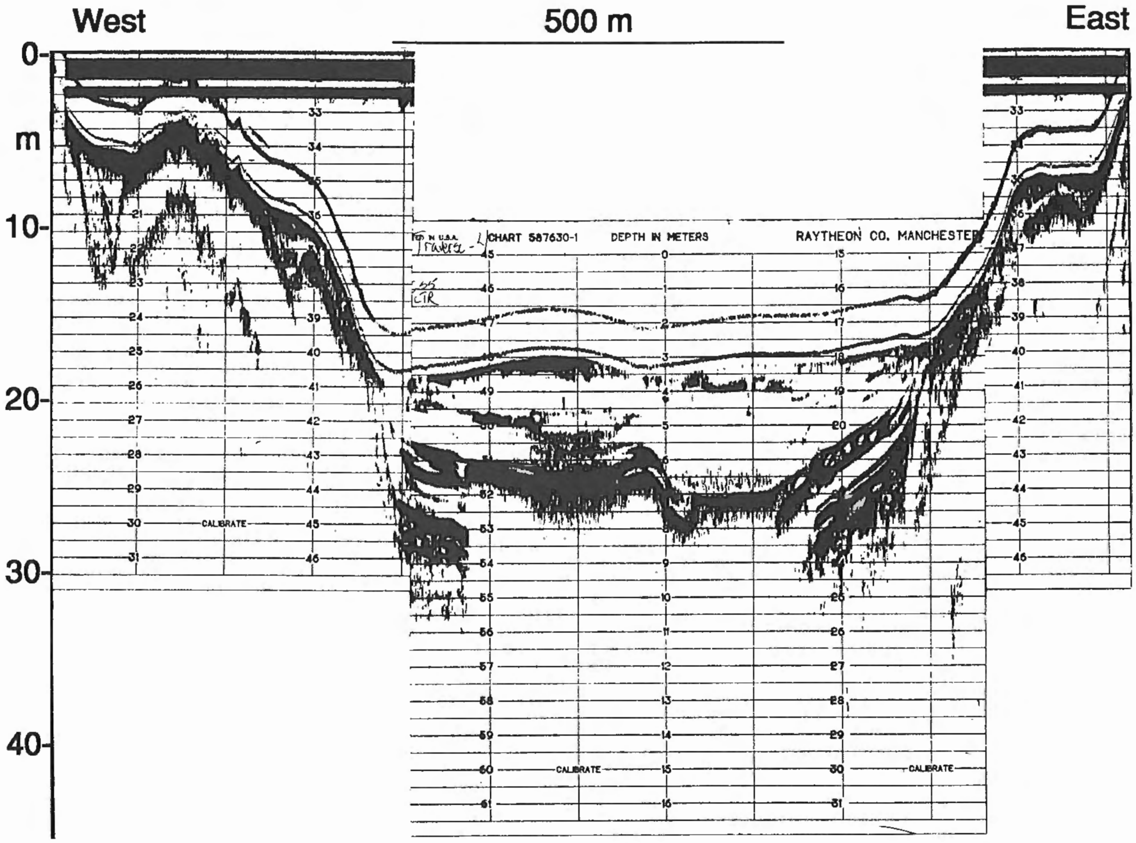


A. Location of subbottom profiles in Long Lake.

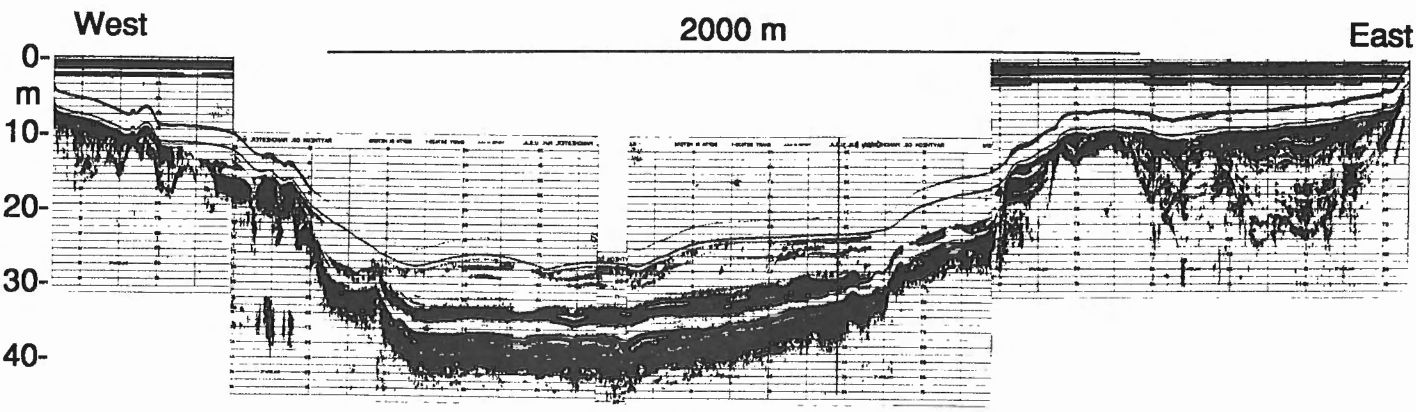


B. Subbottom profile, Long Lake line 3.

APPENDIX 1 (cont'd.)

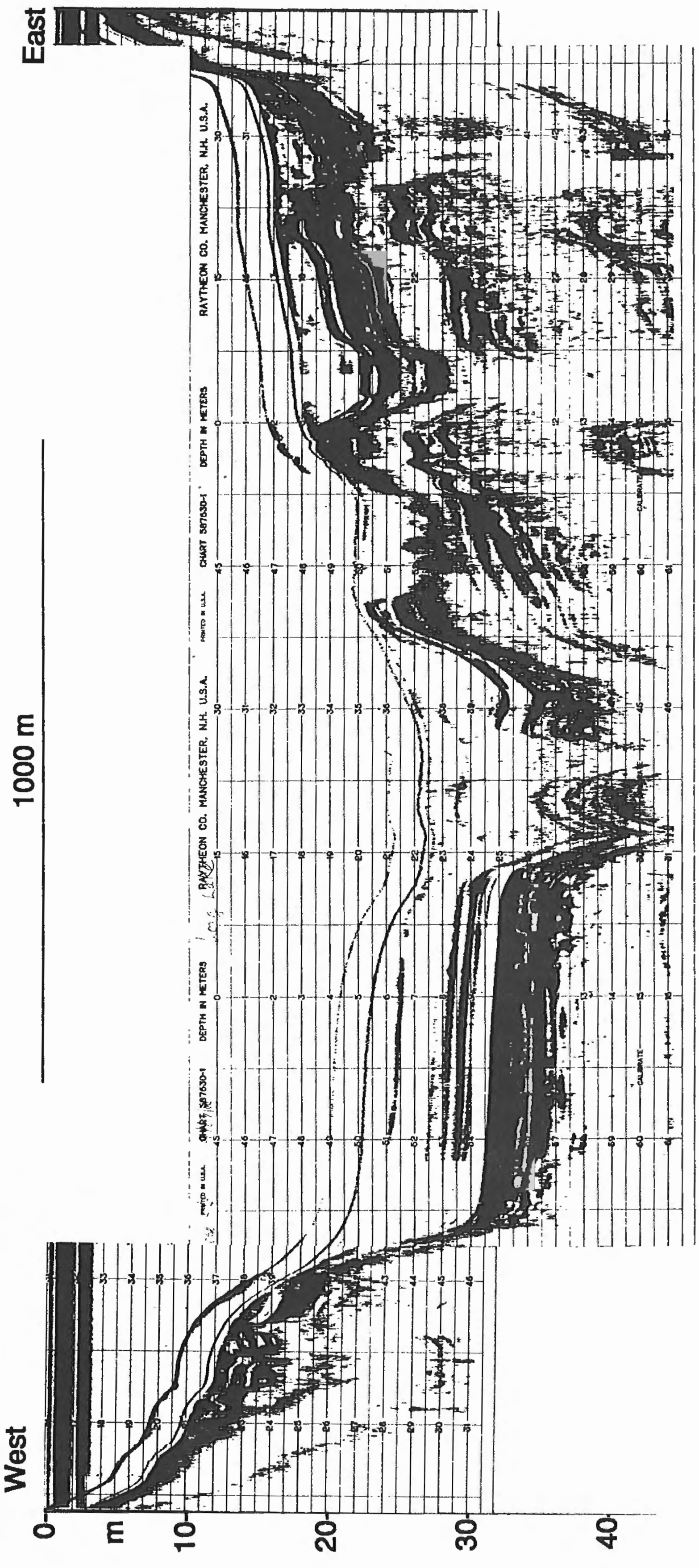


C. Subbottom profile, Long Lake line 4.

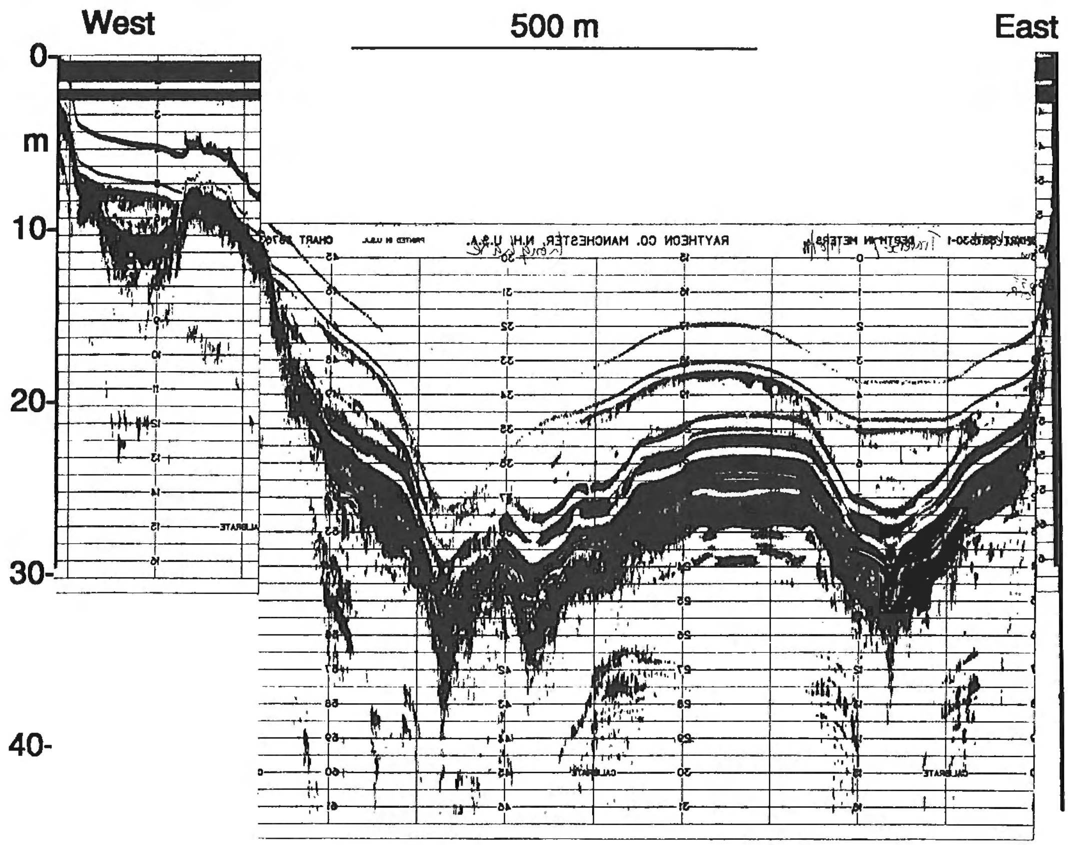


D. Subbottom profile, Long Lake line 5.

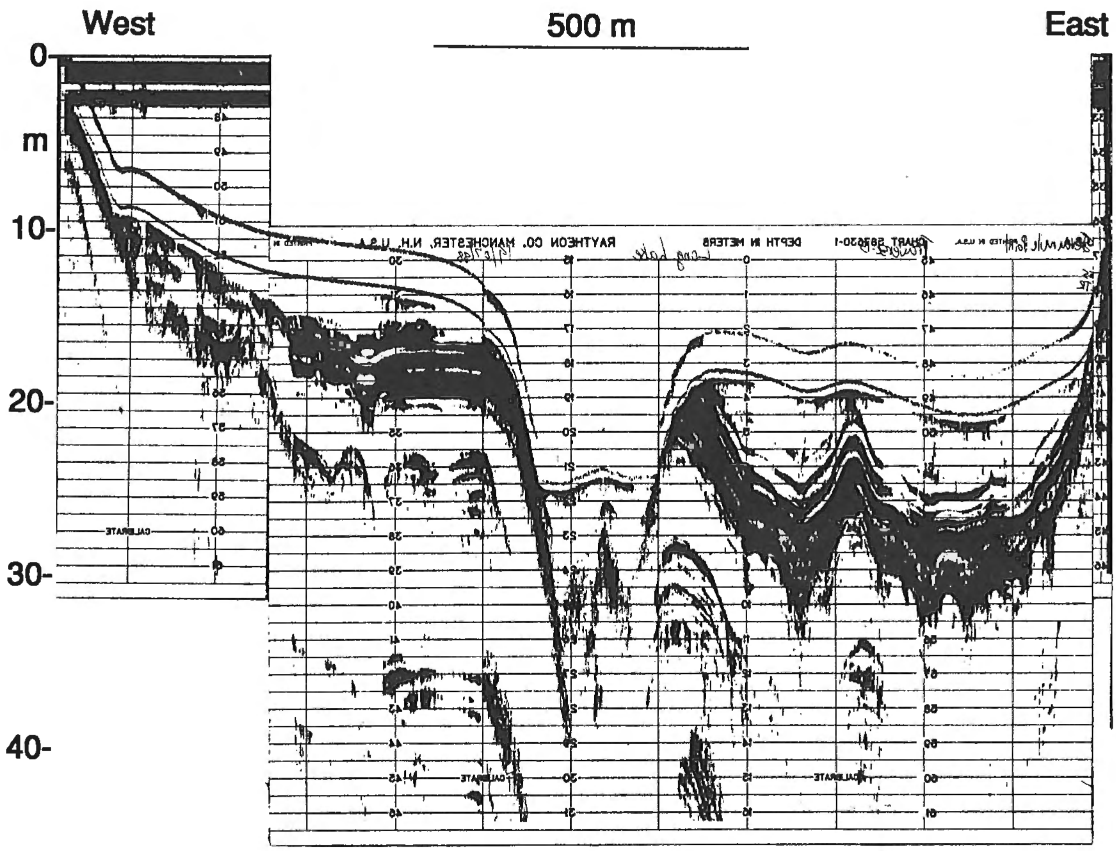
APPENDIX 1 (cont'd.)



E. Subbottom profile, Long Lake line 6.

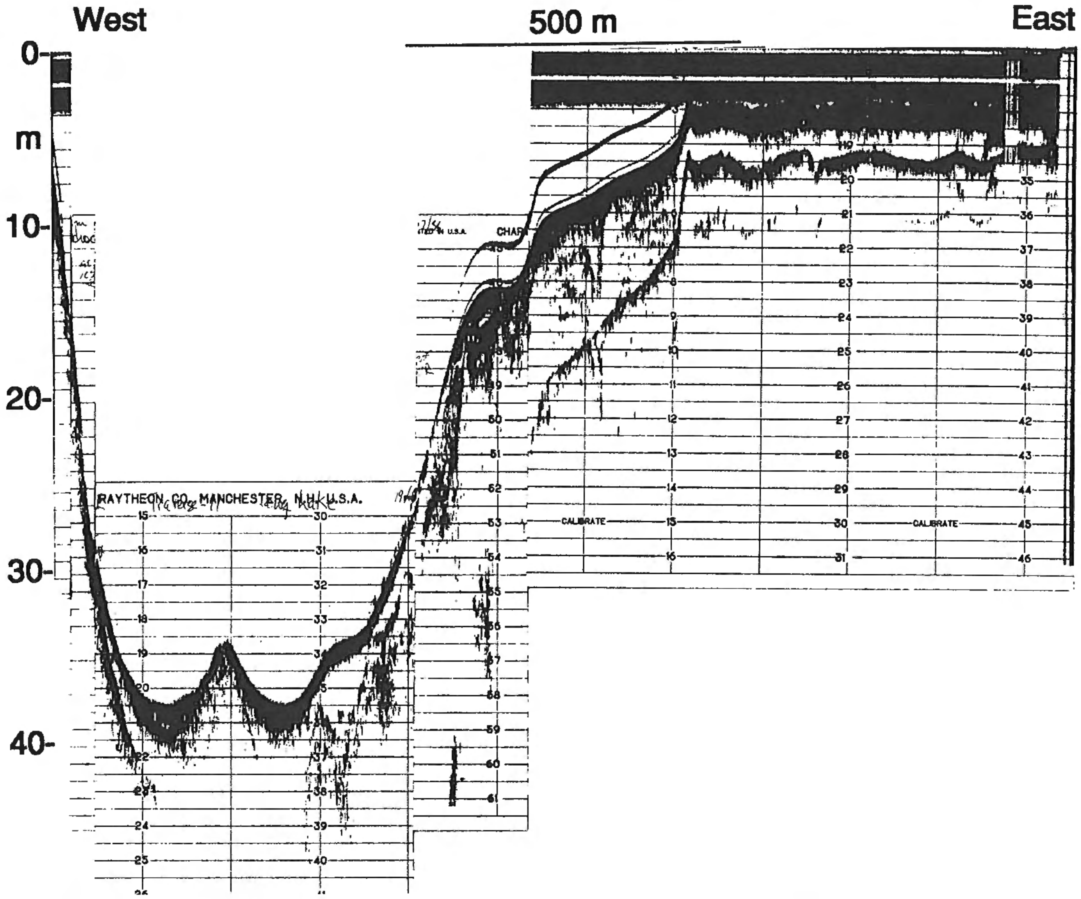


F. Subbottom profile, Long Lake line 7.

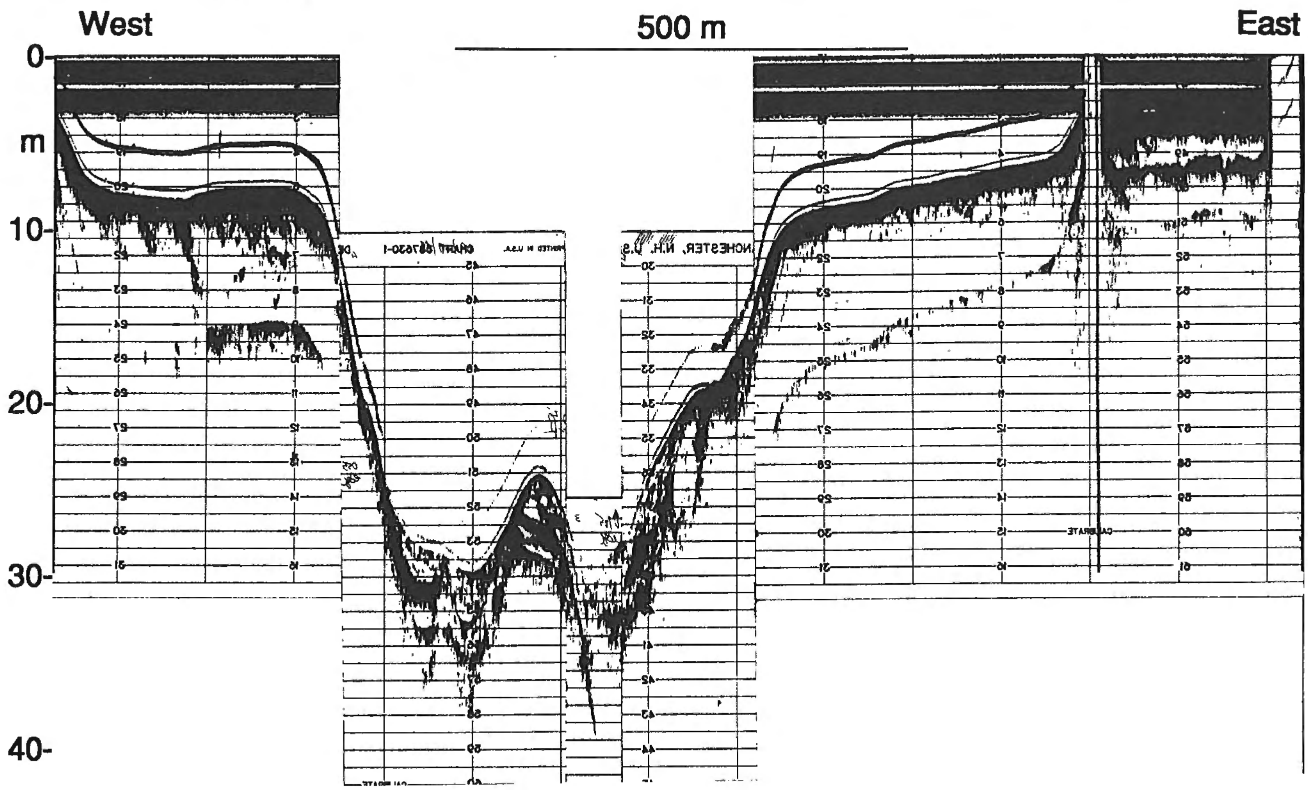


G. Subbottom profile, Long Lake line 15.

APPENDIX 1 (cont'd.)

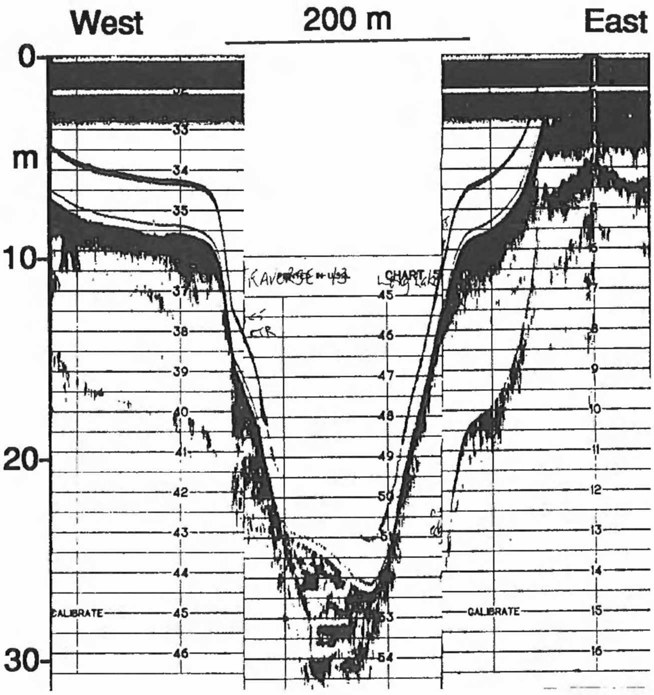


H. Subbottom profile, Long Lake line 11.

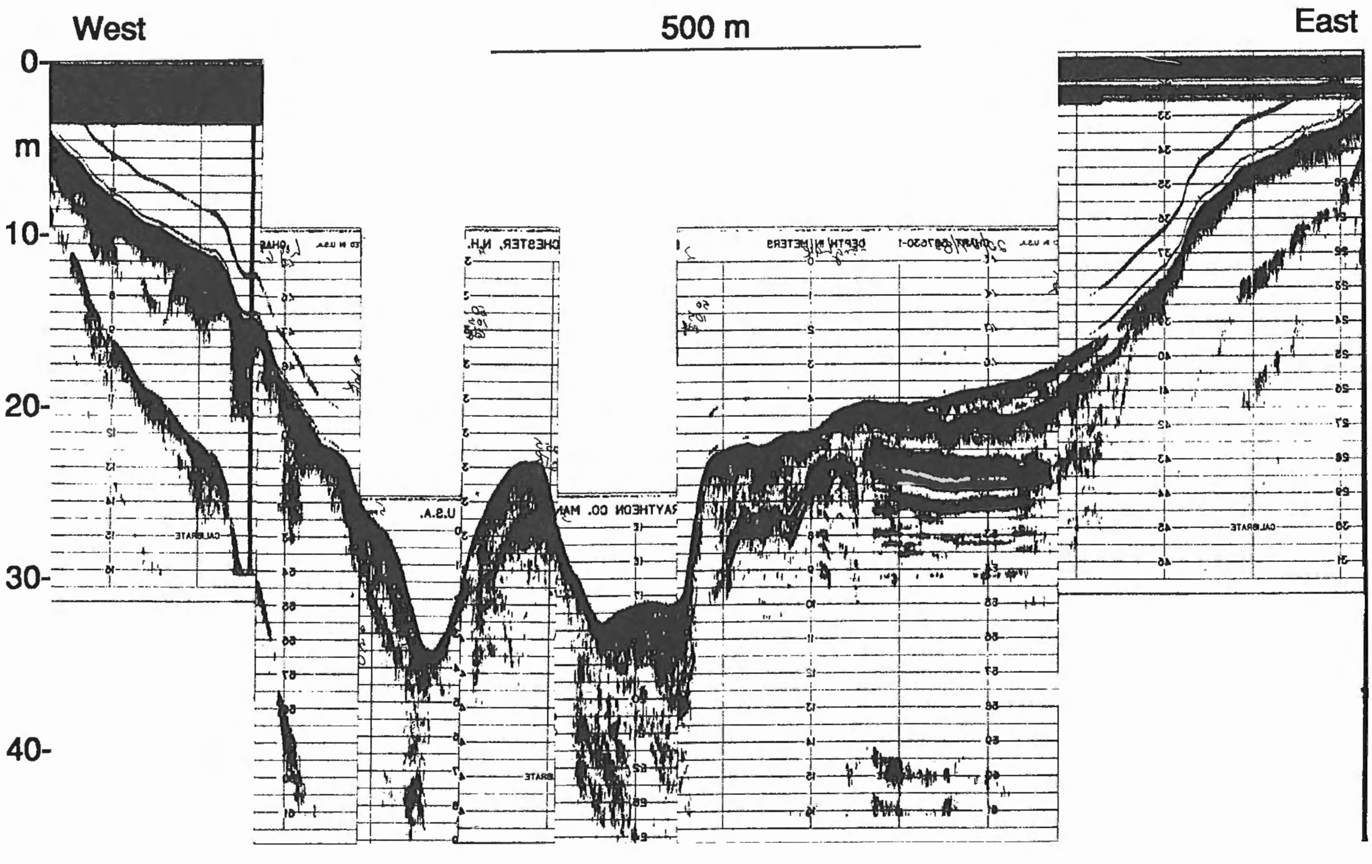


I. Subbottom profile, Long Lake line 12.

APPENDIX 1 (cont'd.)

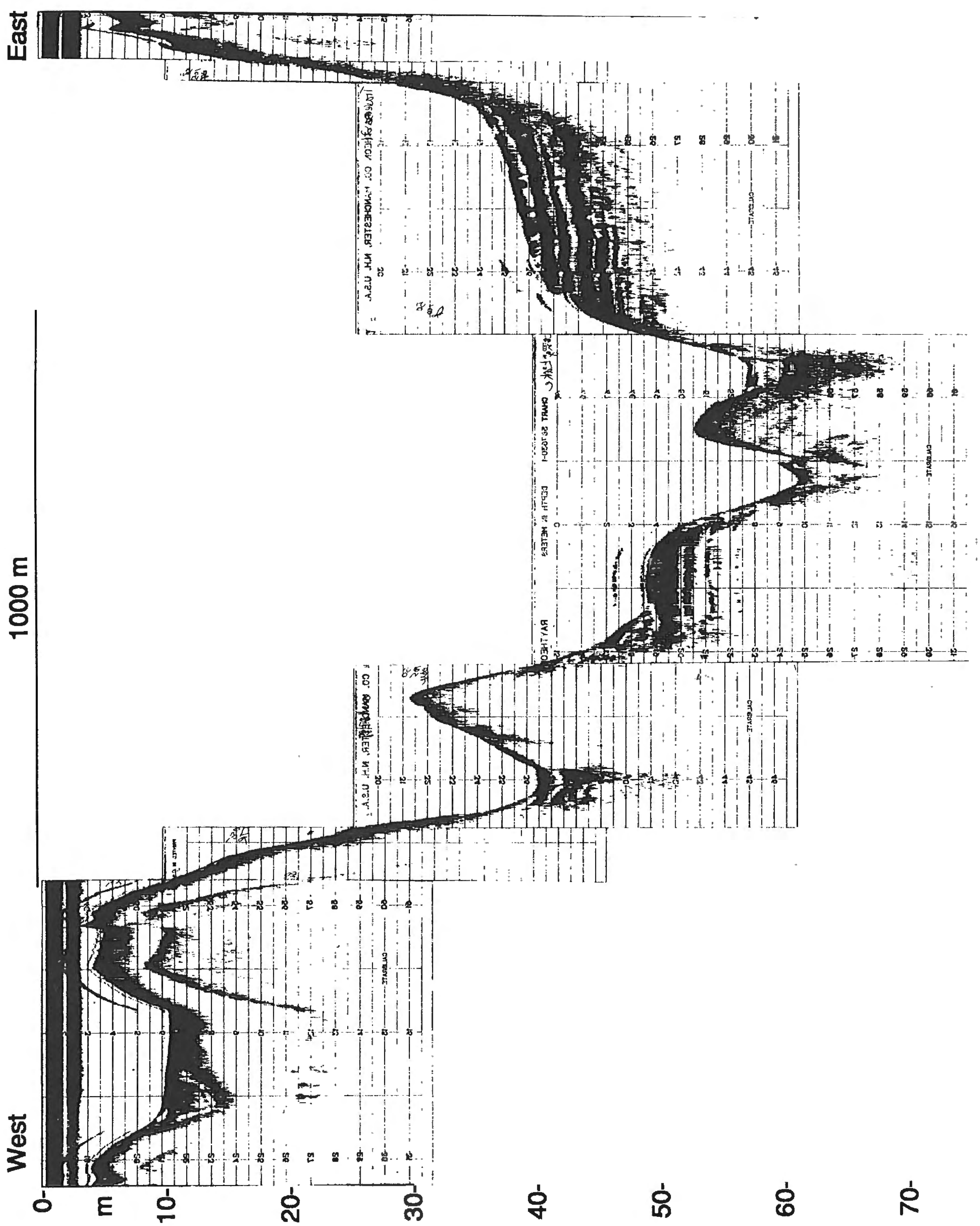


J. Subbottom profile, Long Lake line 13.



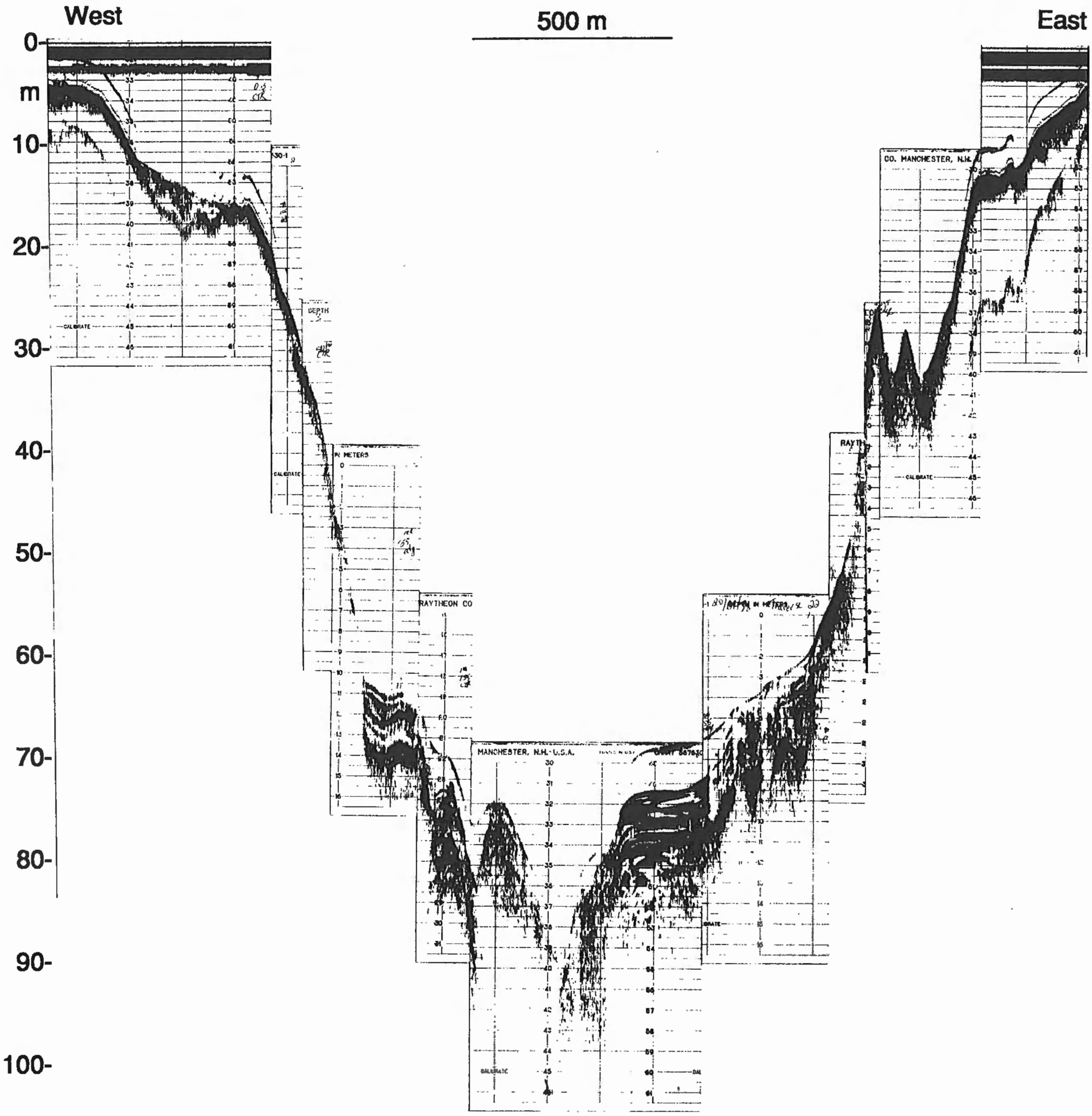
K. Subbottom profile, Long Lake line 19.

APPENDIX 1 (cont'd.)



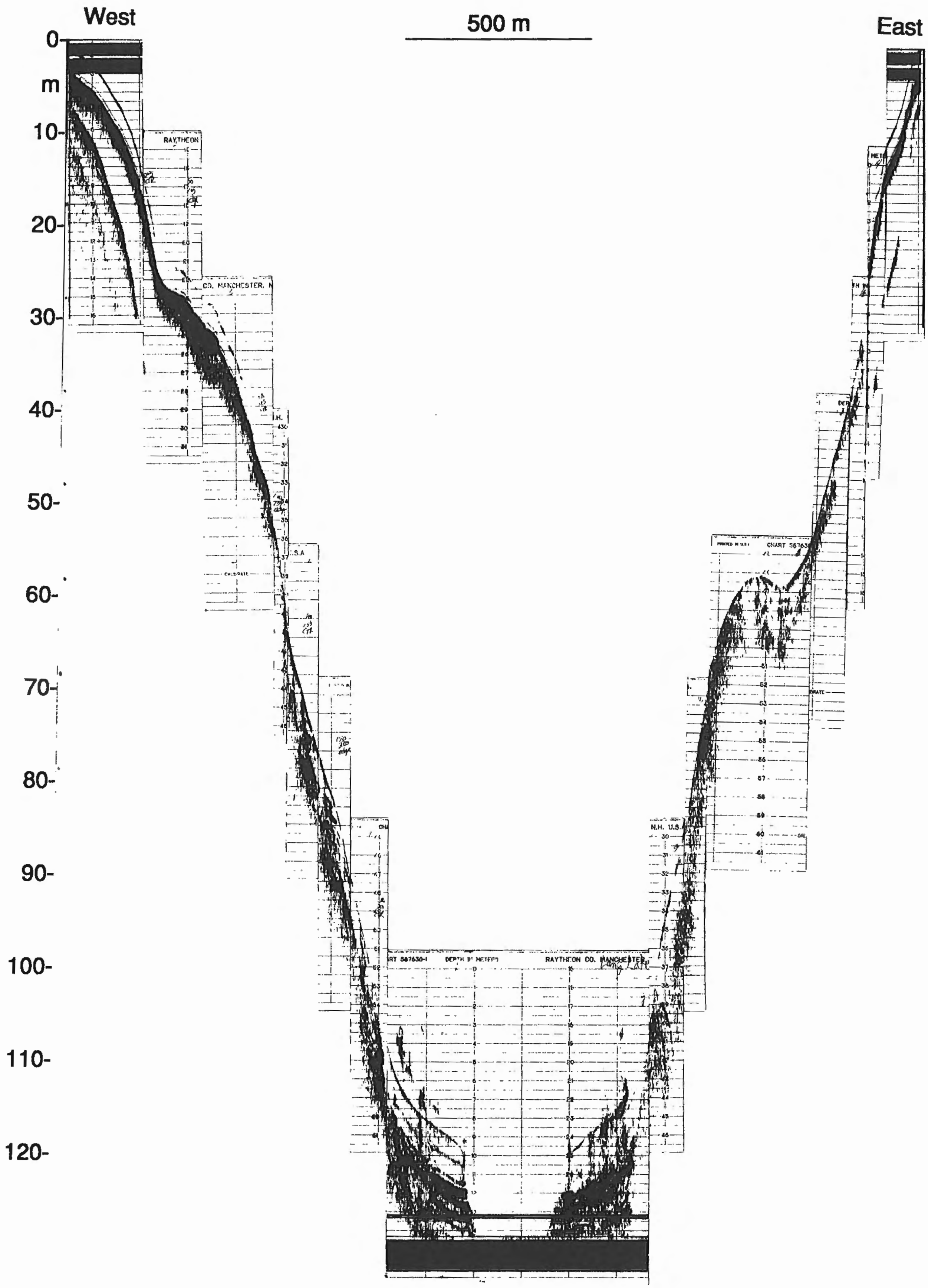
L. Subbottom profile, Long Lake line 21.

APPENDIX 1 (cont'd.)



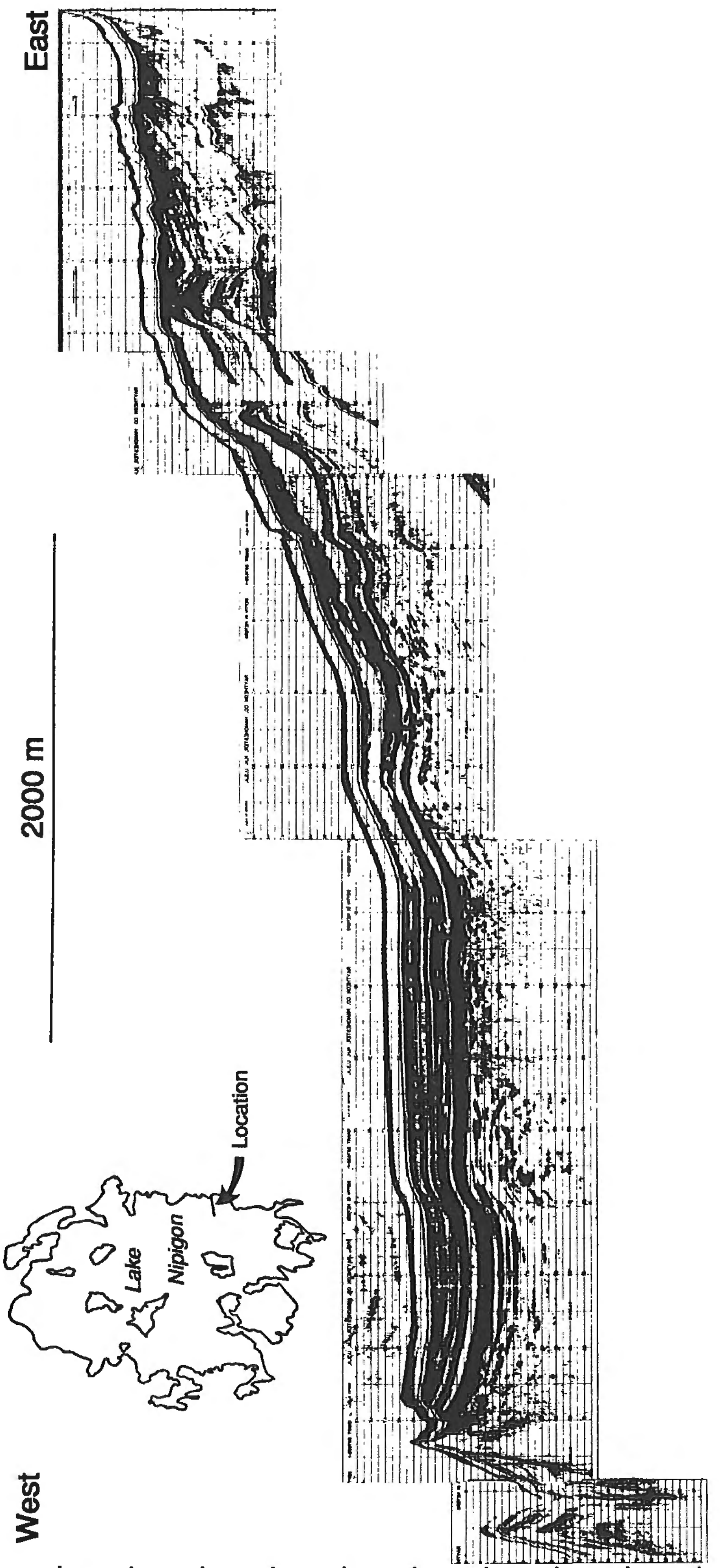
M. Subbottom profile, Long Lake line 22.

APPENDIX 1 (cont'd.)



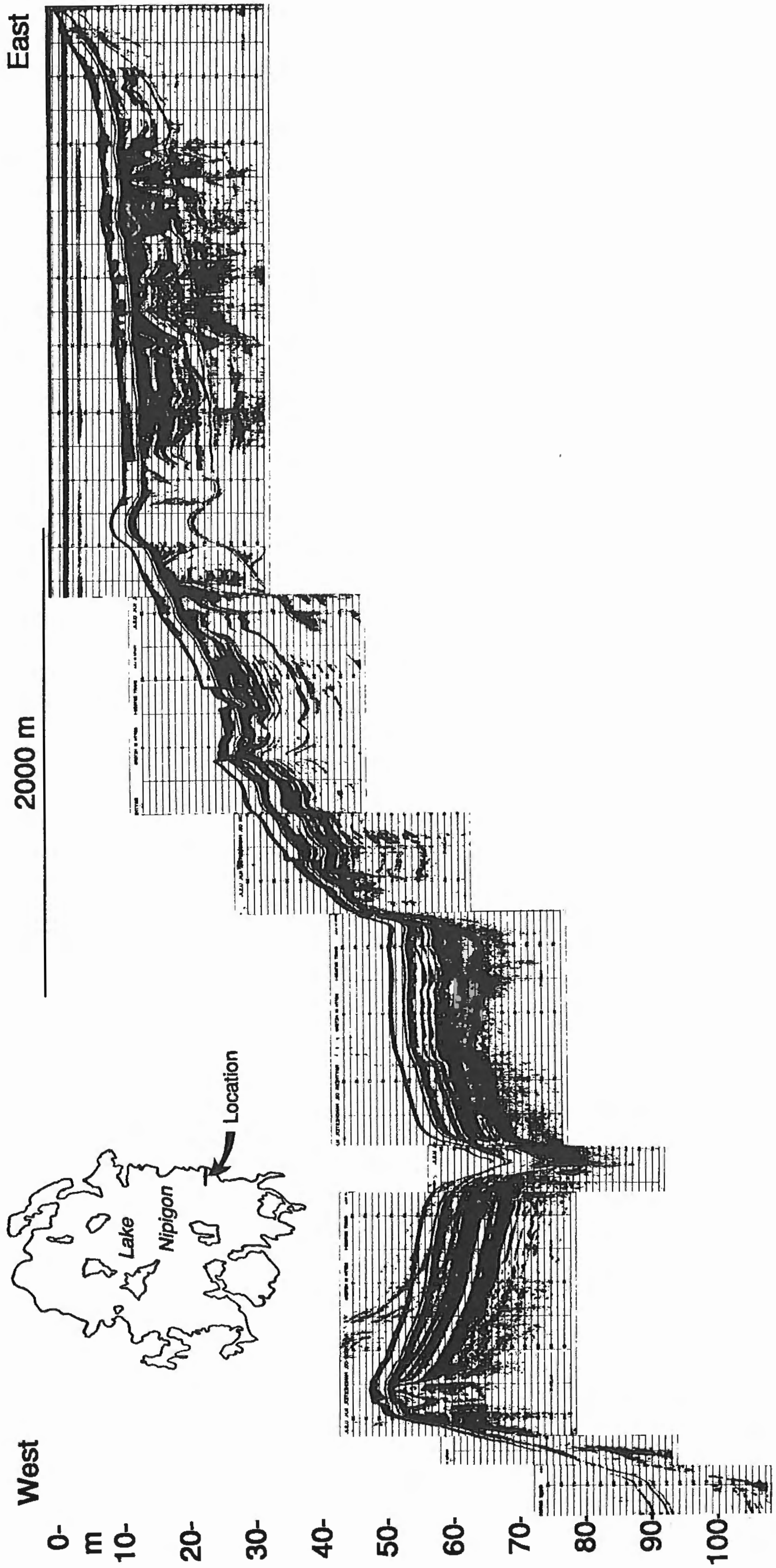
N. Subbottom profile, Long Lake line 24.

APPENDIX 1 (cont'd.)



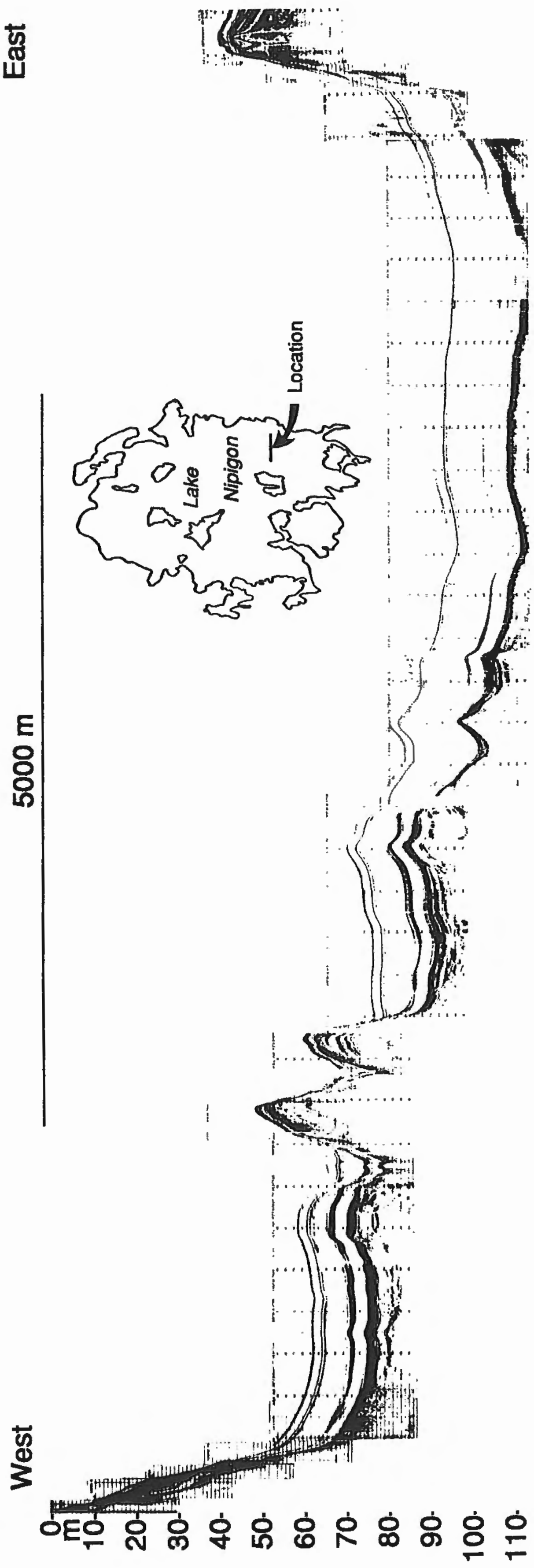
O. Subbottom profile, Lake Nipigon line 1.

APPENDIX 1 (cont'd.)



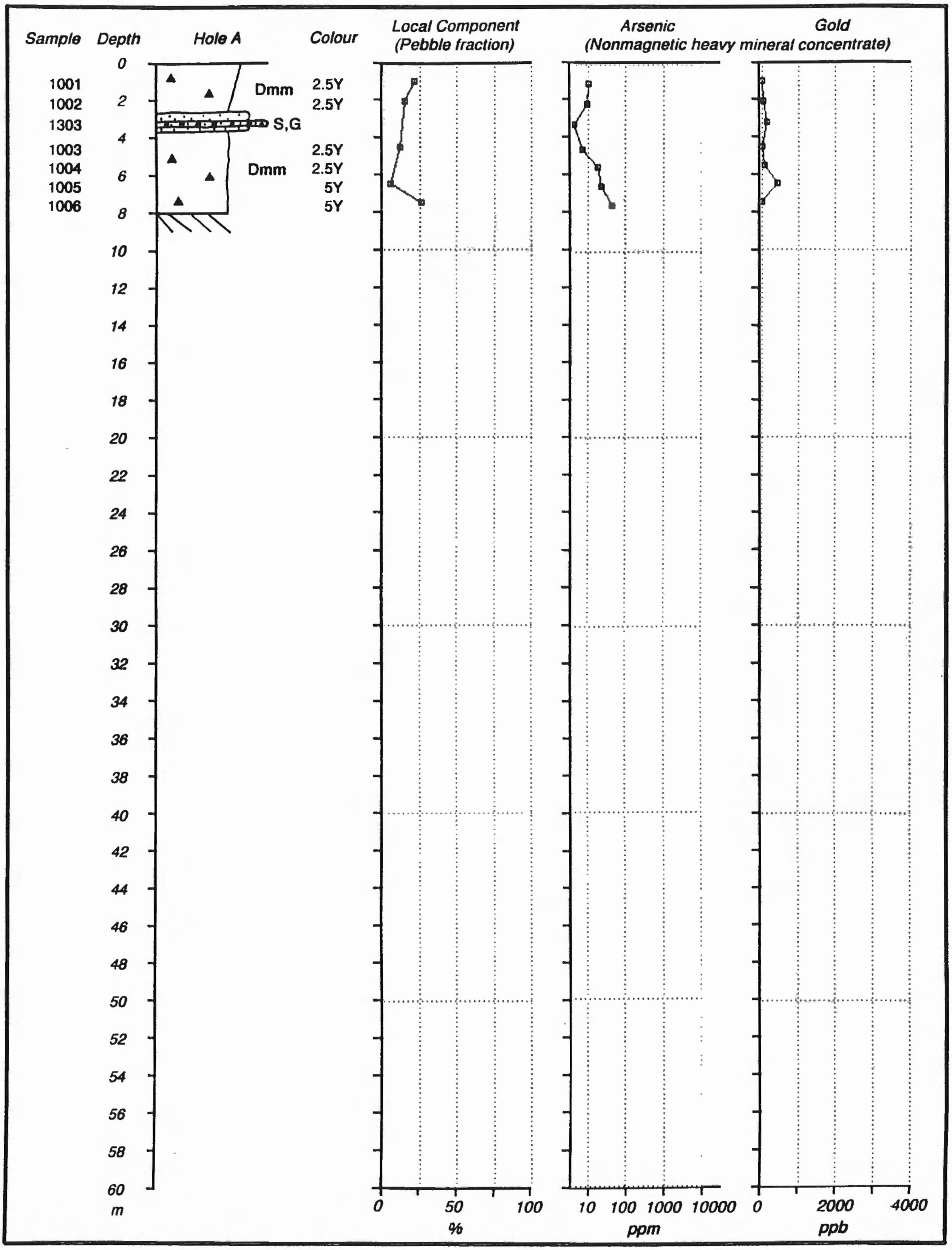
P. Subbottom profile, Lake Nipigon line 2, nearshore.

APPENDIX 1 (cont'd.)



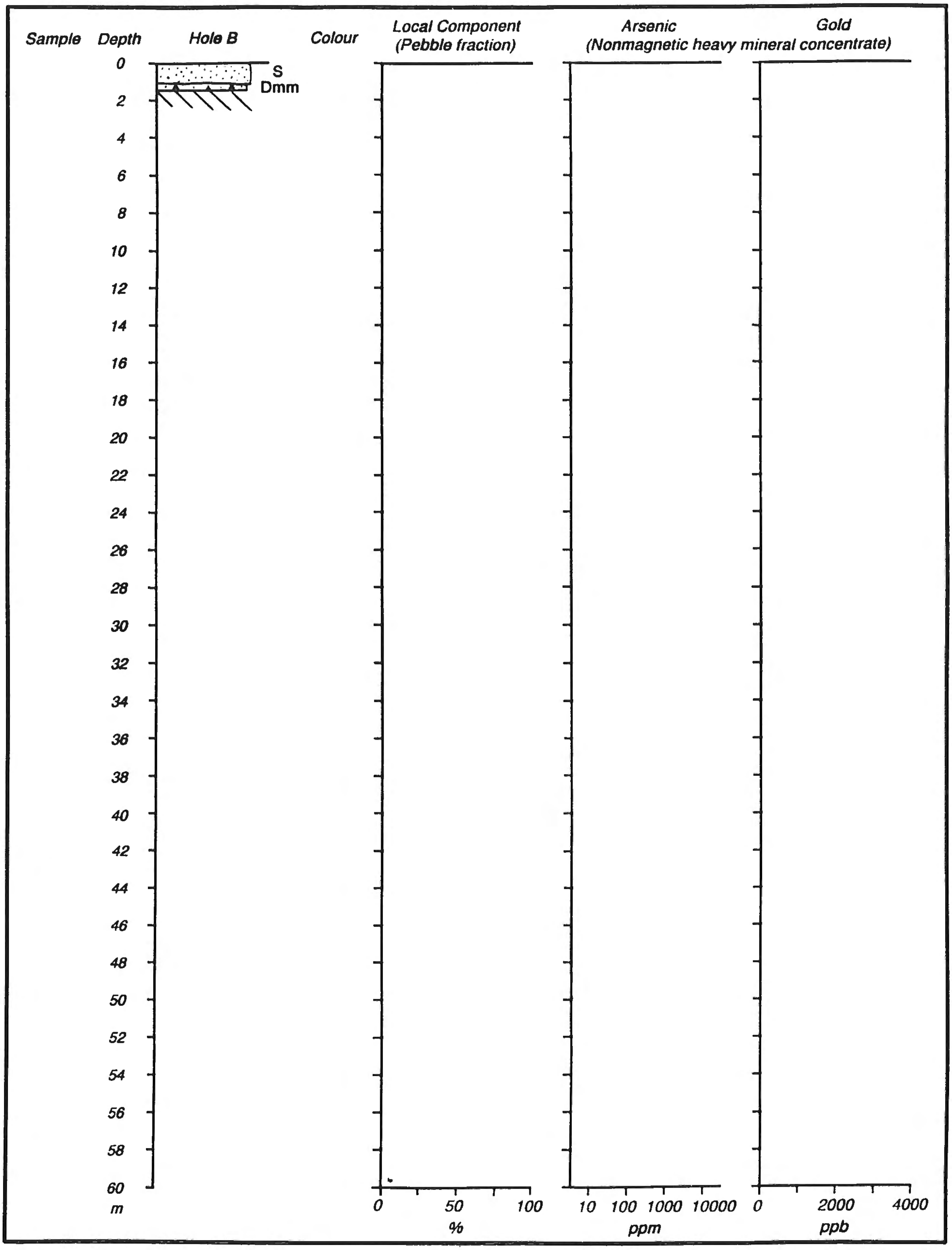
Q. Subbottom profile, Lake Nipigon line 2, offshore.

APPENDIX 2
Drill hole profiles

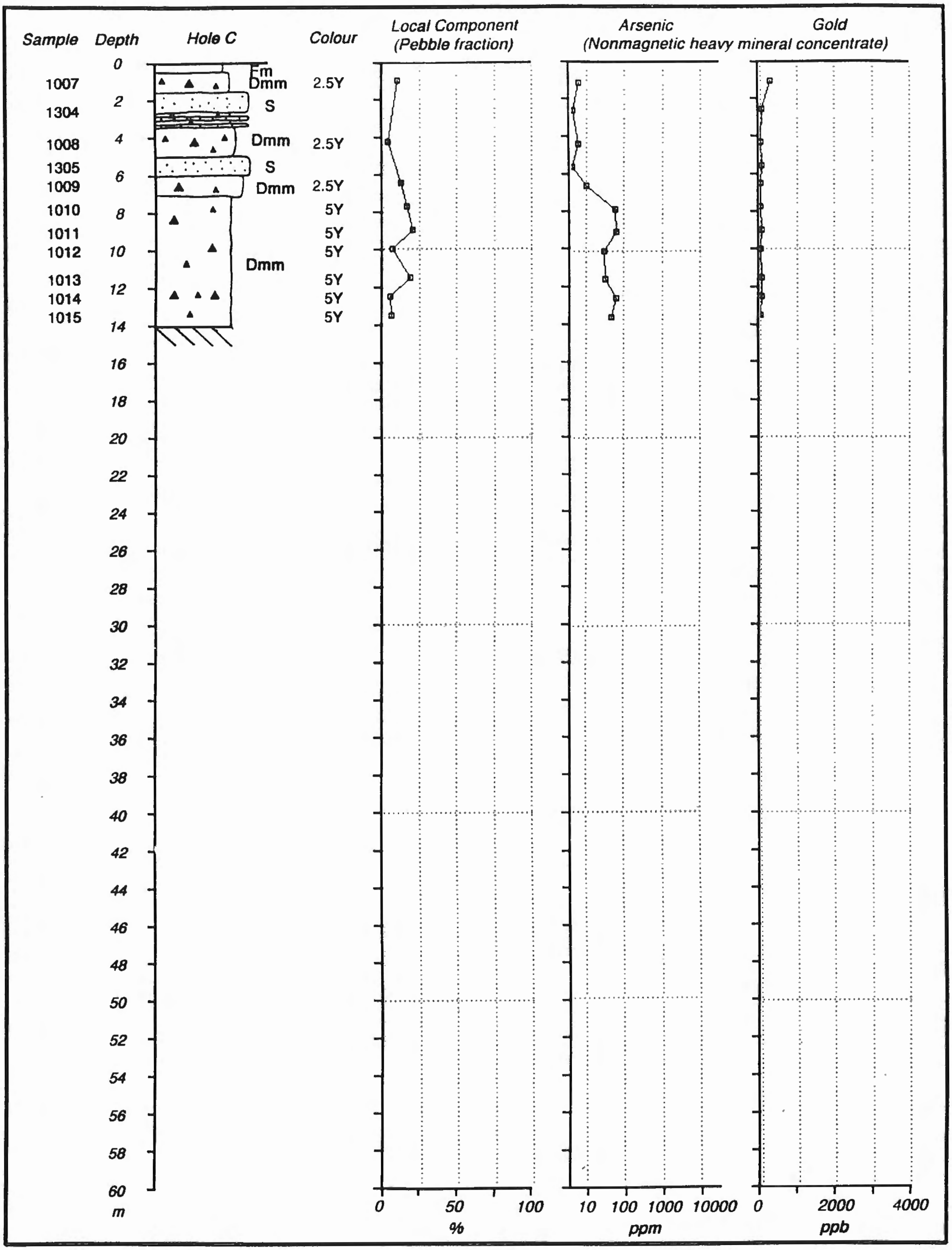


Hole A

APPENDIX 2 (cont'd.)



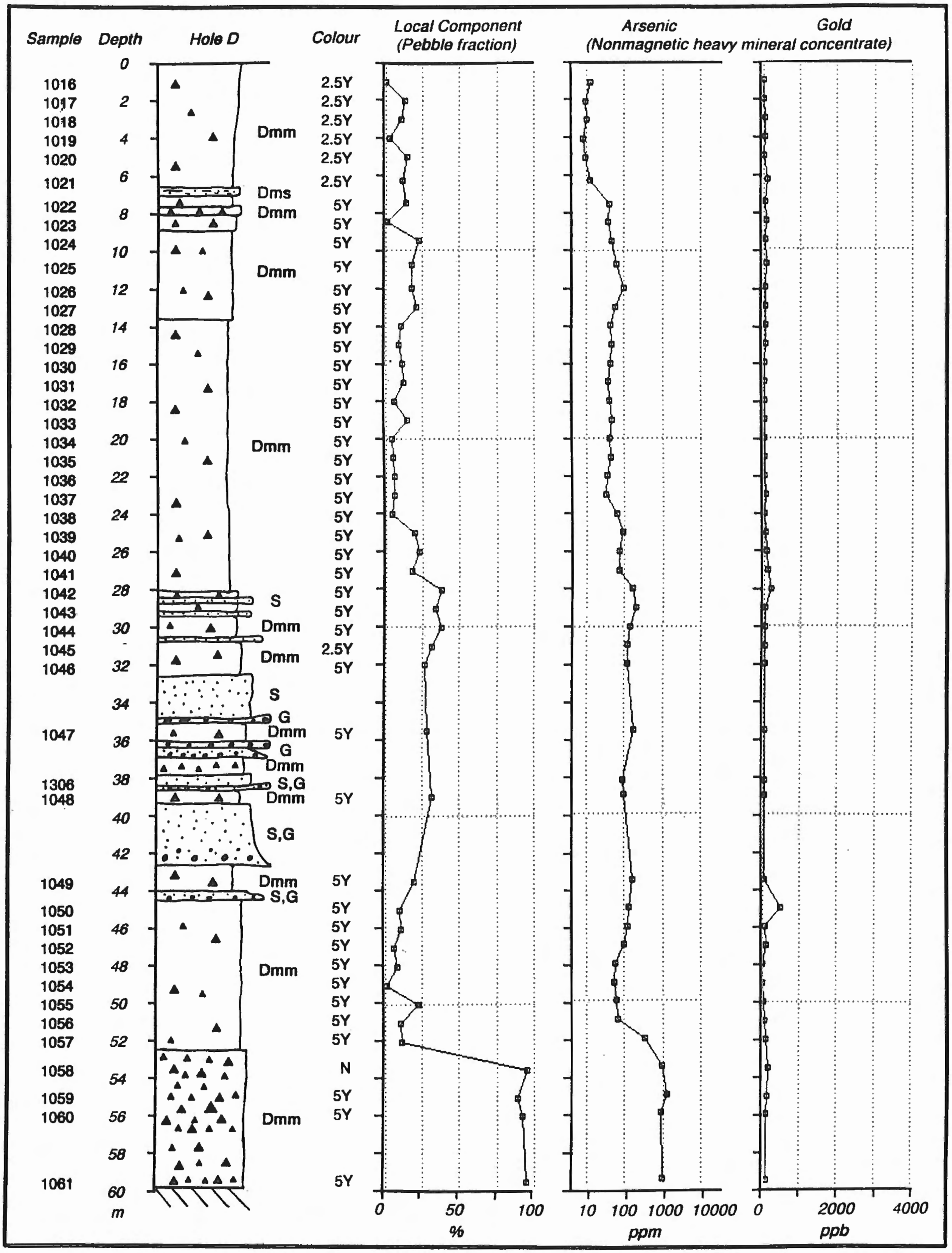
Hole B



Sample
Depth
Hole C
Colour
Local Component (Pebble fraction)
Arsenic
Gold
(Nonmagnetic heavy mineral concentrate)
1007
1304
1008
1305
1009
1010
1011
1012
1013
1014
1015
Fm
Dmm
S
Dmm
S
Dmm
Dmm
2.5Y
2.5Y
2.5Y
5Y
5Y
5Y
5Y
5Y
5Y
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
m
0
50
100
%
10
100
1000
10000
ppm
0
2000
4000
ppb

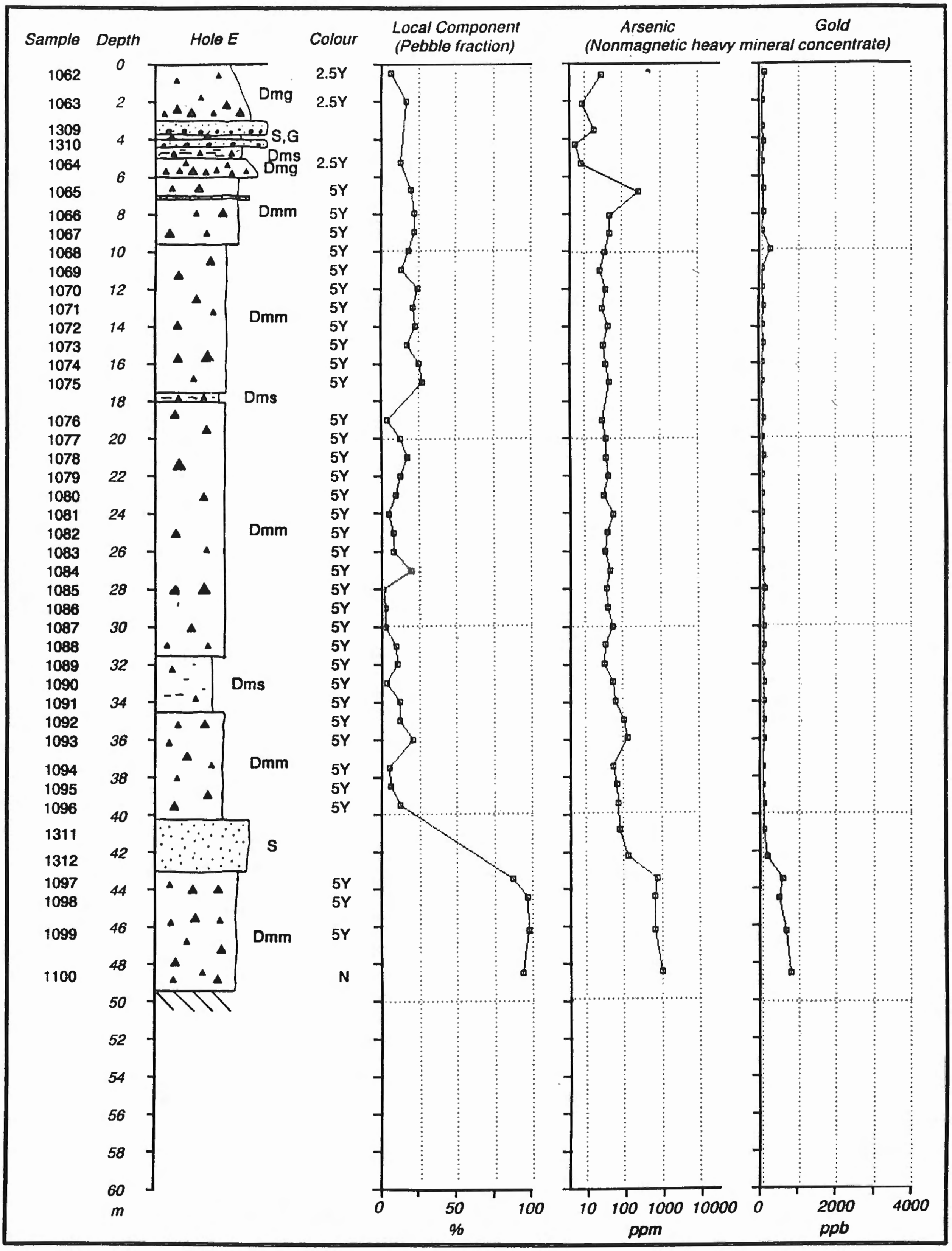
Hole C

APPENDIX 2 (cont'd.)



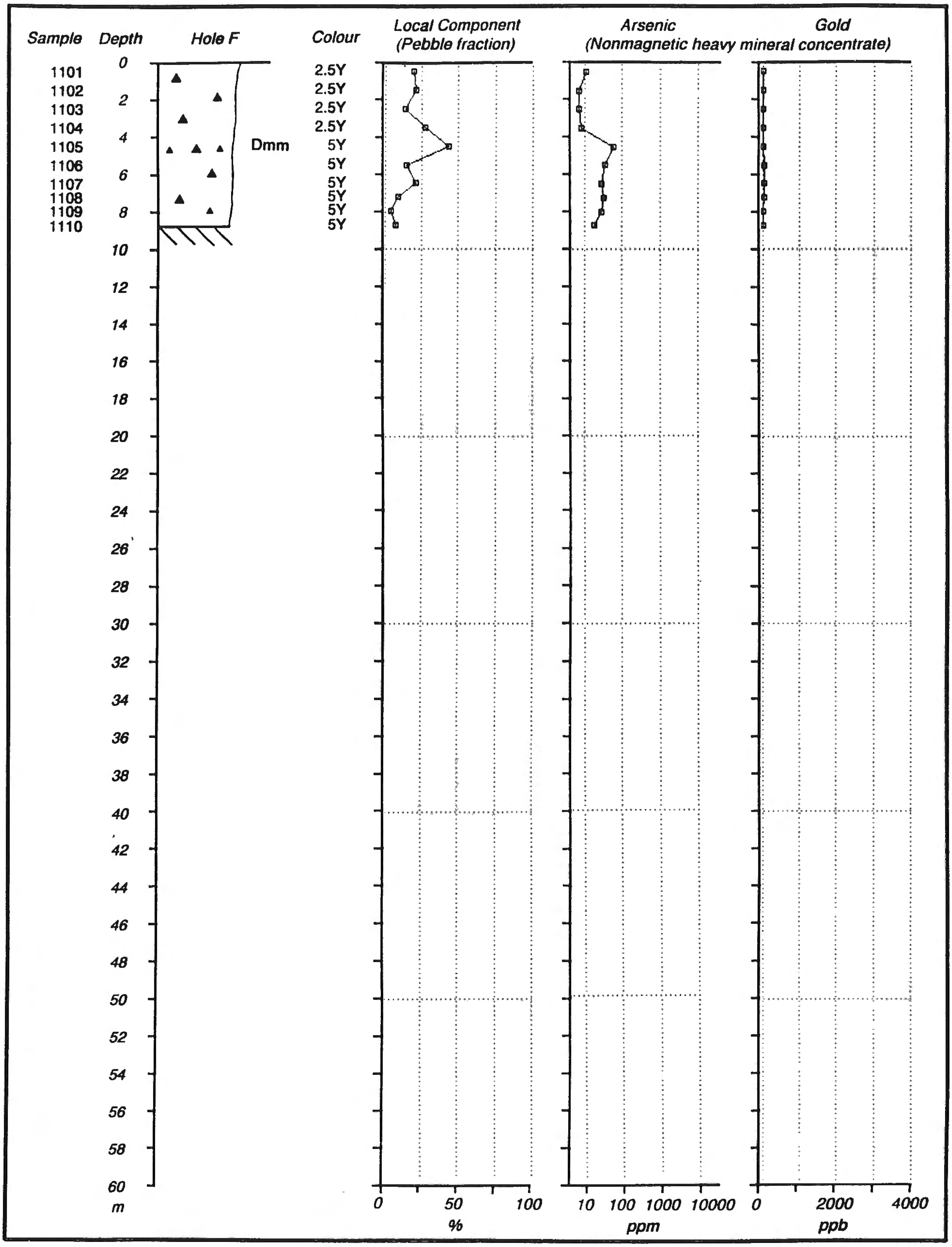
Hole D

APPENDIX 2 (cont'd.)



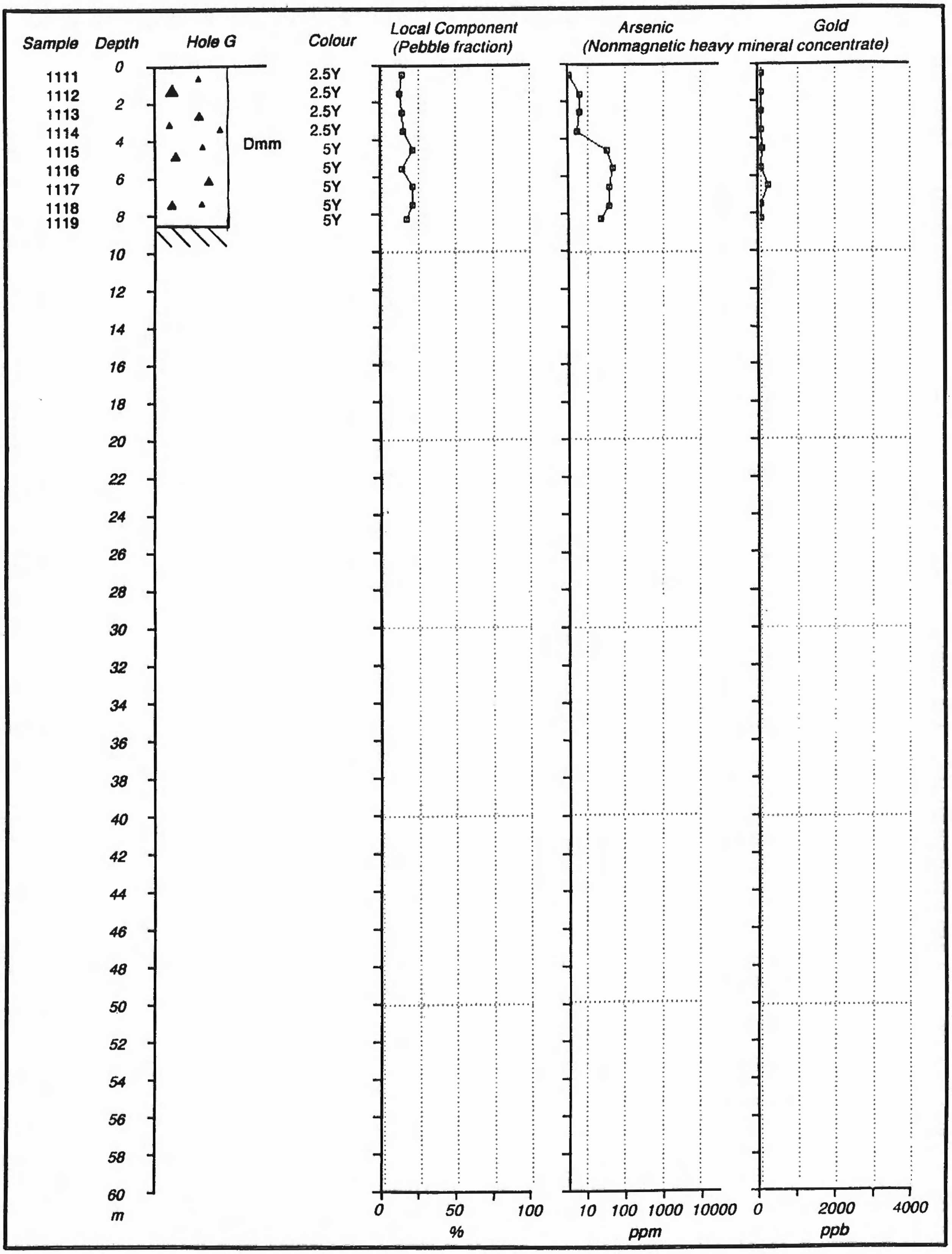
Hole E

APPENDIX 2 (cont'd.)



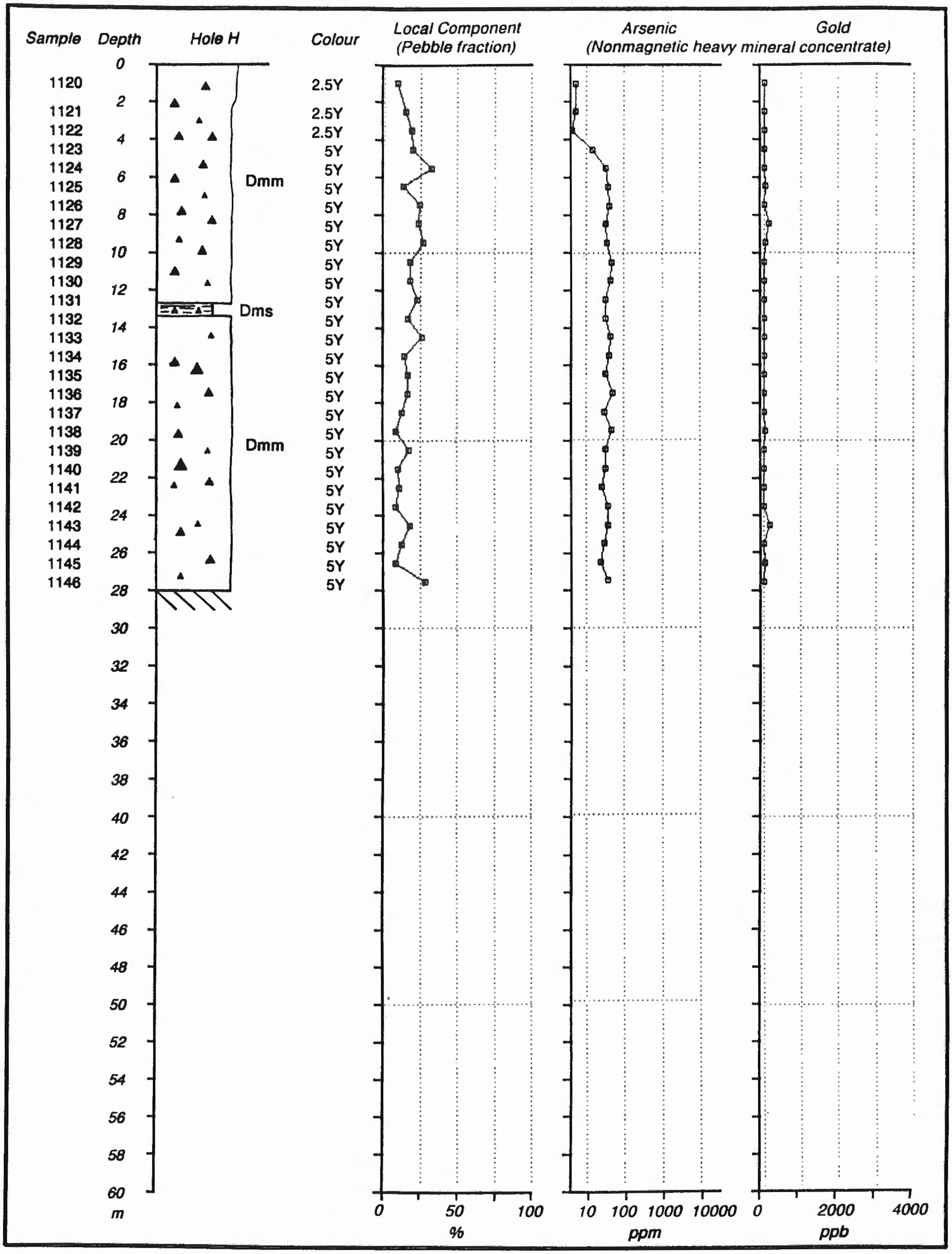
Hole F

APPENDIX 2 (cont'd.)



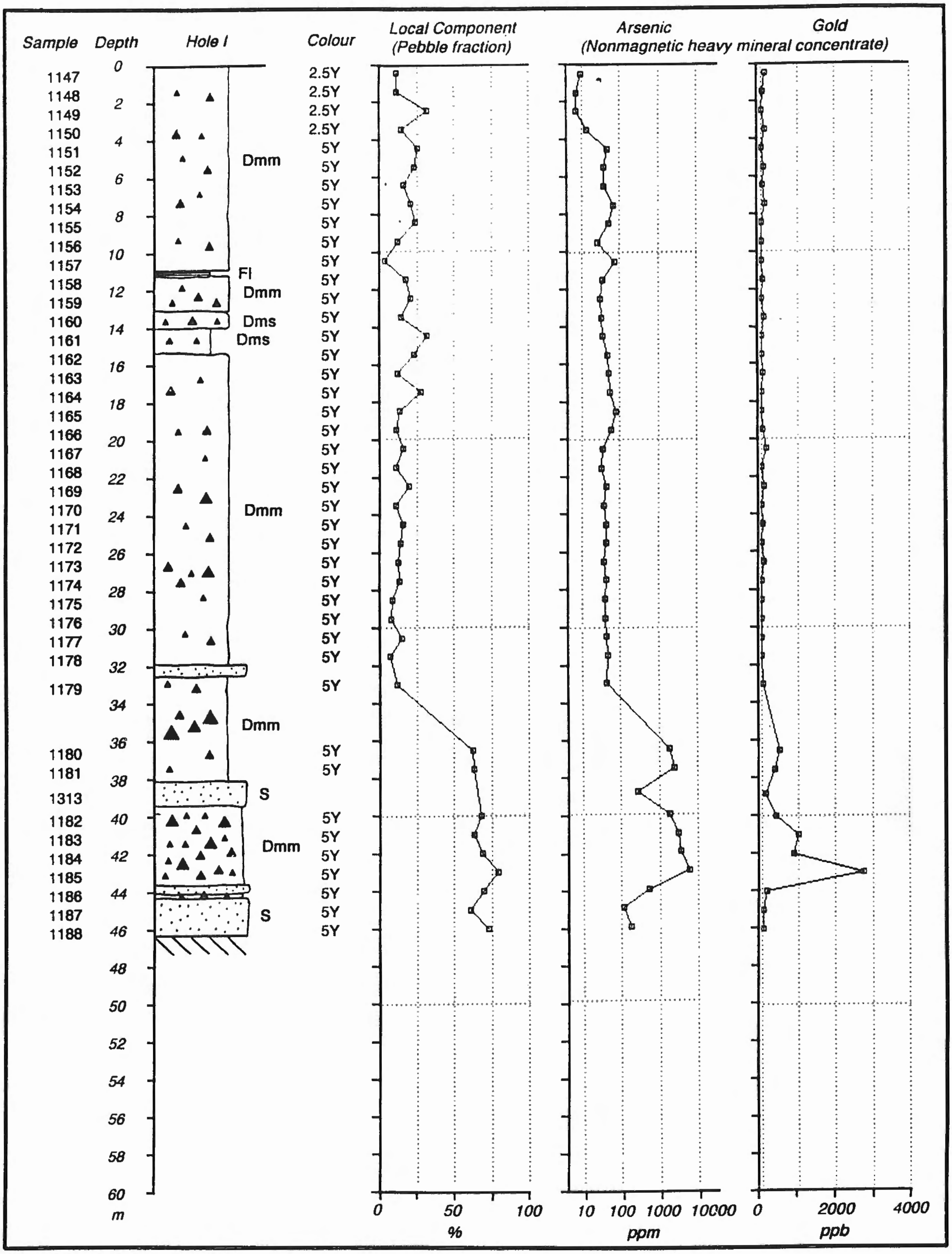
Hole G

APPENDIX 2 (cont'd.)



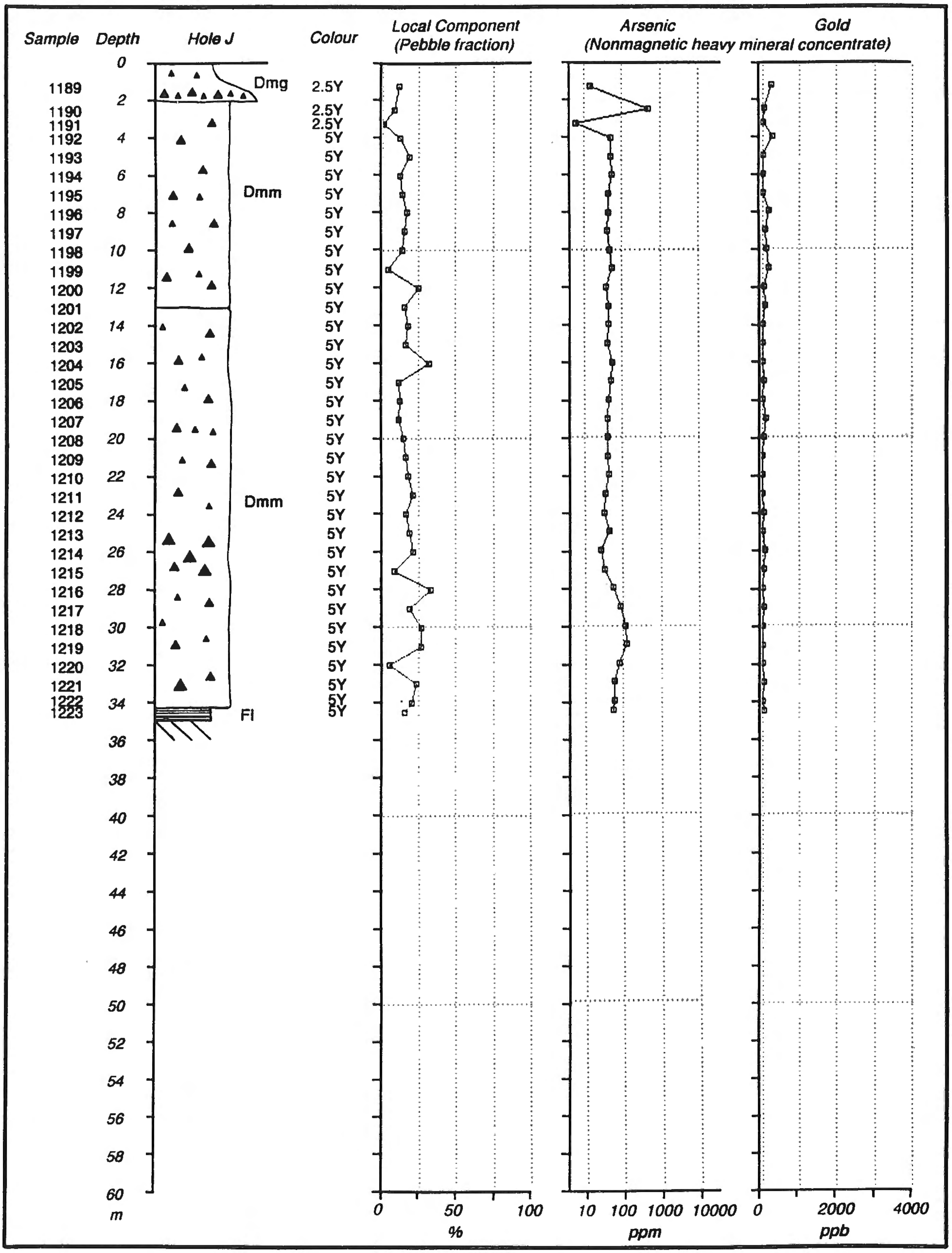
Hole H

APPENDIX 2 (cont'd.)



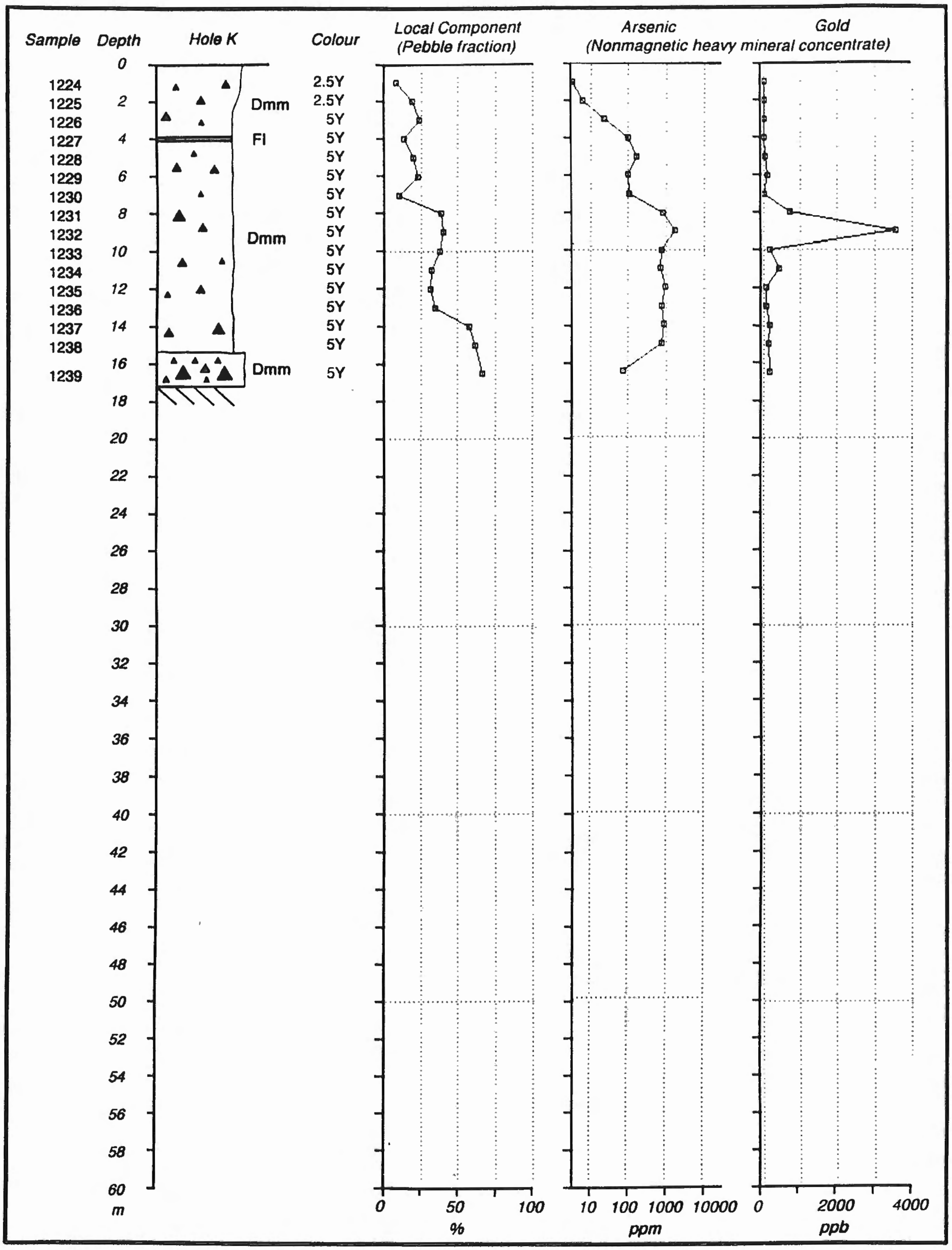
Hole I

APPENDIX 2 (cont'd.)

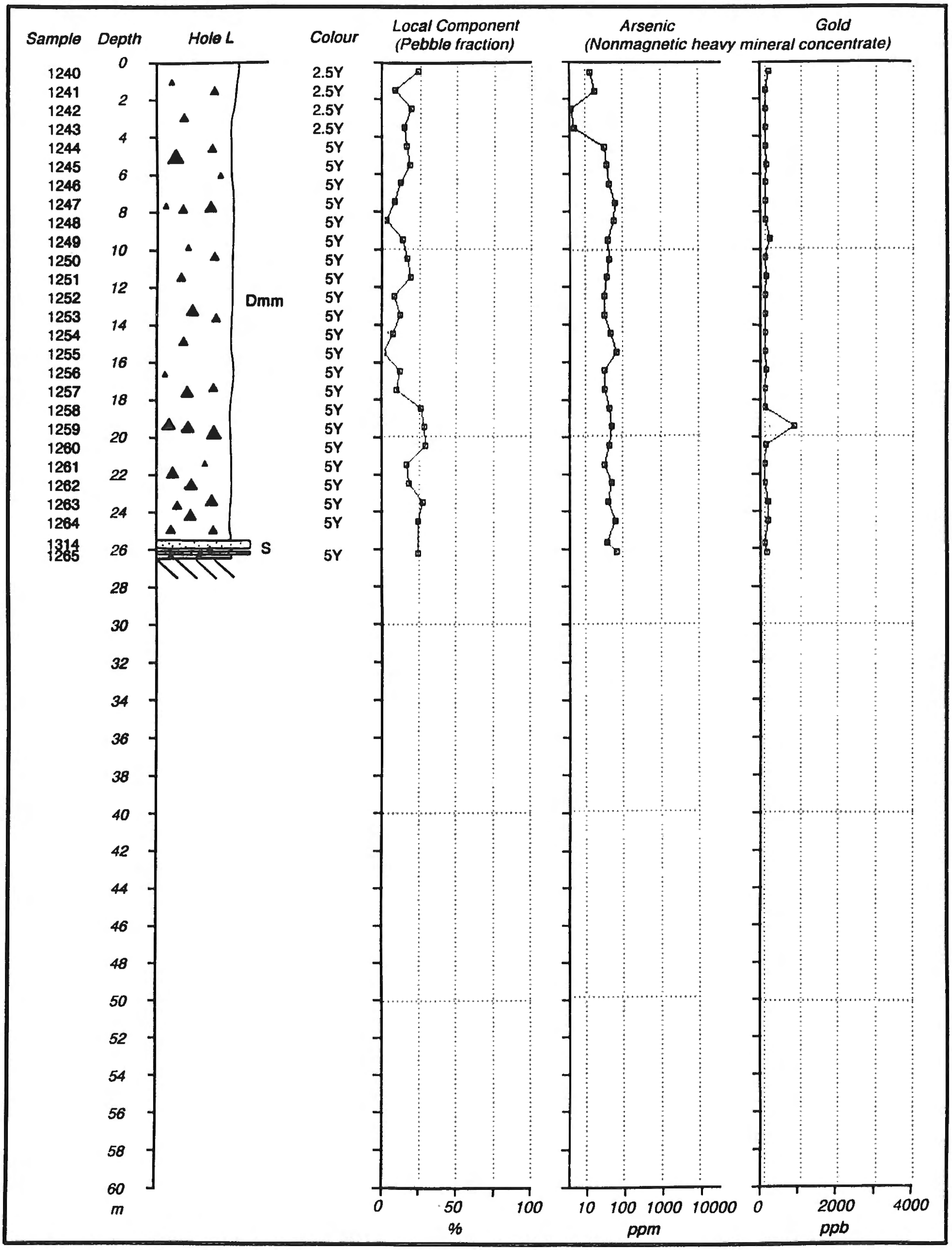


Hole J

APPENDIX 2 (cont'd.)

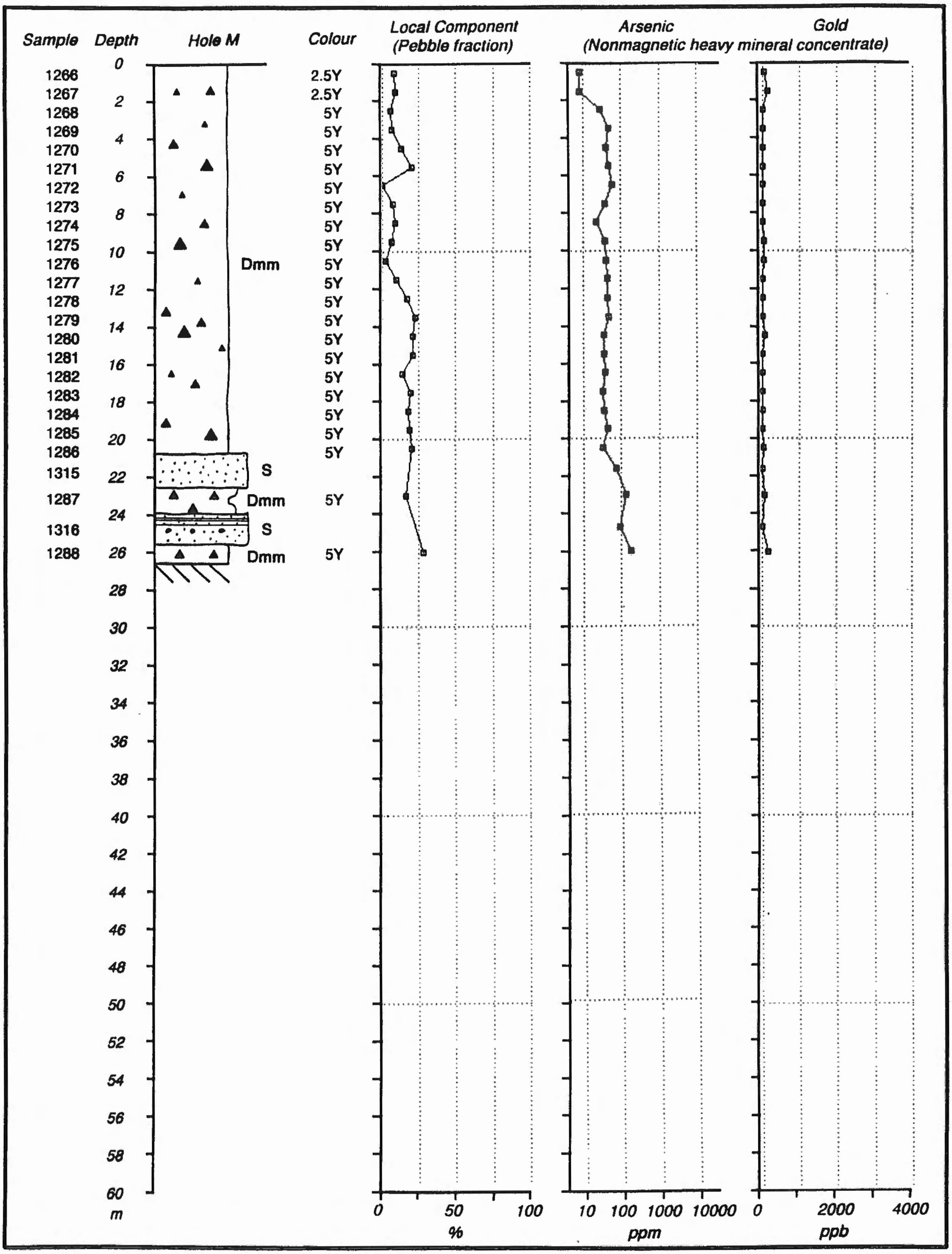


Hole K


Sample
Depth
Hole L
Colour
Local Component (Pebble fraction)
Arsenic
Gold
(Nonmagnetic heavy mineral concentrate)
1240 1241 1242 1243 1244 1245 1246 1247 1248 1249 1250 1251 1252 1253 1254 1255 1256 1257 1258 1259 1260 1261 1262 1263 1264 1314 1265
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 m
Dmm
S
2.5Y 2.5Y 2.5Y 2.5Y 5Y
0 50 100
%
10 100 1000 10000
ppm
0 2000 4000
ppb

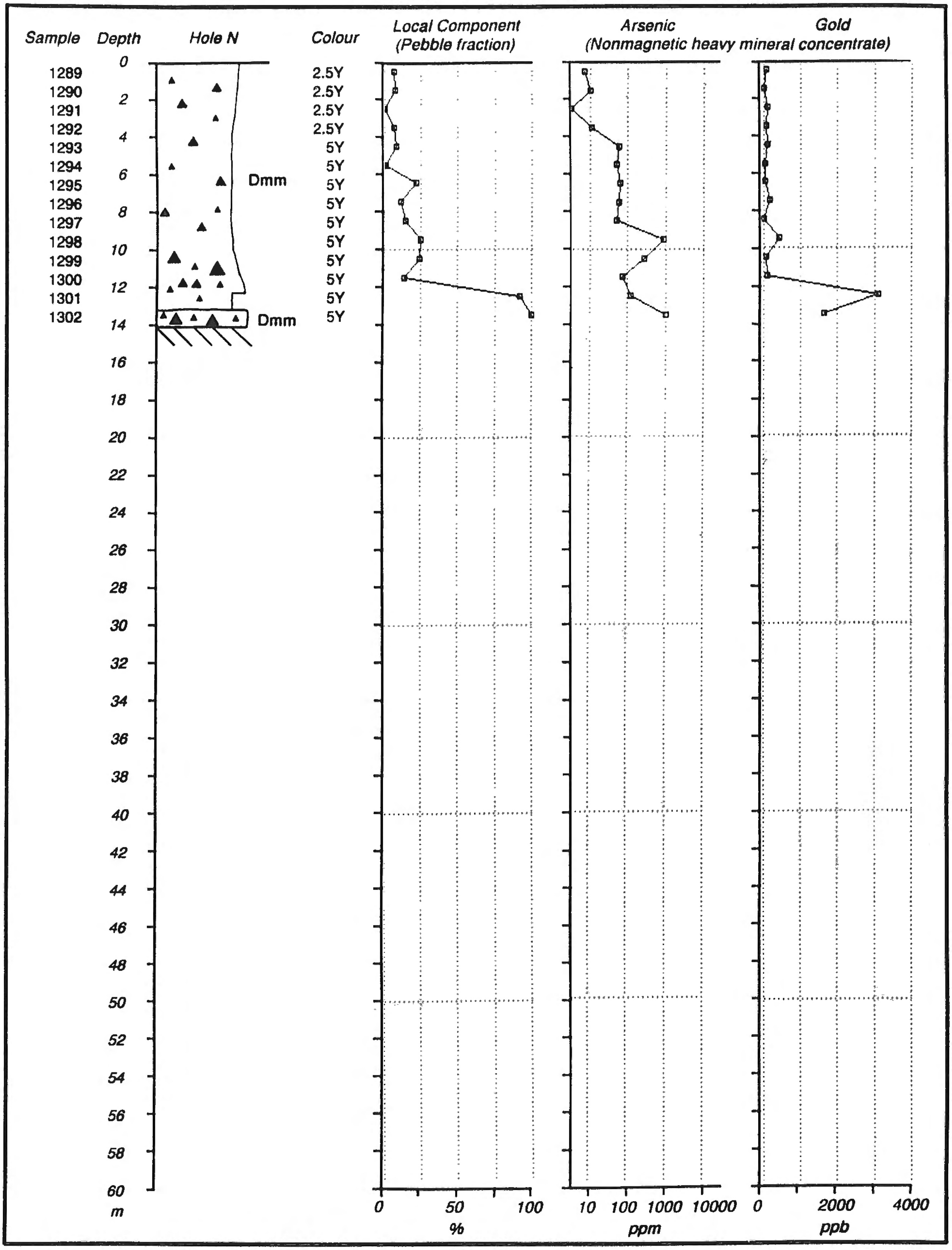
Hole L

APPENDIX 2 (cont'd.)



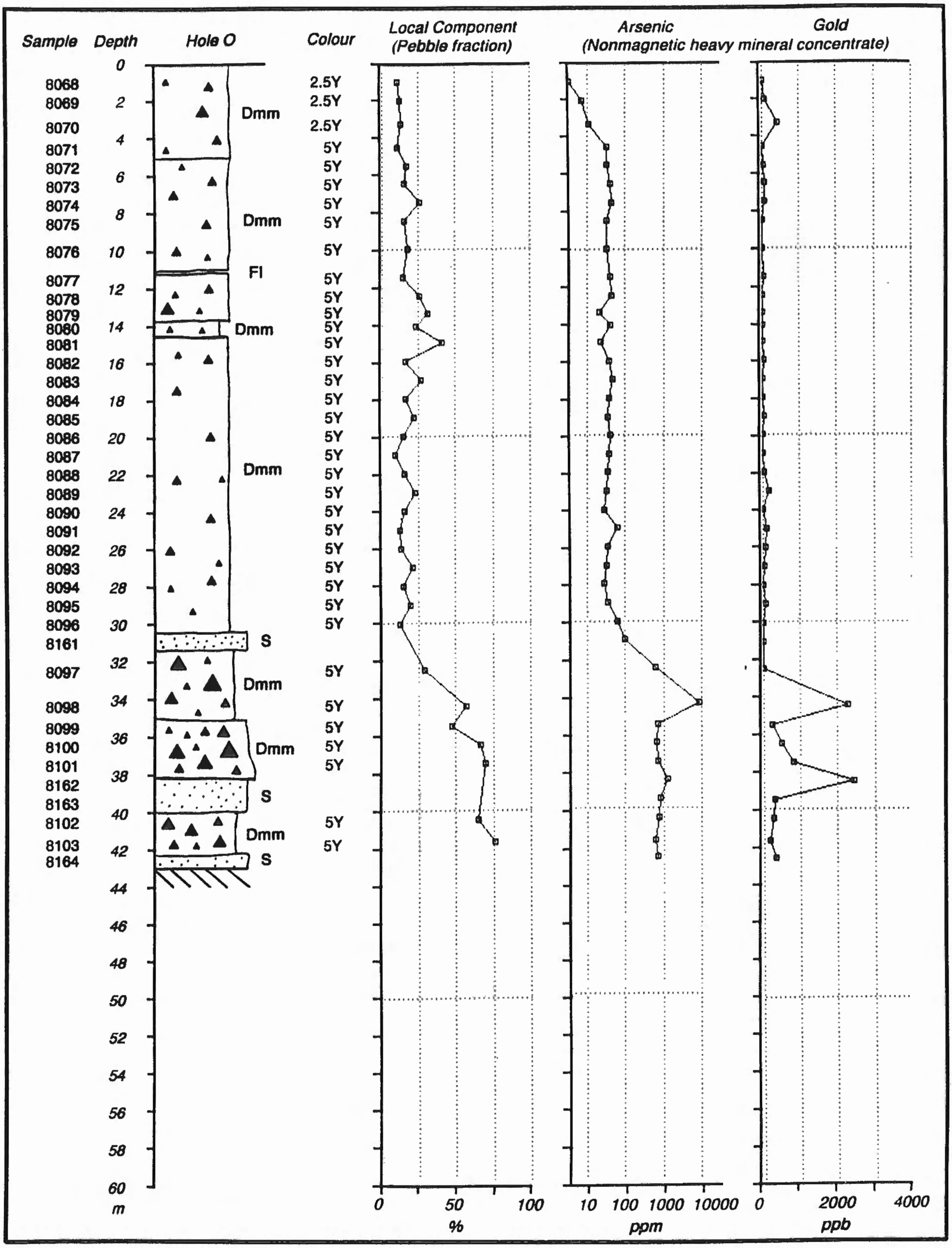
Hole M

APPENDIX 2 (cont'd.)



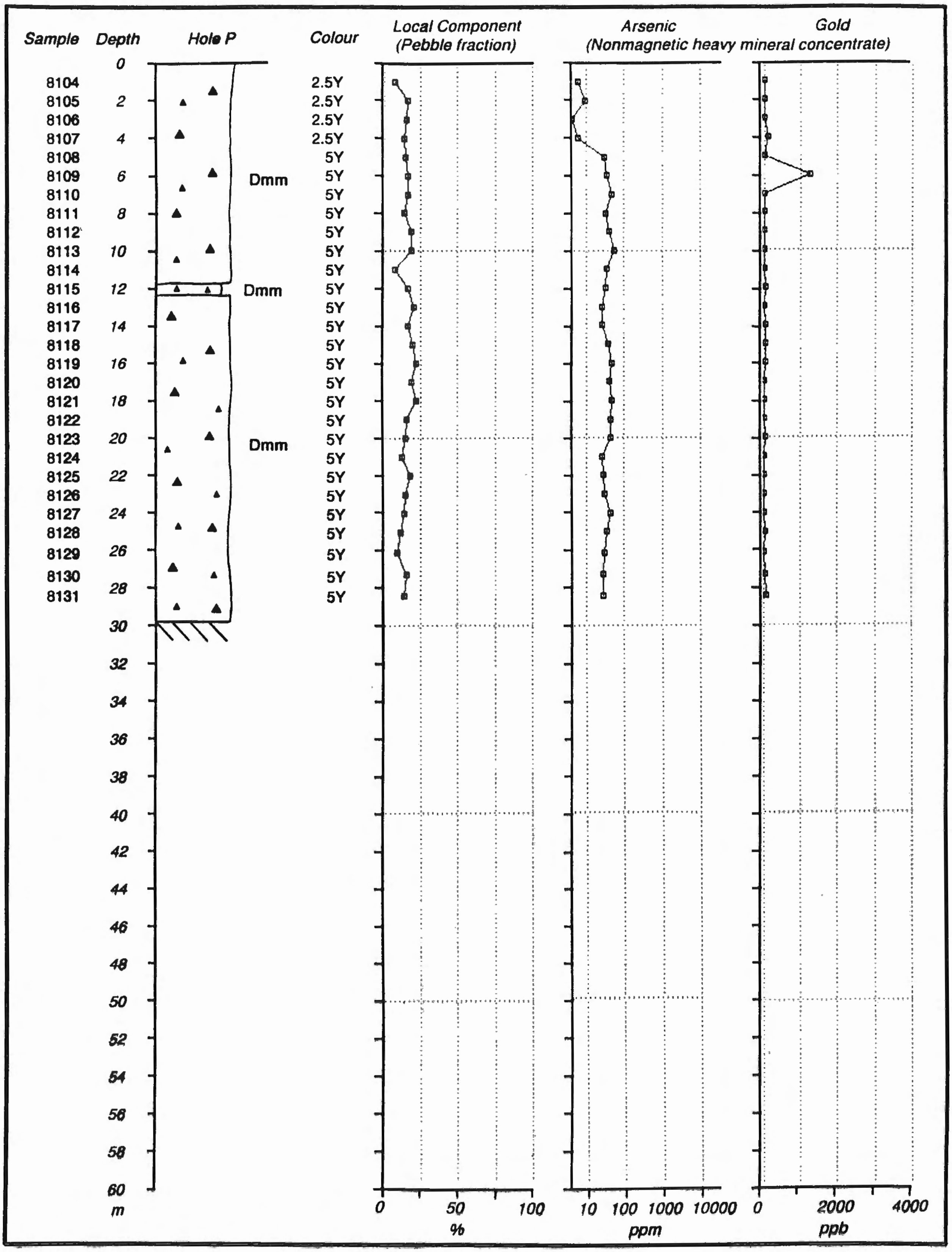
Hole N

APPENDIX 2 (cont'd.)



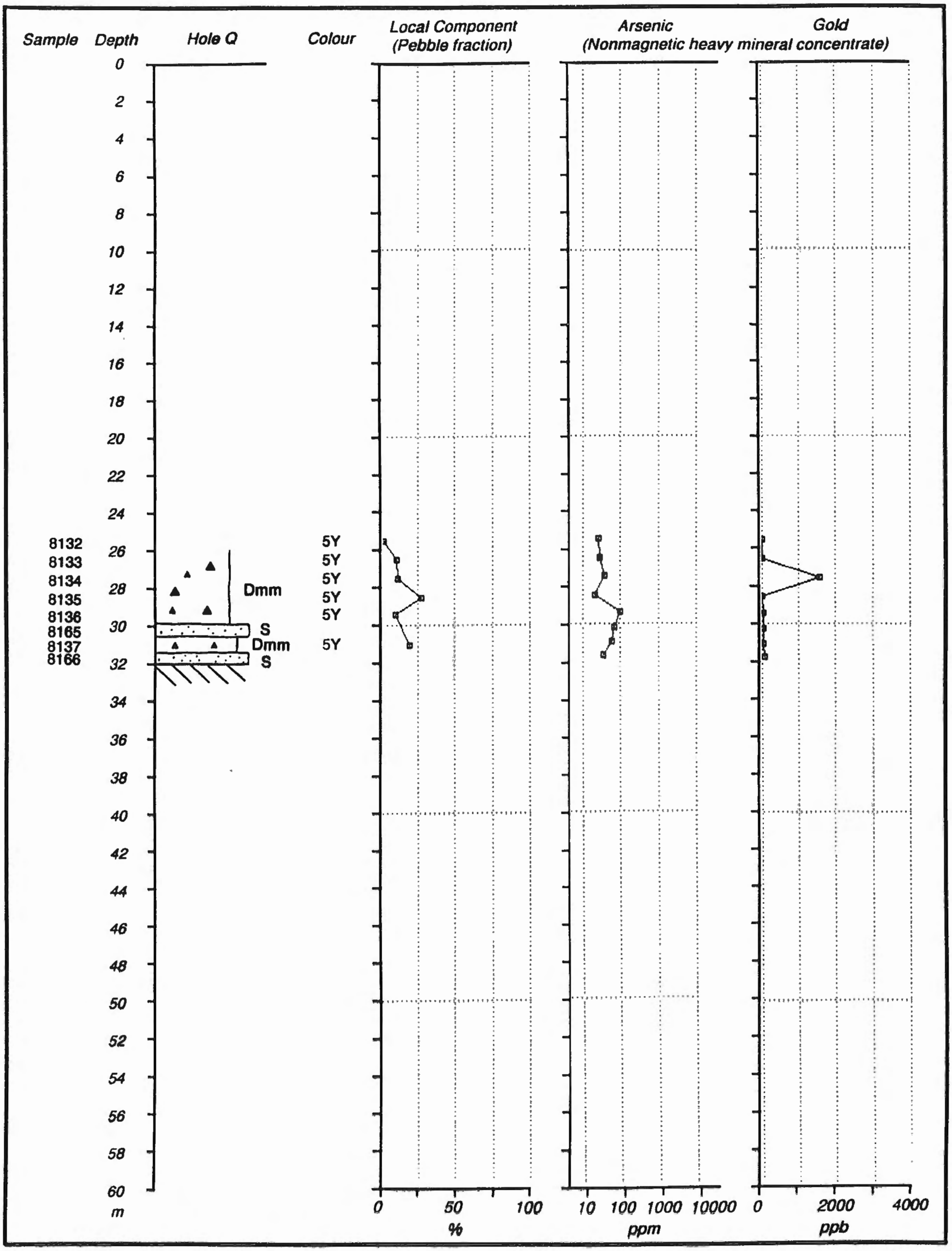
Hole O

APPENDIX 2 (cont'd.)



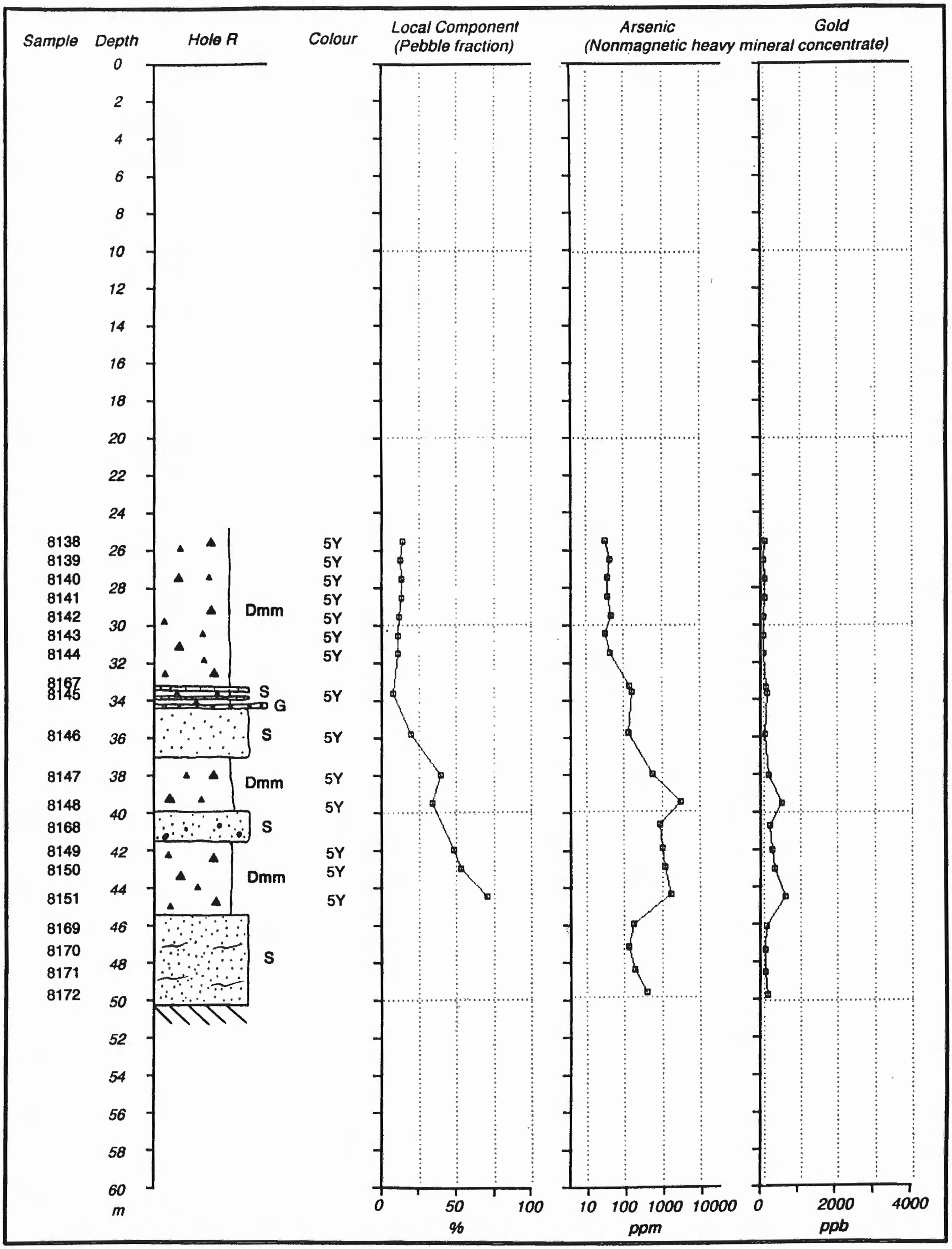
Hole P

APPENDIX 2 (cont'd.)



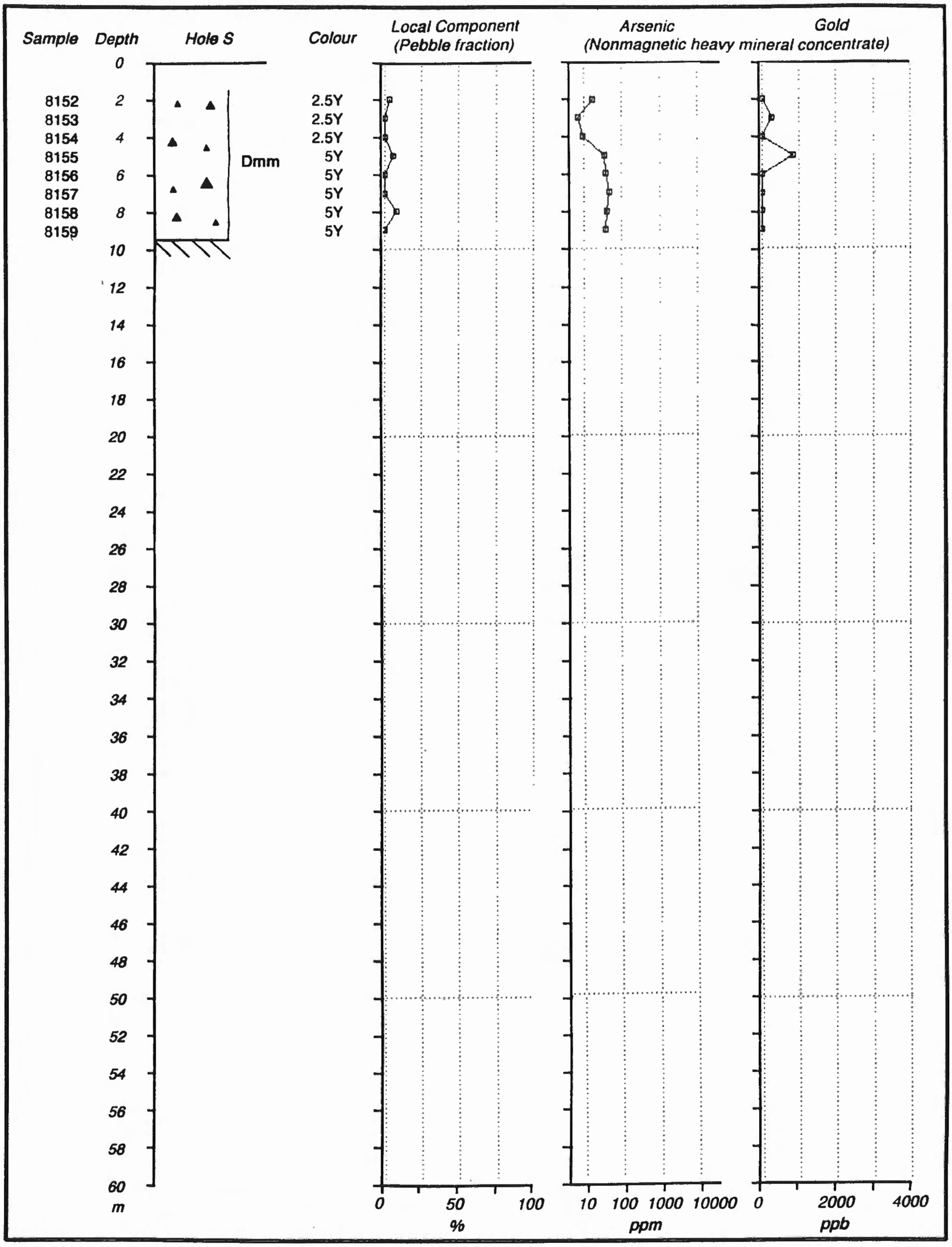
Hole Q

APPENDIX 2 (cont'd.)



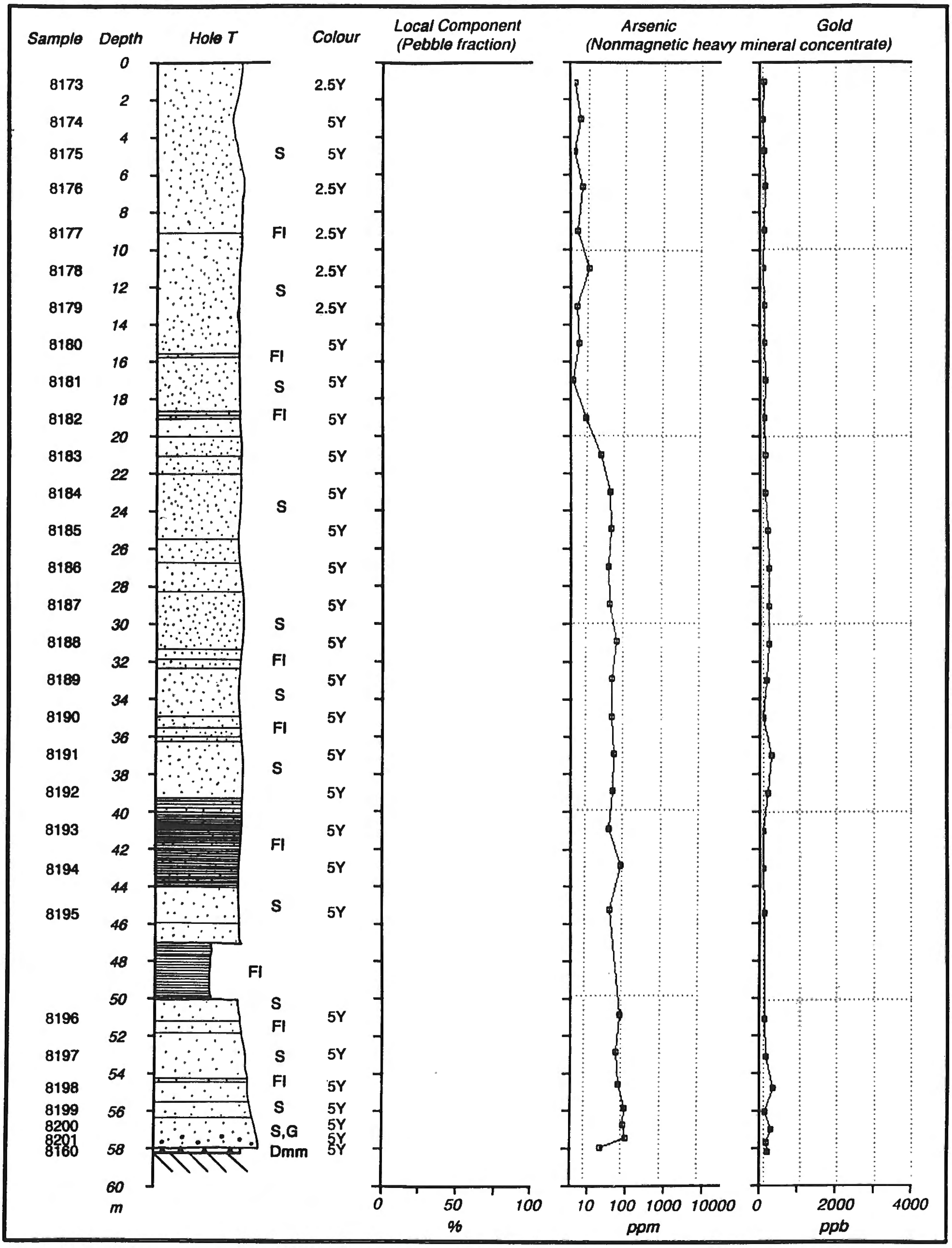
Hole R

APPENDIX 2 (cont'd.)



Hole S

APPENDIX 2 (cont'd.)



Hole T