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GLACIAL HISTORY, DRIFT COMPOSITION, AND MINERAL EXPLORATION, CENTRAL LABRADOR

R.A. Klassen and F.J. Thompson

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Authors' addresses

R.A. Klassen
Terrain Sciences Division
601 Booth Street
Ottawa, Ontario
K1A 0E8

F.J. Thompson
Northwood Geoscience
357 Preston Street, Suite 201
Ottawa, Ontario
K1S 4M8

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Preface

One of the main objectives of the Geological Survey is to provide the geoscience information needed to assess and manage the resources available to Canada, and that is chiefly accomplished through the provision of geological maps. The Canada-Newfoundland Mineral Development Agreement has provided unprecedented opportunity for regional review of glacial deposits in Labrador and mapping of drift composition. The survey reported here encompasses much of southern Labrador, focusing on the areas of greatest mineral potential within the Central Mineral Belt and Labrador Trough. Geological fieldwork, which occupied the summers of 1983 to 1988, has lead to the creation of a geoscience database comprising several thousand samples of till and related observations concerning surficial geology and ice flow. Through analyses of those samples, the work portrays regional variations in the geochemical and lithological composition of glacial deposits, and interprets those variations in terms of bedrock geology, glacial history, and glacial process. As such it represents a geological framework not only for mineral exploration, which is commonly carried out at smaller scales, but for environmental concerns as well which require knowledge of the composition and properties of surficial deposits. Throughout Canada the effects of glaciation are paramount, and the work serves to illustrate the regional geological linkages that can occur between bedrock and the surficial environment.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

L'un des principaux objectifs de la Commission géologique est de fournir l'information géoscientifique nécessaire pour évaluer et gérer les ressources dont dispose le Canada, et ceci est surtout possible avec des cartes géologiques. L'Entente entre le Canada et Terre-Neuve sur l'exploitation minérale a été une occasion exceptionnelle de faire une étude régionale des dépôts glaciaires du Labrador et de cartographier la composition du drift. Le levé dont il est question dans ce rapport englobe une grande partie du sud du Labrador, en particulier les secteurs de potentiel minéral exceptionnel à l'intérieur de la zone minérale centrale et de la fosse du Labrador. Les travaux géologiques de terrain, qui ont eu lieu pendant les étés 1983 à 1988, ont permis d'établir une base de données scientifiques englobant l'examen de plusieurs milliers d'échantillons de till et des observations connexes sur la géologie de surface et sur les écoulements glaciaires. Grâce à des analyses de ces échantillons, on décrit des variations régionales de la composition géochimique et lithologique des dépôts glaciaires, et l'on peut interpréter ces variations en fonction de la géologie de la roche en place, de l'évolution glaciaire, et des processus glaciaires. Ainsi, on établit un cadre géologique qui convient non seulement à la prospection minérale, qui généralement est réalisée à plus petite échelle, mais aussi aux études écologiques, lesquelles exigent que l'on connaisse la composition et les propriétés des dépôts de surface. Dans l'ensemble du Canada, les effets des glaciations jouent un rôle essentiel, et les recherches servent à illustrer les liens géologiques régionaux qui peuvent exister entre la roche en place et les dépôts meubles en surface.

Elkanah A. Babcock,
sous-ministre adjoint
Commission géologique du Canada

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GLACIAL HISTORY, DRIFT COMPOSITION, AND MINERAL EXPLORATION, CENTRAL LABRADOR

Abstract

Ice flow history and drift composition were studied in central Labrador to establish a geological framework for mineral exploration. Striae indicate a complex history of ice flow, indicating marked change in ice flow direction not shown by glacially streamlined landforms. The shape and orientation of glacial dispersal trains record erosion and transport during succeeding ice flow events. The trains appear as ribbons near ice sheet margins, and broaden to fans and patches near ice divides, where ice flow has been most varied. Within dispersal trains, the latest directions of ice flow are commonly the dominant controls on drift composition. Regionally, till geochemistry reflects compositional differences among major geological units and terrains. Glacial dispersal trains derived from supracrustal and peralkaline granite sources, however, can mask bedrock tens to hundreds of kilometres down-ice, and can be recognized in both geochemical and lithological maps.

Résumé

On a étudié dans la région centrale du Labrador l'évolution de l'écoulement des glaces et la composition du drift, dans le but d'établir un contexte géologique pour la prospection minérale. Les stries indiquent une évolution complexe de l'écoulement glaciaire, avec de fortes variations de la direction d'écoulement des glaces que ne révèlent pas les structures topographiques profilées. La configuration et l'orientation des traînées de dispersion glaciaires témoignent de l'érosion et du transport glaciaires qui ont eu lieu au cours des épisodes successifs d'écoulement glaciaire. Les traînées se présentent sous forme de rubans près des marges des calottes, et s'élargissent en formant des éventails et des nappes près des lignes de partage des glaces, où l'écoulement glaciaire a été particulièrement varié. Dans les traînées de dispersion des glaces, les plus récentes directions de l'écoulement glaciaire constituent généralement le contrôle dominant de la composition du drift. Régionalement, la géochimie du drift reflète les différences de composition entre les principales unités géologiques et les principaux terrains. Les traînées de dispersion glaciaires issues de secteurs de roches supracrustales et de granites hyperalcalins, peuvent toutefois masquer la roche en place sur des dizaines ou même sur des centaines de kilomètres en aval des glaces, et peuvent être reconnues à la fois sur les cartes géochimiques et les cartes lithologiques.

SUMMARY

A study of ice flow history and of drift composition was carried out in Labrador as part of the Canada-Newfoundland Mineral Development Agreement, to establish a geological framework for drift prospecting and to develop exploration methods suited to the region. The area of study lies within the Canadian Shield and includes most of central Labrador and parts of adjacent Quebec. It is bounded by the Labrador coast and longitude 70°W, and by latitudes 52° and 57°N. From the perspective of Quaternary geology and the Laurentide Ice Sheet, the area extends from the geographic centre of the Labradorean Sector in Labrador-Quebec (Prest, 1984) to its margins along the Labrador coast. Thus, the region has experienced marked variation in ice flow direction, and patterns of

SOMMAIRE

On a réalisé au Labrador une étude de l'évolution de l'écoulement glaciaire et de la composition du drift dans le cadre de l'Entente CanadaTerre-Neuve d'exploitation minérale, de façon à établir un contexte géologique pour la prospection du drift et pour élaborer des méthodes d'exploration qui soient appropriées à la région. Le secteur étudié se trouve dans les limites du Bouclier canadien, et comprend la majeure partie de la région centrale du Labrador et des portions adjacentes du Québec. Il est délimité par la côte du Labrador et 70°W de longitude, et par les parallèles 52° et 57°N. Du point de vue de la géologie du Quaternaire et par rapport à l'inlandsis Laurentidien, la région s'étend du centre géographique du secteur labradorien dans la région du Labrador-Québec (Prest, 1984) aux marges de ce secteur en bordure du littoral du Labrador. Ainsi, la région a subi des variations marquées de la direction de l'écoulement glaciaire, et les schémas de la dispersion des glaces glacial dispersal are correspondingly complex. Bedrock includes sequences of sedimentary and volcanic rock of the Central Mineral Belt and of the Labrador Trough, and a basement complex comprising parts of several geological provinces. The supracrustal rocks have potential for economic mineralization, including rare-earth elements, uranium, gold, platinum group elements, and base metals.

This report is a summary of work completed under Canada-Newfoundland Mineral Development Agreement, 1984-1989. It presents description of ice flow directions and sketch maps of drift lithology and geochemistry, and interpretation of that information in terms of bedrock geology, glacial history, and debris transport. The models of ice flow history and of glacial dispersal trains serve as a framework for mineral exploration by drift prospecting in the region. As in most regional studies, there are constraints on fieldwork and geological interpretations that relate to the large size and remote setting of the study area, limited duration of fieldwork (1984-1988), and lack of previous information on drift composition. As a result, the work emphasizes geological variations at regional scales of tens to hundreds of kilometres. It provides a geological context for exploration which is commonly carried out at local (tens of kilometres) and detailed (hundreds of metres to kilometres) scales.

Till is the glacial sediment that forms the basis of this report. It is the geological product of ice flow, and is the surficial sediment best suited for exploration because it has the simplest and most direct compositional relationship to bedrock. Till is derived almost entirely from bedrock as the result of mechanical processes associated with glacial erosion, transport, and deposition. Within glaciated terrain, other surficial sediments are derived primarily from till, and they have been subject to additional physical and chemical alteration that make determination of provenance more difficult.

Models of glacial dispersal trains are based on the distributions of indicator debris defined by geochemical and lithological analyses of till. In bedrock, the indicator sources are easily identified, and well known in their extent. The dispersal models illustrate directions and distances of glacial transport characteristic of different parts of the study area and differences in the provenance of glacial debris.

Detailed examination of outcrop has revealed that older striae are commonly preserved on sheltered outcrop surfaces, recording change in ice flow direction of more than ninety degrees. The record of older striae is widespread and defines coherent patterns of ice flow characteristic of large areas. Ice flow history and resulting patterns of glacial dispersal in Labrador are more complex than recorded by the trends of glacially streamlined landforms illustrated by the Glacial Map of Canada (Prest et al., 1968).

sont en conséquence complexes. La roche en place comprend des séquences de roches sédimentaires et de roches volcaniques de la zone minérale centrale et de la fosse du Labrador, et un socle métamorphique contenant des portions de plusieurs provinces géologiques. Les roches supracrustales se prêtent à une minéralisation en éléments exploitables, en particulier en terres rares, en uranium, en or, en éléments du groupe du platine, et en métaux communs.

Le présent rapport résume les travaux complétés dans le cadre de l'Entente entre le Canada et Terre-Neuve, allant de 1984 à 1989. On y présente une description des directions de l'écoulement glaciaire et des cartes schématiques de la lithologie et de la géochimie du drift, et l'interprétation de cette information du point de vue de la géologie de la roche en place, de l'évolution glaciaire et du transport des débris glaciaires. Les modèles de l'évolution de l'écoulement glaciaire et des traînées de dispersion des glaces servent de cadre à la prospection minérale du drift de la région. Comme dans la plupart des études régionales, les interprétations des études de terrain et les interprétations géologiques présentent certaines limitations associées à la grande étendue et à l'éloignement de la région étudiée, à la durée limitée des études de terrain (1984-1988), et au manque d'information antérieure sur la composition du drift. De ce fait, la recherche met l'accent sur les variations de la géologie à une échelle régionale de quelques dizaines à quelques centaines de kilomètres. Elle constitue un contexte géologique pour l'exploration qui habituellement est réalisée à une échelle locale (dizaines de kilomètres) et à une échelle détaillée (plusieurs centaines de mètres à plusieurs kilomètres).

Le till est le sédiment glaciaire dont traite principalement le présent rapport. Il provient directement de l'écoulement glaciaire, et c'est le sédiment de surface qui se prête le mieux à l'exploration parce que sa composition est simple et directement reliée à la roche en place. Le till est presque entièrement issu de la roche en place, sous l'effet de processus mécaniques associés à l'érosion, au transport et à la sédimentation glaciaires. Dans les terrains glaciés, d'autres sédiments superficiels sont principalement dérivés du till, et ont subi une altération à la fois physique et chimique supplémentaire qui rend difficile toute détermination de leur provenance.

Les modèles des traînées de dispersion glaciaire sont fondés sur les distributions des débris indicateurs définis d'après les analyses géochimiques et lithologiques du till. Dans la roche en place, les sources indicatrices sont facilement identifiées, et leur étendue est bien connue. Les modèles de dispersion illustrent les directions et les distances du transport glaciaire caractéristiques des diverses parties de la région étudiée, et les différences du point de vue de la provenance des débris glaciaires.

Les examens détaillés des affleurements ont révélé que les anciennes stries sont souvent conservées sur les surfaces d'affleurements protégées, et témoignent de variations de la direction de l'écoulement glaciaire, qui dépassent quatre-vingt dix degrés. Les anciennes stries sont répandues et définissent des schémas cohérents d'écoulement glaciaire qui caractérisent de vastes régions. L'histoire de l'écoulement glaciaire et les schémas résultants de la dispersion glaciaire au Labrador sont plus complexes que ne l'indiquent les directions générales des structures glaciaires profilées qui apparaissent dans la Carte glaciaire du Canada (Prest et al., 1968).

In combination with striae, indicator erratics (particularly iron-formation of the Labrador Trough) provide evidence for the characterization of ice flow history in terms of events. The events are associated with regional, coherent patterns of ice flow and with significant distance of glacial transport (tens to hundreds of kilometres) in directions defined by striae sets. The emphasis of this report is on the use of events as a practical guide to modeling glacial dispersal trains and predicting likely pathways of glacial transport characteristic of different parts of the study area. At the present stage of investigation, their interpretation in terms of ice divides and glacial history is preliminary, and only a relative chronology is provided for them.

Five events are defined, named from oldest to youngest I to V. Four (EI, EII, EIII, and EIV) are major, having affected large parts of the area. They are associated with large ice divides of the Labradorean Ice Sheet. The events are further subdivided (e.g. EIIa, EIIb) to distinguish minor change in ice flow related to change in either magnitude or location, or both, of the controlling ice divide. Event V relates to lesser, late glacial flow that was topographically controlled and affected relatively small parts of the area.

In terms of glacial erosion and transport, the characteristics of events vary among and within the areas that they affected. Over the Ashuanipi Complex of western Labrador and eastern Quebec, for example, the compositional record of Event II has not been significantly modified by later ice flow associated with Event III. In that area, the products of older glacial transport remain predominant in the surficial record. To the south, in contrast, Event IV was much more erosive, having largely 'erased' the compositional evidence of Event II. Along its path of ice flow to the east, Event IV appears to have transported debris previously entrained within the ice, with little addition of new material by the continued erosion of bedrock.

Regional dispersal trains that originate with supracrustal sequences of sedimentary and volcanic rock of the Labrador Trough and of the Central Mineral Belt dominate drift composition far beyond their area of outcrop. That is also true for peralkaline granite sources. In comparison with the basement complex, supracrustal bedrock has been subject to preferential glacial erosion because it is relatively softer and little metamorphosed. In addition, it is geochemically distinct from crystalline rock, and its erosional products tend to be preferentially concentrated within the finer size fractions that are most commonly subject to geochemical analyses. Consequently, glacial dispersal trains derived from those sources can be readily defined at low concentrations by both lithological and geochemical methods, and they can mask the expression of other bedrock types tens to hundreds of kilometres outside their source area. Although

En même temps que les stries, les erratiques indicateurs, en particulier la formation ferrifère de la fosse du Labrador, donnent des indices qui permettent de caractériser les épisodes d'écoulement glaciaire. Ces épisodes sont associés à des schémas régionaux cohérents de l'écoulement glaciaire et à un transport glaciaire qui a eu lieu sur des distances significatives (quelques dizaines à quelques centaines de kilomètres), dans des directions définies par des ensembles de stries. Dans le présent rapport, on expose principalement la possibilité d'utiliser ces épisodes pour se guider dans la modélisation des traînées glaciaires de dispersion et dans la détermination des trajets probables du transport glaciaire qui caractérisent divers secteurs de la région étudiée. Au stade actuel des recherches, l'interprétation des épisodes en fonction des lignes de partage glaciaire et de l'évolution glaciaire n'est que préliminaire, et la chronologie qui leur est attribuée n'est que relative.

On a défini cinq épisodes, désignés I à V du plus ancien au plus récent. Quatre d'entre eux (EI, EII, EIII et EIV) sont importants, parce qu'ils ont touché de vastes portions du secteur. Ils sont associés à de grandes lignes de partage des glaces de la calotte labradorienne. Ces épisodes se laissent subdiviser (par exemple EIIa, EIIb), ce qui permet de distinguer des variations mineures de l'écoulement glaciaire associées à une variation soit de la dimension, soit de l'emplacement de la ligne dominante de partage glaciaire, soit des deux à la fois. L'épisode V se rapporte à un écoulement tardiglaciaire de moindre importance, qui a été contrôlé par la topographie et a touché des étendues relativement modestes du secteur.

Du point de vue de l'érosion et du transport glaciaires, les caractéristiques des épisodes varient parmi les secteurs affectés et à l'intérieur de ceux-ci. Par exemple, dans le complexe d'Ashuanipi de l'ouest du Labrador et de l'est du Québec, la colonne compositionnelle de l'épisode II n'a pas été nettement modifiée par l'écoulement glaciaire ultérieur associé à l'épisode III. Dans ce secteur, les produits de l'ancien transport glaciaire restent prédominants dans la colonne chronostratigraphique superficielle. Par contre, au sud, l'épisode IV a été caractérisé par une plus forte érosion, qui a largement «effacé» les indices compositionnels de l'épisode II. Suivant l'écoulement glaciaire de direction est le caractérisant, l'épisode IV a apparemment transporté des débris antérieurement entraînés à l'intérieur des glaces, et peu de matériaux frais ont été apportés par l'érosion continue de la roche en place.

Les traînées régionales de dispersion qui ont eu pour origine les séquences supracrustales de roches volcaniques et sédimentaires de la fosse du Labrador et de la zone minérale centrale sont l'élément essentiel de la composition du drift bien au-delà de leur secteur d'affleurement. Il en est de même pour les sources de matériaux granitiques hyperalcalins. Contrairement au socle métamorphique, les roches supracrustales composant la roche en place ont subi une érosion glaciaire préférentielle, parce qu'elles sont relativement plus tendres et sont relativement peu métamorphisées. En outre, elles sont géochimiquement distinctes des roches cristallines, et les produits générés par l'érosion sont préférentiellement concentrés dans les fractions granulométriques fines, lesquelles font le plus souvent l'objet d'analyses géochimiques. Par conséquent, on peut facilement définir les traînées de dispersion glaciaires issues de ces sources de matériaux, même en faibles concentrations, par des méthodes lithologiques et géochimiques, et ces traînées peuvent masquer l'expression des autres types de roches en place à des dizaines ou même des centaines de kilomètres en dehors de leur far-travelled debris can be a significant control on drift composition, even at low (<5 wt. %) concentrations, the bulk of glacial debris is of local origin and has undergone glacial transport distances less than a few kilometres.

The shape and orientation of glacial dispersal trains are related to their geographic location within the ice sheet. The trains are the net geological product of glacial history, recording continued erosion of bedrock and glacial debris, and change in ice flow direction during succeeding glacial events. Near the ice sheet margins, along the Labrador coast, they are relatively simple in shape and appear as ribbons streamed down-ice from the bedrock source. With increasing distance inland from the coast and increasing complexity of ice flow, dispersal trains are shaped as fans opening eastward from their bedrock source. The fans are the product of transport in two or more directions of ice flow, and their lateral margins are aligned with the two most divergent directions of flow. Near ice divides, where ice flow directions are subject to greatest change, dispersal trains can appear as patches, centred more or less about their source. West of ice divides in western Labrador, fans open generally northward and westward.

Zonation within the fans indicates that glacial dispersal trains originating with older flow events can be partially or completely eroded during succeeding events. The latest glacial events generally are the dominant controls on drift composition, and narrow core zones can be defined by a relative abundance of debris that extend down-ice in the direction of last of ice flow.

For this report clay-sized material has been routinely analyzed to portray geochemical properties and regional geochemical variations in till. That fine fraction is enriched in phyllosilicates such as clay minerals, mica, and chlorite, and it typically contains less quartz and feldspar than coarser size fractions. Clay also has the potential of retaining indicator elements released by weathering of more labile fractions due to its cation exchange capacity, which is typically much greater than that of coarser fractions. As a result of mineralogical differences, metal levels are commonly much greater within clay than within coarser fractions.

Regional geochemical patterns relate to the occurrence and distribution of major lithological units and terrains, including the Labrador Trough; Ashuanipi Complex; peralkaline rocks in the 'Strange' Lake, Flowers River, and Letitia Lake areas; and the Bruce River and Aillik groups of the Central Mineral Belt. All those sources are compositionally distinctive and to varied degrees have been more eroded during glaciation than crystalline basement rocks. The effects of glacial transport on the regional geochemical

région d'origine. Les débris qui ont été transportés sur de grandes distances ont pu influencer de façon significative la composition du drift, même en faibles concentrations (< 5 % en poids), toutefois la majeure partie des débris glaciaires sont d'origine locale et ont été transportés sur des distances de quelques kilomètres au plus.

La configuration et l'orientation des traînées de dispersion glaciaires sont liées à leur situation géographique dans les limites de l'inlandsis. Les traînées sont le produit géologique net de l'évolution glaciaire et témoignent de l'érosion continue de la roche en place et des débris glaciaires, et des variations de la direction de l'écoulement glaciaire durant les épisodes glaciaires successifs. Près des marges de la calotte, le long de la côte du Labrador, elles ont une configuration relativement simple et se présentent sous forme de rubans profilés en aval des glaces, à partir des sources de matériaux arrachés à la roche en place. À mesure que l'on s'éloigne du littoral vers l'intérieur des terres, et qu'augmente la complexité de l'écoulement glaciaire, les traînées de dispersion apparaissent comme des éventails qui s'ouvrent vers l'est à partir du terrain d'origine de leurs matériaux, issus de la roche en place. Les éventails sont le produit du transport dans deux directions au moins d'écoulement glaciaire, et leurs marges latérales sont alignées avec les deux directions d'écoulement les plus divergentes. Près des lignes de partage glaciaire, où les directions de l'écoulement glaciaire montrent les plus fortes variations, les traînées de dispersion peuvent se présenter sous formes de nappes plus ou moins centrées autour de leur terrain d'origine. À l'ouest des limites de partage glaciaire situées dans l'ouest du Labrador, les éventails s'ouvrent généralement vers le nord et vers l'ouest.

La zonation visible dans les éventails indique que les traînées de dispersion glaciaire apparues lors d'épisodes d'écoulement plus anciens peuvent être partiellement ou entièrement érodées au cours des épisodes ultérieurs. Ce sont en général les derniers épisodes glaciaires qui déterminent surtout la composition du drift, et l'on peut définir les étroites zones centrales d'après l'abondance relative des débris qui s'étendent en aval des glaces dans la direction du dernier écoulement glaciaire.

Aux fins de ce rapport, on a effectué des analyses courantes des matériaux de la dimension des argiles, pour décrire les propriétés géochimiques et les variations géochimiques régionales du till. Cette fraction fine est enrichie en phyllosilicates tels que les minéraux argileux, en mica et en chlorite, et contient typiquement moins de quartz et de feldspath que les fractions granulométriques plus grossières. L'argile peut également retenir les éléments indicateurs libérés par l'altération des fractions plus labiles, grâce à sa capacité d'échange ionique, qui typiquement est bien supérieure à celle des fractions plus grossières. Du fait de ces différences minéralogiques, les teneurs en métaux sont habituellement bien plus élevées dans les argiles que dans les fractions plus grossières.

Les schémas géochimiques régionaux sont liés à la présence et à la distribution des principales unités lithologiques et des principaux terrains, en particulier la fosse du Labrador; le complexe d'Ashuanipi; les roches hyperalcalines des régions du lac «Strange», de la rivière Flowers et du lac Letitia; et les groupes de Bruce River et d'Aillik de la zone minérale centrale. Toutes ces roches sources se caractérisent par une composition distincte et ont été à divers degrés plus fortement érodées pendant la glaciation que les roches du socle cristallin. Toutefois, il n'est pas possible de déterminer les effets du transport glaciaire sur les schémas patterns, however, cannot be determined from the form and orientation of contours alone and requires the additional information of till lithology and provenance.

Till lithology and ice flow history are the keys to distinguishing the effects of glacial transport from bedrock composition on the geochemical patterns. Lithological analyses provide an unequivocal basis for defining: 1) distance and direction of glacial transport characteristic of the bulk of glacial debris; 2) till provenance; and 3) variation in the relative contributions of different bedrock sources. Where glacial transport effects can be defined from till lithology, till geochemistry can be of use to mineral exploration by reflecting compositional differences among areas of similar lithology that may not be readily apparent from geological maps.

Regional glacial dispersal trains can affect the geochemical expression of smaller trains originating from sources underlying them. The definition of smaller sources depends on the relative proportions of, and the geochemical contrasts between, local and far-travelled debris. Glacial erosion of compositionally distinctive terrain can lead to the formation of trains that appear either geochemically enriched ('positive' dispersal train) or depleted ('negative' dispersal train). Thus, the geochemical expressions of similar bedrock sources can differ depending on their geographic context within larger trains and on the geochemical properties of those trains.

In comparison with glacial sediments derived from the basement complex, till derived from supracrustal bedrock can be either geochemically enriched or depleted. In western Labrador, for example, positive dispersal trains that are geochemically defined by iron, manganese, lead, and zinc extend west from the Labrador Trough, masking the geochemical expression of crystalline bedrock. The Trough, however, is impoverished in chromium and cannot be a source of the relatively high levels of chromium within till overlying the basement rock. Thus, the chromium concentrations reflect the composition of crystalline bedrock, although they are presumed to be diminished by chromium-poor debris originating within the Trough.

Both positive and negative geochemical dispersal trains can also be defined at local scales, originating with peralkaline bedrock sources such as the Flowers River Igneous Suite. Peralkaline sources are generally enriched in lead, yttrium, niobium, cerium, and zirconium, and depleted in nickel and chromium. Eastward glacial transport from the basement complex across the southern and western margins of the Flowers River Igneous Suite can be defined 5 km to 20 km down-ice by low levels of niobium and lead, and by elevated levels of nickel. Thus, geochemical differences within the Flowers River Igneous Suite must be interpreted within the context of background variations resulting from glacial transport from other sources.

régionaux uniquement d'après la forme et l'orientation des isolignes géochimiques, et l'on doit obtenir de l'information additionnelle sur la lithologie et sur la provenance du till.

La lithologie du till et l'évolution des écoulements glaciaires sont les détails essentiels qui permettent de distinguer les effets du transport glaciaire des effets dus à des variations de la composition de la roche en place sous-jacente. Les analyses lithologiques nous fournissent une base solide pour définir: 1) la distance et la direction du transport glaciaire caractérisant la majeure partie des débris glaciaires; 2) la provenance du till; et 3) les variations de la contribution relative des différentes sources de matériaux issus de la roche en place. Lorsqu'il est possible de définir les effets du transport glaciaire d'après la lithologie du till, on peut appliquer la géochimie du till à la prospection minérale en mettant en relief les différences de composition difficilement discernables sur les cartes géologiques, entre les régions de lithologie similaire.

Les traînées de dispersion glaciaires régionales peuvent influencer l'expression géochimique des traînées plus petites issues de sources sous-jacentes de matériaux. La définition de sources plus petites de matériaux dépend des proportions relatives de débris locaux et de débris d'origine distante et des contrastes géochimiques entre ces débris. L'érosion glaciaire de terrains de composition distincte peut aboutir à la formation de traînées qui sont apparemment soit géochimiquement enrichies (traînées de dispersion «positives»), soit appauvries (traînées de dispersion «négatives»). Ainsi, l'expression géochimique de sources similaires de matériaux issus de la roche en place peut varier selon leur localisation à l'intérieur de traînées plus grandes, et selon les propriétés géochimiques de ces traînées.

Comparativement aux sédiments glaciaires dérivés du socle métamorphique, le till dérivé de la roche en place supracrustale peut être soit enrichi soit appauvri géochimiquement. Par exemple, dans l'ouest du Labrador, des traînées de dispersion géochimiquement caractérisées par la présence de fer, de manganèse, de plomb et de zinc, s'étendent vers l'ouest à partir de la fosse du Labrador, et masquent l'expression géochimique de la roche en place cristalline. Toutefois, la fosse est appauvrie en chrome et ne peut être la source des taux relativement élevés de chrome à l'intérieur du till qui recouvre le socle. Par conséquent, les concentrations de chrome reflètent la composition de la roche en place cristalline, bien qu'elles soient sans doute réduites par des débris pauvres en chrome issus de l'intérieur de la fosse.

On peut aussi définir à des échelles locales à la fois les traînées de dispersion positives et les traînées de dispersion négatives, qui ont pour point d'origine des sources de matériaux issus de la roche en place hyperalcaline, comme la suite ignée de Flowers River. Les roches sources hyperalcalines sont généralement enrichies en plomb, en yttrium, en niobium, en cérium et en zirconium, et sont appauvries en nickel et en chrome. Il est possible de déterminer, à une distance de 5 km à 20 km en aval de l'écoulement glaciaire, le transport glaciaire vers l'est à partir du socle métamorphique à travers les marges sud et ouest de la suite ignée de Flowers River, d'après les faibles concentrations de niobium et de plomb et d'après les concentrations élevées de nickel. Ainsi, on doit interpréter les différences géochimiques existant à l'intérieur de la suite ignée de Flowers River dans le contexte des variations de fond qui résultent

Geochemical differences indicated by till within and among bedrock units can represent a basis for establishing a strategy for mineral exploration, allowing focus of exploration effort to be established.

Physical and chemical soil-forming processes alter the geochemical properties of parent materials, resulting in vertical zonation in what may have originally been a uniform glacial deposit. Thus, soil formation during postglacial time can change the geochemical properties of till and its compositional relationship with bedrock. The effects of weathering vary with depth, and geochemical properties are significantly changed within a metre of surface, and likely deeper. Therefore, the position of a sample within a soil profile can be critical to the interpretation of geochemical data especially at detailed scale. Logistical constraints related to time, expense, and sample access have meant that samples in the regional collection are all from the near-surface, and as such have been subject to postglacial weathering.

Labrador soils are generally podzolic. Their principal features are: 1) concentrations of most trace elements (copper, zinc, nickel) are least in the Ae horizon, and generally increase with depth through the B and upper C horizons; 2) vertical variations in trace elements generally follow the distribution of manganese and would appear to result from the removal of those elements from both A and B horizons during soil formation; 3) lead and chromium can be concentrated within the Ae horizon, and as such are notable exceptions; and 4) Within the upper part of the C horizon, trace element concentrations vary least with depth, and are generally greater than within overlying horizons. Trace elements can accumulate within reducing horizons (Bg) at the contact with underlying bedrock.

The marked geochemical variations with depth indicate that soil development is an important concern of exploration, particularly for programs based on analyses of the upper B horizon, where trace element variation with depth is typically greatest. Furthermore, geochemical patterns derived from sampling programs carried out over relatively small areas can be strongly biased by variations in soil development among sample sites.

Unweathered glacial sediment provides the most reliable basis for exploration because geochemical analyses can be interpreted in terms of mechanical processes of glacial transport. The depth of weathering renders unweathered material effectively inaccessible without mechanical means such as backhoe or drill. Consequently, a strategy for geochemical exploration is to sample the least weathered part of the soil profile as the nearest approximation of parent material, including either the lower portion of the B or upper C horizons. Within well drained profiles, the BC and C horizons commonly occur a half to a full metre below surface.

du transport glaciaire à partir d'autres sources. Les différences géochimiques qui existent dans les unités lithologiques de la roche en place et entre celles-ci peuvent servir à établir une stratégie de la prospection minérale, ce qui permet de concentrer les efforts de prospection.

Les processus physiques et chimiques de pédogenèse modifient les propriétés géochimiques des matériaux parentaux, et créent une zonation verticale dans ce qui initialement a peut-être été un dépôt glaciaire uniforme. Ainsi, la pédogenèse qui a eu lieu pendant l'époque post-glaciaire a pu modifier les propriétés géochimiques du till et les relations existant entre sa composition et la composition de la roche en place. Les effets de l'altération varient avec la profondeur, et les propriétés géochimiques varient fortement sur une profondeur d'un mètre à partir de la surface, et probablement sur une plus grande profondeur. Par conséquent, la situation d'un échantillon dans un profil du sol peut être de la plus grande importance pour l'interprétation des données géochimiques, surtout à une échelle détaillée. En raison des limitations logistiques associées à la durée, aux coûts, et aux possibilités d'échantillonnage, les échantillons de la collection régionale proviennent tous de la subsurface, et de ce fait, ont subi l'altération post-glaciaire.

Les sols du Labrador sont généralement podzoliques. Leurs principaux caractères sont les suivants: 1) les concentrations de la plupart des éléments traces (cuivre, zinc, nickel) sont minimales dans l'horizon Ae, et augmentent généralement avec la profondeur dans l'ensemble de l'horizon B et dans la partie supérieure de l'horizon C; 2) les variations verticales dans la concentration des éléments traces suivent généralement la distribution du manganèse et apparemment résultent du retrait de ces éléments à la fois de l'horizon A et de l'horizon B pendant la pédogenèse; 3) le plomb et le chrome peuvent se concentrer dans l'horizon Ae, et de ce fait constituent des exceptions notables; et 4) c'est dans la partie supérieure de l'horizon C que les concentrations d'éléments traces varient le moins avec la profondeur, et elles sont généralement supérieures à celles relevées dans les horizons sus-jacents. Les éléments traces peuvent s'accumuler dans des horizons réducteurs (Bg) au contact de la roche en place sous-jacente.

Les variations géochimiques marquées en fonction de la profondeur indiquent que la pédogenèse est un important détail de la prospection, en particulier dans le contexte de programmes basés sur les analyses de la partie supérieure de l'horizon B, où la variation de la concentration des éléments traces est habituellement maximale. De plus, les schémas géophysiques tirés des programmes d'échantillonnage qui ont été réalisés sur des étendues relativement modestes peuvent être fortement biaisés par des variations de la pédogenèse parmi les sites d'échantillonnage.

Les sédiments glaciaires non altérés représentent la base la plus fiable de prospection, puisque l'on peut interpréter les analyses géochimiques en fonction des processus mécaniques de transport glaciaire. La profondeur de l'altération rend les matériaux non altérés pratiquement inaccessibles sans moyens mécaniques tels que l'emploi d'une pelle rétrocaveuse ou d'une foreuse. Par conséquent, l'une des stratégies de prospection géochimique consiste à échantillonner la partie la moins altérée du profil du sol en la considérant comme l'approximation la plus proche du matériau parental, qui comprend soit la portion inférieure de l'horizon B ou la portion supérieure de l'horizon C. Dans les profils bien drainés, les horizons BC et C se trouvent souvent entre un demi-mètre et un mètre au-dessous de la surface.

INTRODUCTION

Within glaciated terrain, mineral exploration by drift prospecting is based on tracing indicators of mineralization within glacial sediments in an up-ice direction to locate their bedrock origins. Indicators can include mineralized erratics as well as the results of geochemical, lithological, and mineralogical analyses. Variations in glacial sediment type and in the direction of glacial transport, however, can obscure the compositional relationship between surficial deposits and bedrock. Thus, mineral tracing is not always a simple task. Effective exploration requires understanding of ice flow history, the geological origins of the glacial deposits, and the mechanisms by which glaciers erode, transport, and deposit debris.

As part of the Canada – Newfoundland Mineral Development Agreement, a study of ice flow history and of drift composition was carried out in Labrador to establish a geological framework for drift prospecting and to develop exploration methods suited to the region. The area of study lies within the Canadian Shield and includes most of central Labrador and parts of adjacent Quebec. It is bounded by the Labrador coast and longitude 70°W, and by latitudes 52° and 57°N (Fig. 1). From the perspective of Quaternary geology and the Laurentide Ice Sheet, the area extends from the geographic centre of the Labradorean Sector in Labrador-Quebec (Prest, 1984) to its margins along the Labrador coast. Thus, the region has experienced marked variation in ice flow direction and glacial history, and patterns of glacial dispersal are correspondingly complex. Bedrock includes sequences of sedimentary and volcanic rock of the Central Mineral Belt and of the Labrador Trough, and a basement complex comprising parts of several geological provinces. The supracrustal rocks have potential for economic mineralization, including rare-earth elements (REE), uranium, gold, platinum group elements (PGE), and base metals (Fig. 2).

This report is a summary of the Labrador Mineral Development Agreement work. It presents description of ice flow directions and sketch maps of drift lithology and geochemistry, as well as interpretation of that information in terms of bedrock geology, glacial history, and debris transport. As in most regional studies, there are constraints on geological interpretations that relate to the large size and remote setting of the study area, limited duration of fieldwork (1984-1988), and lack of previous information on drift composition. As a result, the work emphasizes geological variations at regional scales of tens to hundreds of kilometres. The models of ice flow history and of glacial dispersal trains serve as a geological context for exploration which is commonly carried out at local (tens of kilometres) and detailed (hundreds of metres to kilometres) scales. Definitions of terms used in this report are provided in Appendix 1.

Till is the glacial sediment that forms the basis of this report. Till is the geological product of ice flow and is the surficial sediment best suited for exploration because it has the simplest compositional relationship to bedrock. It is derived almost entirely from bedrock as the direct result of mechanical processes associated with glacial erosion, transport, and deposition. Within glaciated terrain, other surficial sediments are derived primarily from till, and they have been subject to additional physical and chemical alteration that make determination of provenance more difficult.

Models of glacial dispersal trains are based on the distributions of indicator debris within till. The bedrock sources of indicators are easily identified, and of well known extent. The dispersal models portray directions and distances of glacial transport characteristic of different parts of the study area. As found by other workers (e.g. Bouchard and Martineau, 1985; Veillette, 1986), ice flow history and resulting patterns of glacial dispersal in Labrador are more complex than recorded by the trends of glacially streamlined landforms illustrated by the Glacial Map of Canada (Prest et al., 1968).

Review of previous work

Quaternary geology

Quaternary map coverage of Labrador and eastern Quebec is incomplete. Studies have been carried out in relatively small areas near communities such as Goose Bay and Schefferville (Hare, 1955; Henderson, 1959; Ives, 1960; Gray, 1969) and, more recently, have included areas of mineral exploration at 1:50 000 scale (Batterson et al., 1985; Batterson and LeGrow, 1986; Batterson et al., 1987; Batterson et al., 1988). Reconnaissance mapping of southern Labrador has been completed at a scale of 1:250 000 (Fulton and Hodgson, 1979; Fulton, Hodgson, and Minning, 1979, 1980a, b, c, d, 1981a, b, c; Fulton, Hodgson, Minning, and Thomas, 1974, 1980a, b; Fulton, Hodgson, Thomas, and Minning, 1981; Fulton, Minning, and Hodgson, 1981; Klassen and Paradis, 1990), and has been compiled at a scale of 1:500 000 for southeastern Labrador (Fulton, 1986a, b).

The regional distribution and trends of glacially streamlined landforms, eskers, and ribbed (Rogen) moraine are recorded on the Glacial Map of Canada (Prest et al., 1968). Within the area of study, the Glacial Map outlines ice flow trends that appear to be produced by ice flowing generally from western Labrador southward to eastward across central Labrador toward the Labrador coast. North and west of Schefferville, ice flow trends are generally northward, and define part of a regional pattern of ice flow convergent towards Ungava Bay. Patterns defined by streamlined landforms are mimicked by esker systems, which are commonly interpreted as late glacial. The zone separating northward convergent ice flow from southward divergent patterns has been defined as the location of an ice divide within the Labradorean sector of the ice sheet (Flint, 1971, Fig. 18-7, p. 480; Hillaire-Marcel, 1981; Dyke et al., 1982).

Detailed studies of glacial deposits and landforms indicate that western Labrador and eastern Quebec have undergone complex ice flow (e.g. Henderson, 1959; Hughes, 1964), and that during deglaciation the last residual ice mass occupied the Schefferville region (Ives, 1960; Kirby, 1966; Derbyshire, 1962). There, drift composition and striae have provided

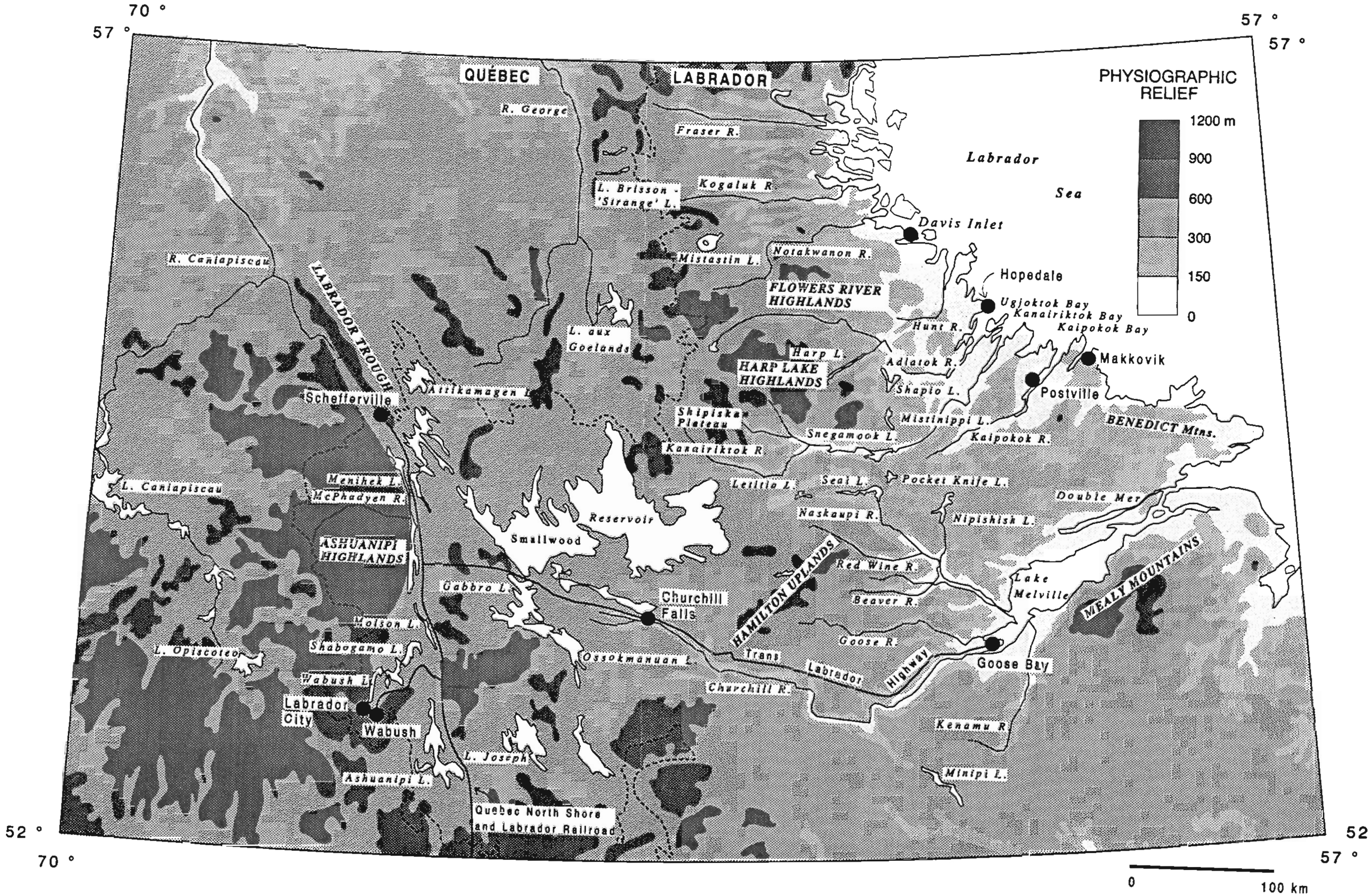


Figure 1. Location map of the study area, including names of physiographic features.

evidence of five distinct ice flow directions (Klassen and Thompson, 1987, 1988, 1989), not all of which are evident by examination of glacially streamlined landforms. Elsewhere in the study area, striae also record 'older' directions of ice flow that are not obvious in the surficial record (Klassen and Bolduc, 1984; Thompson and Klassen, 1986).

Drift prospecting and geochemical surveys

Reports on drift composition and drift prospecting in central Labrador are few, principally including unpublished records of BRINCO Mining Co. (see Ryan, 1984), and 1:50 000 scale mapping projects recently undertaken by the Newfoundland Department of Mines and Energy in areas of mineral exploration near 'Strange' Lake (Lac Brisson) (Batterson et al., 1985; McConnell and Batterson, 1987; Batterson, 1989a, b), Letitia Lake (Batterson and LeGrow, 1986) and parts of the eastern Central Mineral Belt (Klassen, 1983, 1984; Batterson et al., 1987; Batterson et al., 1988). One of the earliest geochemical surveys in eastern Canada was conducted in south-central Labrador where geochemical analysis of sediments within streams led to the discovery of lead, thorium, and niobium (columbium) mineralization near Letitia Lake (Brummer, 1960).

Geochemical surveys of lake sediments and "soils" have been conducted throughout Labrador (Kerr and Davenport, 1986; Hornbrook and Friske, 1990), including the Flowers River Highlands and the Labrador Trough (McConnell, 1984), and the Ashuanipi Complex, western Labrador (McConnell and Newman, 1988; Butler, 1988). The surveys have lead to recognition of regional variations in trace element concentrations within surficial sediments, and to the identification of areas characterized by geochemical "anomalies".

In eastern Labrador, search for uranium mineralization has included numerous investigations based on drift geochemistry and boulder tracing, most of which have been conducted by BRINCO Mining Co. Helium in lake water has been directly associated with the distribution of uranium in bedrock in the region of the Kaipokok River (Clarke et al., 1977). North of Goose Bay, uranium mineralization was found in bedrock of the Grenville Province following investigation of anomalies defined by the Uranium Reconnaissance Program (URP) of the Geological Survey of Canada (Kerswill and McConnell, 1979; Erdmer, 1984).

In the Churchill Falls area, the distribution and composition of heavy minerals in streams has been related to underlying bedrock, and geochemical data indicate 'anomalous' metal patterns of uncertain origin (Callahan, 1980, 1981). West of the Labrador Trough, in areas underlain by Archean basement rocks of the Ashuanipi Complex, bedrock and erratics have been analyzed for gold, and target areas that are suitable for further exploration have been identified on the basis of anomalous samples (Thomas and Butler, 1987).

Physiography

The physiography of central Labrador broadly reflects regional variations and structural trends in bedrock geology, and physiographic terms and descriptions in this report are intended to illustrate that linkage (Fig. 1, 2). Published descriptions of physiography are presented by Douglas and Drummond (1955), Hare (1955), Bostock (1970), Greene (1974), and Rogerson (1981). Bedrock is described in a following section.

Central Labrador displays marked variation in physiographic character, and represents parts of several of the Physiographic Regions of Canada described by Bostock (1970). The region generally comprises terrain of low relief, typical of much of the Canadian Shield. It is punctuated by rugged highland plateaus and areas of elongate hills and valleys, and it is cut by deeply incised valleys extending eastward from the coast. Typical Shield terrain occupies much of central Labrador in areas underlain by granitic gneisses of the Grenville, Churchill, and Nain geological provinces, and by sedimentary rock of the southern Labrador Trough. Such terrain generally lies below 500 m a.s.l. and is characterized by low relief (<50 to 100 m) and a uniform skyline. Bedrock hills are commonly streamlined by glacial abrasion, and areas of extensive drift cover are characterized by poor drainage and numerous lakes, many of which are elongate in the direction of last ice flow. To the north, the Shield forms part of an extensive uplifted paleoplain of presumed Tertiary age, rising eastward from the interior of the Labrador Peninsula to the coast where its truncated eastern margin comprises the Torngat Mountains, north of Fraser River.

There are several distinctive areas that stand as rugged highland plateaus having surface elevations of 600 to 1000 m a.s.l. and topographic relief of 100 to 300 m. They include: 1) the Ashaunipi Highlands to the west, which are underlain by high grade metamorphic rocks of the Superior and Grenville provinces; 2) the Harp Lake and Flowers River highlands, and the Mealy and Benedict mountains in the central and eastern parts, which are underlain by intrusive complexes; and 3) the Hamilton Uplands, which define an elongate zone extending northeast across the central region and are underlain by Grenville gneisses and gabbroic rocks. Along the eastern margin of the study area, the Benedict Mountains form a prominent coastal rampart between 500 and 700 m a.s.l. that is underlain by granitic intrusive rocks of the Trans-Labrador Batholith.

Volcanic and sedimentary bedrock sequences in the Labrador Trough and Seal Lake areas are characterized by elongate, subparallel hills and valleys having relief of 100 to 200 m. The topographic trends closely reflect variations in bedrock lithology and structure.

Deep valleys cut into Shield terrain extend inland from the Labrador coast. They include the Churchill River-Lake Melville system, which is the most prominent, and the Kaipokok, Kanairiktok, Adlatok, and Hunt river valleys. The

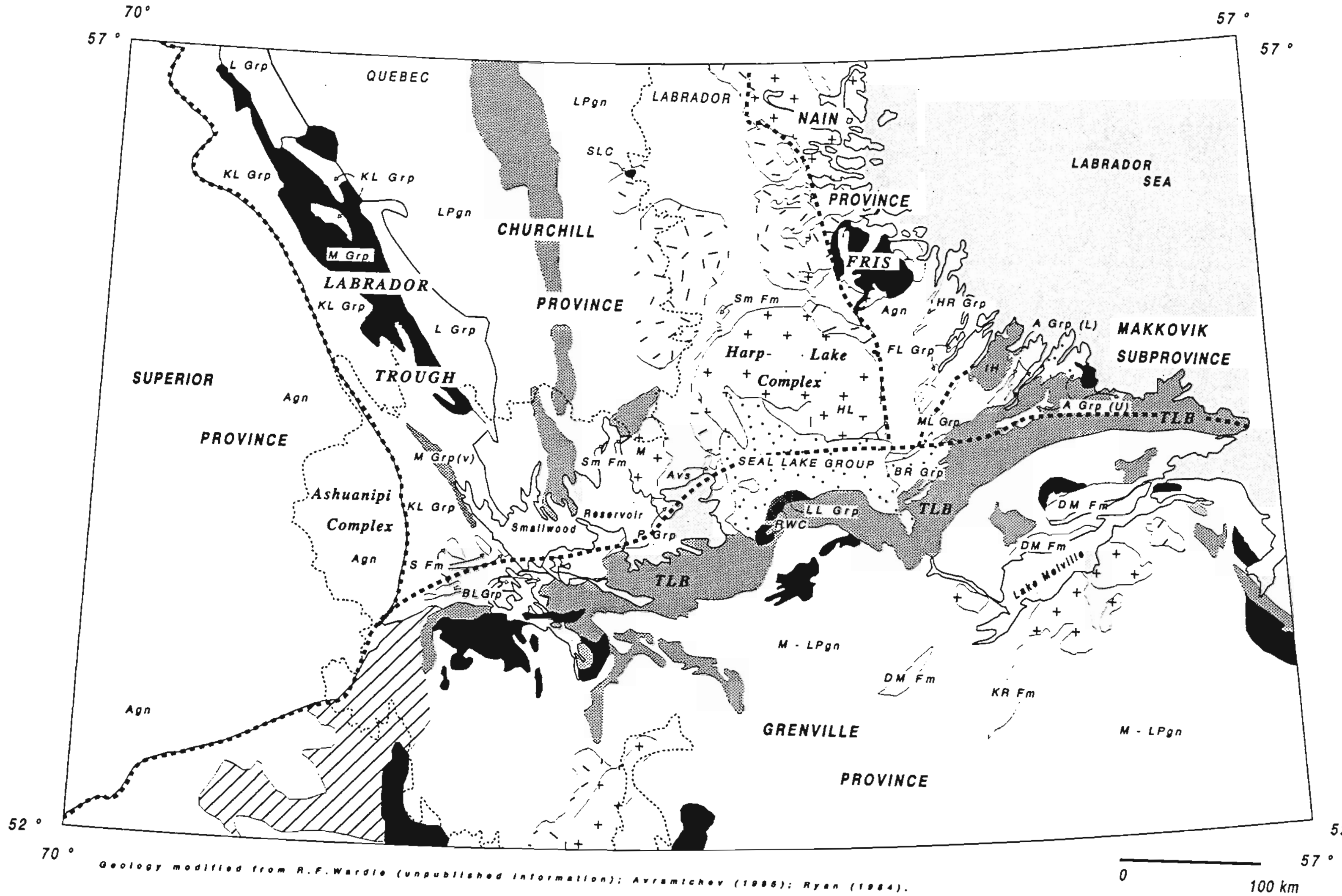


Figure 2. Bedrock geological map illustrating the principal geological units (A geological outline map and legend is also given by Appendix 2, Fig. A2-1).

SEDIMENTARY, VOLCANIC, and METAMORPHIC ROCKS

LOWER CAMBRIAN and UPPER PROTEROZOIC

Sandstone, conglomerate	DM Fm	Double Mer Formation
	KR Fm	Kenamu River Formation

MIDDLE PROTEROZOIC

CENTRAL MINERAL BELT	SLG	Seal Lake Group
	BR Grp	Bruce River Group
	ML Grp	Martin Lake Group
	A Grp(U)	Aillik Group (upper)
	A Grp(L)	Aillik Group (lower)

Metamorphosed equivalents of Kaniapiskau Supergroup [Labrador Trough]

M - LPgn Undifferentiated Igneous and Metamorphic rocks of the Grenville Province

LOWER PROTEROZOIC

Sedimentary and volcanic rock, including:	Sm Fm	Siamarnekh Formation
	BL Grp	Blueberry Lake Group
	P Grp	Petscapiskau Group
Kaniapiskau Supergroup [Labrador Trough] including:	S Fm	Sims Formation
	KL Grp	Knob Lake Group
	D Grp	Doublet Group
	L Grp	Laporte Group

LPgn Undifferentiated Lower Proterozoic to Archean Gneisses of the Churchill Province

ARCHEAN

Agn Undifferentiated Gneisses, Paragneisses of the Superior and Nain Provinces

Avs Undifferentiated Volcanic and Sedimentary Rocks of the Nain Province, including:	HR Grp	Hunt River Group
	FL Grp	Florence Lake Group

INTRUSIVE ROCKS

MIDDLE PROTEROZOIC

Granite

MIDDLE to LOWER PROTEROZOIC

Alkaline, peralkaline granitoid intrusive rock, including:	LL Grp	Letitia Lake Group
	RWC	Red Wine Complex
	SLC	'Strange' Lake Complex
	FRIS	Flowers River Igneous Suite
Anorthosite, including:	HL	Harp Lake anorthosite
	M	Michikamau anorthosite
Gabbro, including:	M Grp	Montagnais Group (Wakuach Gabbro; (v) associated Felsic Volcanic rock)

LOWER PROTEROZOIC

Granite, including:	TLB	Trans-Labrador Batholith
	IH	Island Harbour

Geological province boundary

Figure 2 legend

valleys are subparallel, trending generally east-west, and appear controlled by bedrock structure. Sedimentary bedrock of late Proterozoic or early Paleozoic age occurs as outliers within the Lake Melville basin and the Churchill and Kenamau river valleys. Its occurrence only on valley floors indicates that the valleys are of preglacial origin.

Quaternary deposits tend to be thin (<2 m) and discontinuous, having minimal physiographic expression. Exceptions occur: 1) within and fifty kilometres south and east (down-ice) of the southern Labrador Trough where till tends to be 2 m to more than 5 m thick and characterized by streamlined, hummocky, and morainic landforms; 2) in valleys which are commonly floored by extensive esker and outwash complexes; and, 3) in coastal areas, where marine and glaciomarine sediments in places form blanket deposits below postglacial marine limit (approximately 100 m a.s.l.).

Bedrock geology

A geological outline of central Labrador is necessary as a background guide for interpretation of drift composition (Fig. 2; Appendix 2, Fig. 2A-1). It is derived from information provided by R.J. Wardle, Newfoundland Department of Mines and Energy (unpub. data), and from Greene (1974), Baragar (1981), Ryan (1981, 1984), and Avramtchev (1985). The reader is referred to those references for detailed geological descriptions.

The study area occupies parts of four structural geological provinces of the Canadian Shield; the Superior, Churchill, Grenville, and Nain, which includes the Makkovik Subprovince (Fig. 2). The boundaries between provinces can be gradational and poorly defined, particularly along the northern margin of the Grenville Province (Gower et al., 1980). According to Greene (1974, p. 9) the bedrock "... is composed essentially of intrusive and high grade metamorphic rocks overlain in several areas by less deformed assemblages of sedimentary and volcanic sequences". Summary geological descriptions were given by Stockwell et al. (1970), Greene (1974), Taylor (1979), and Wardle et al. (1986).

The Superior structural province is represented by the Archean Ashuanipi Complex west of the Labrador Trough. The Complex consists of granulite facies felsic gneisses and granitic intrusive rocks and, north of McPhadyen River, includes large areas of pyroxenite, peridotite, and gabbroic sills (Thomas and Butler, 1987; Percival, 1987; Percival and Girard, 1988).

Basement rocks of the Churchill Province include amphibolite and granulite facies felsic gneisses of Archean and Early Proterozoic ages that have north to northwest structural trends. The basement complex is overlain by supracrustal assemblages of the Labrador Trough and Seal Lake Group, which are of Early and Middle Proterozoic age, respectively, and is intruded by anorthosite and other felsic intrusive rocks. Other supracrustal assemblages include: 1) quartzite of the Sims Formation; 2) clastic sedimentary rock of the Petscapiscau Group underlying and adjacent to Smallwood Reservoir, 3) volcanic rock of the Blueberry Lake Group, west of the Reservoir, which has experienced varied degrees of metamorphism (Wardle, 1985), and 4) nearly unmetamorphosed red sandstone of the Siamarnekh Formation, northeast of the Reservoir.

The Labrador Trough contains a deformed sequence of sedimentary and volcanic rocks (Wardle and Bailey, 1981). To the west, nearly unmetamorphosed sediments, including sandstone, shale, chert, dolomite, iron-formation, and felsic volcanic rock of the Knob Lake Group rest unconformably on bedrock of the Superior Province. To the east, mafic volcanic rock of the Doublet Group is either in fault contact or gradational contact with gneisses of the Churchill Province. Both groups within the Trough are intruded by gabbro and ultrabasic sills of the Montagnais Group, which includes the Wakuach Gabbro.

Large plutonic complexes of gabbroic, granitic, and anorthositic compositions occupy much of the Churchill Province within the area of study, including the Harp Lake and Michikamau anorthosites. The intrusive rocks do not display evidence of regional metamorphic overprint (Wardle, 1985; Emslie, 1980).

The Nain Province occupies coastal Labrador, and includes 1) amphibolite facies gneisses, 2) deformed metavolcanic rocks of the Florence Lake and Hunt River groups (Ermanovics and Raudsepp, 1979), 3) foliated granites, 4) gabbroic and granitic intrusive rocks of the Nain Igneous Complex, and 5) alkaline and peralkaline intrusive and volcanic rocks of the Flowers River Igneous Suite (FRIS) (Hill, 1982). The Province is characterized by north-trending structures. The Makkovik Subprovince is characterized by east-trending structures, and includes gneisses that have undergone strong retrograde metamorphism, and supracrustal (Aillik Group) and granitic rocks.

The Grenville Province consists of reworked extensions of the older Superior, Churchill, and Makkovik structural provinces, a later granitic intrusive complex named the Trans-Labrador Batholith, and a group of lithotectonic terranes characterized by high grade metamorphism and plutonism (Gower and Owen, 1984; Wardle et al., 1986). The Trans-Labrador Batholith forms a linear belt along the northern margin of the Grenville Province, striking generally east across much of the area of study. Clastic sedimentary rocks of Late Proterozoic to early Cambrian age occur within the valleys of Churchill River and Lake Melville (Double Mer and Kenamu River formations) (Erdmer, 1984).

Volcanic, sedimentary, and peralkaline intrusive rocks of Aphebian to Neohelikian ages occupy a zone along the northern foreland of the Grenville Province. The rocks include Aillik, Moran Lake, Bruce River, Letitia Lake, and Seal Lake groups. Collectively, the supracrustal rocks form the Central Mineral Belt of Labrador, so-named because it is characterized by numerous base metal and uranium occurrences and has been the focus of mineral exploration in central Labrador (Ryan, 1984). The rocks unconformably overlie igneous and metamorphic rocks to the north, and are in either tectonic or intrusive contact with high-grade metamorphic and intrusive rocks of the Grenville Province to the south. They have been subject to varied degrees of deformation and metamorphism associated with the Churchill, Nain, and Grenville provinces.

Economic geology

Mineral production in Labrador is related to iron ore from mines in Wabush-Labrador City, western Labrador; there are no operating mines elsewhere. Mineral occurrences are widespread within supracrustal sequences of the Labrador Trough and the Central Mineral Belt (CMB). Maps of mineral occurrences are available at 1:250 000 scale from the Newfoundland Department of Mines and Energy (Mineral Occurrence Map 7636; 7637; 7639; 7640; 7641; 7644; 7648; 7649; 7650; 7651; 7652; 7653; 7654A; 7654B; 7655; 7656; 7657; 8336; 8337; 8347; 8422).

In the eastern Labrador Trough, mafic and ultramafic intrusive rocks contain copper, nickel, and zinc showings, and have potential for platinum group minerals (Scott, 1988). Mineralization in the Central Mineral Belt is varied, and includes copper, lead, and zinc sulphides, and uranium, particularly within sedimentary and volcanic rocks of the Bruce River Group (Ryan, 1984; North and Wilton, 1987; Wilton, 1988). Uranium mineralization, including the sub-economic Kitts and Michelin deposits, is widespread within the Aillik Group to the east (Gandhi, 1978; Ryan, 1984), and lead-zinc, molybdenite, and uranium mineralization occur within the Upper Aillik Group (Wilton and Wardle, 1987). Native copper and copper sulphide mineralization occur within basalts and shales of Seal Lake Group (Gandhi and Brown, 1975).

Exploration has also been conducted in Archean greenstone belts (e.g. Florence Lake Group) for gold as well as base metal sulphides. More recently, there have been reports of a potential for gold and platinum mineralization in the high-grade metamorphic terrane of the Ashuanipi Complex (Thomas and Butler, 1987; Percival, 1987; Percival and Girard, 1988), and of base metal and uranium mineralization within the Grenville Province (Kerswill and McConnell, 1979; Gower and Erdmer, 1984).

Neohelikian peralkaline igneous centres have also been subject to mineral exploration. They include the 'Strange' Lake alkaline complex (Zr-Y-Nb-Be-REE) (Miller, 1988); the Flowers River Igneous Suite (F, Pb, Zn, among other elements) (Hill, 1982), and the Letitia Lake volcanic complex (Y-Nb-Be) (Hill and Thomas, 1983; Miller, 1987, 1988), all of which contain mineralization of potential economic significance.

Within the Harp Lake Complex, iron-titanium oxide occurs in a few locations, and sulphide mineral occurrences, including chalcopyrite, are widespread (Emslie, 1980). The potential for economic mineralization and geochemical characteristics of granitoid plutons of the Trans-Labrador Batholith have been described by Kerr (1988).

Climate, vegetation, and soils

There are marked changes in climate and vegetation across Labrador; between coastal and inland areas, and among highlands and low-lying regions (Banfield, 1981). Inland, the area of study is characterized by a continental climatic regime, with annual precipitation of 900 to 1100 mm, long, severe winters and short, cool summers. Mean daily air temperatures vary from about -16 to -22°C in winter (February), to 12 to 14°C in summer (July). Coastal regions are less continental, and are characterized by frequent storms and strong winds, and weather conditions are subject to marked change with shift in wind direction between onshore and offshore. Annual precipitation is 1000-1200 mm, and rain and fog can present important hindrances to fieldwork near the coast.

Southern Labrador lies within the zone of Boreal Woodland, and includes lesser area of Forest Tundra, particularly near coastal highland areas and highland plateaus of the interior (MacPherson, 1981, Fig. 6-1). Woodlands are dominated by spruce, and tree development varies depending on soil substrate and climate. To the north and west, interior regions lie within the zone of discontinuous permafrost.

Most soils in Labrador are Podzols, which is a soil Order that occurs typically "...in coarse to medium textured, acid parent materials, under forest or heath vegetation in cool to very cold, humid to per-humid climates." (Canadian Soil Survey Committee, Subcommittee on Soil Classification, 1978, p. 93). Podzolic soils are characterized by B horizons with accumulations of amorphous material composed mainly of humified organic matter combined in varied degrees with aluminum and iron. The soils generally have organic surface horizons and an underlying pale horizon that has been strongly oxidized and leached. The development of soil horizons depends on texture and composition of parent materials, forest cover, moisture, and drainage.

FIELD METHODS

Till was collected at densities from 10 to 20 samples per km^2 (detailed scale) to 1 to 2 per 100 km^2 (regional scale). Sample intervals were decreased in areas of known mineral potential, such as the Central Mineral Belt and parts of the Labrador Trough. In regions having limited potential, such as high-grade metamorphic terrane of the Grenville Province, sampling densities were decreased and are typically 1 per 100 to 200 km^2. Most samples were collected from hilltops because they are relatively exposed and permit direct access by helicopter (Fig. 3). Along roads, such as the Trans-Labrador Highway, sampling was conducted by truck. The collection used to characterize regional variation in drift composition contains over 2300 samples.

Samples typically weighed 2 to 4 kg, and were collected from the base of pits at depths of 50 to 80 cm, where till thicknesses were great enough, or near the bedrock contact in areas of thin drift. Where soil profiles were evident, samples were collected from within the C or lower B soil horizons. That part of the soil profile can be readily sampled and represents the zone where geochemical variation with depth is least (Klassen, 1984). Location of the sample in the context of soil horizons is estimated qualitatively by colour variation related to organic matter and to secondary oxides and hydroxides of iron and manganese. Samples were also collected from "mud boils" found in areas of tundra vegetation where periglacial action has prevented soil horizonation. In all cases effort was made to collect the least weathered sample, and to avoid contaminants such as roots or finely divided organic material that can affect geochemical analytical results. Less than 5% of samples have been significantly altered by weathering, as indicated by low manganese levels (<250 ppm), and they have been removed from the geochemical data base used to plot geochemical maps.

Figure 3. Till sampling procedures. Samples were collected at more than 2300 sites throughout the area of study, commonly from hilltop locations. Samples (2 to 4 kg) were collected at the base of pits, from the least weathered part of the soil profile (B or BC). GSC 20483-J

Samples include till deposited by varied mechanisms, including lodgement, meltout, and ablation. Lodgement till has been deposited directly from glacier ice, and it is typically massive. Meltout till has been deposited at the base of a glacier during meltout, and can be partially stratified. Ablation till has been deposited from ice during melting, and includes debris carried above the base of the ice sheet. It is less compact and can be more stony. At most collection sites, however, drift is thin (<2 m) and till facies were not distinguished, either because primary depositional structures have been obliterated, or because they were not evident in the walls of sample pits. Fewer than 5% of the samples were collected from low-lying areas and include sediments deposited by topographically controlled tongues of ice under late glacial conditions, and from meltwater. As such, they could have a provenance and transportation history different from till at nearby hilltop locations (e.g. Batterson et al., 1987).

LABORATORY PREPARATION AND ANALYSES

Samples were returned from the field in plastic bags for preparation and analyses. In the laboratory, part of each sample was retained for storage, and the remainder processed for lithological and geochemical analyses (Fig. 4). The clay-sized fraction (<0.002 mm) was routinely separated by centrifuge settling (Jackson, 1969), with laboratory methods modified to accommodate large numbers of samples and to recover at least 5 g of material for geochemical analyses. Briefly, clay separation includes: 1) suspension of a 350 g sample in water with sodium hexametaphosphate added as dispersant; 2) removal of silt and sand (>0.002 mm) from the muddy suspension by centrifuge settling; 3) collection of clay (<0.002 mm) from the supernatant suspension by a second,

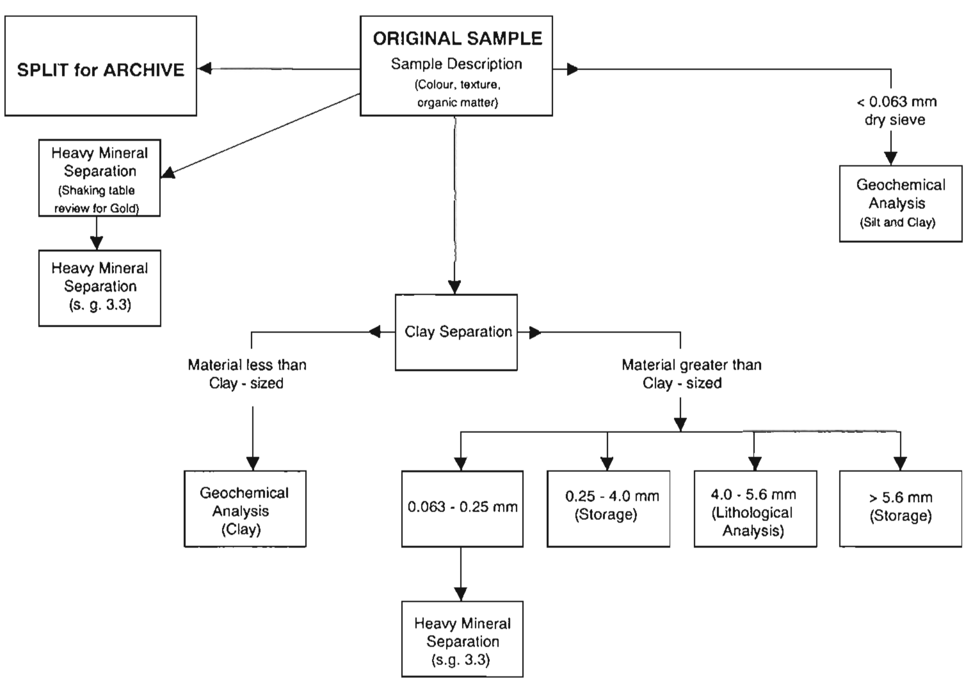


Figure 4. Schematic chart of sample processing in the laboratory.

longer period of settling at greater centrifuge speed. Coarse sediment (>0.002 mm) washed within the clay separation circuit was retained for separation of heavy minerals (0.063 to 0.250 mm) and for lithological analyses of pebbles (4 to 5.6 mm). Silt and clay (<0.063 mm) were obtained by sieving samples that had been dried at low temperature.

Geochemical analyses

The clay-sized fraction of most samples was analyzed for copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), chromium (Cr), iron (Fe), and manganese (Mn) by atomic absorption spectrophotometry, and for uranium (U) by delayed neutron activation methods (Table 1). The silt and clay-sized fraction was analyzed for cerium (Ce), yttrium (Y), niobium (Nb), strontium (Sr), thorium (Th), and zirconium (Zr) by X-ray fluorescence (XRF) methods, and for gold (Au) by instrumental neutron activation, fire assay, and atomic fluorescence spectrophotometry (Table 1).

Geochemical analyses were by Bondar-Clegg and Co. (Ottawa) (1984 to 1988), and by Chemex (Vancouver) (1987, 1988) under contract with the Geological Survey. Results were reported in Geological Survey of Canada Open Files (1282, Klassen et al., 1986), (1318, 1319, 1320, Thompson et al., 1986a, b, c) at map scales of 1:250 000; and in Open File 1901 at 1:500 000 (Thompson et al.,1988). Open File 2170 presents summary geochemical maps and data tables (Klassen and Thompson, 1990).

Heavy mineral analyses

Sand-sized heavy minerals (0.250 to 0.063 mm) were obtained by settling within methylene iodide (s.g. 3.3), and the magnetic fraction separated by hand magnet. For mineralogical analyses, heavy mineral grains were mounted on glass slides, and their mineralogy determined with the aid of binocular and petrographic microscopes. The abundance of heavy minerals was estimated by point counting either 300 grains or, when a specific indicator mineral was sought, 150 grains. Review of all grains within the slide to establish the "presence" or "absence" of indicator heavy minerals was done to determine overall patterns of glacial dispersal. Such determinations have proven sensitive and reliable indicators of dispersal, even where indicators occur at extremely low concentrations. Heavy mineral analyses were performed by Consorminex Inc., Gatineau, Quebec.

Lithological analyses

Till lithology has been determined from debris exposed at the surface in the field, and from analyses of pebbles washed from till in the laboratory. From field observations, the occurrence of indicator clasts, including iron-formation and other lithologies (Table 2), is qualitatively described as 'absent', 'rare', 'present', 'common', and 'abundant'. Descriptions are based on visual review of thousands of clasts of all sizes at sites where debris is exposed at the surface. The method has proven to be a sensitive indicator of net glacial dispersal, particularly where indicator debris is visually distinctive, and fairly describes relative compositional variations within glacial dispersal trains.

Pebbles (4-5.6 mm) are subdivided according to broad criteria, and pebble composition is reported as weight per cent (Table 3). Where diagnostic features are not evident, pebbles are placed with the category 'crystalline, undifferentiated'. The basis for provenance determination is limited by their small size, and pebbles that can be identified as having been derived from a bedrock source are some fraction of all the debris originating with that source. Commonly about fifty grains totalling more than 10 g were counted, although sample size varies depending on the pebble content of the original sample and the amount of till washed during clay separation. Variation in estimates of indicator pebble abundance are about ±5 to ±20%, depending on the numbers of rock fragments available for counting. Generally, pebbles do not provide a reliable basis for determination of indicator debris at concentrations below 5 wt.%. Thus, glacial dispersal patterns based on pebbles are imprecise, portraying minimum glacial transport distances and debris concentrations.

GEOLOGY OF SURFICIAL DEPOSITS

The following summary description of surficial geology and landforms (Fig. 5, 6) is based on published maps, field observations, and review of aerial photographs. It serves to illustrate that while the focus of this report is on one type of surficial deposit, i.e. till, surficial geology is far more complex, including glaciofluvial, glaciolacustrine, glaciomarine, and marine and other nonglacial deposits. Deposits other than till can be extensive, although the basis for their use in mineral exploration is not the subject of this report. There is little available information concerning the sediment type and internal structure of glacial landforms. The reader is referred to Geological Survey of Canada Map 1814A which illustrates the regional distribution of glacial landforms and deposits throughout Labrador and adjacent Quebec (Klassen et al., in press).

Glacial deposits and landforms

Till

Colour, texture, and thickness of till vary widely, depending on bedrock lithologies incorporated within the eroding ice sheet. Perhaps the only uniform characteristic of till is that it is stony and poorly sorted (Fig. 7a, b). Till derived from high grade metamorphic terrane is sandy, grey, generally thin (1 to 2 m), and discontinuous over bedrock. In highlands, such as Harp Lake and Ashuanipi, bedrock is generally exposed over hilltops and till is locally thicker (<1 to 2 m) in valleys. Exceptions occur near Churchill Falls and north of Lake Melville where till derived from Grenville gneisses tends to be thicker (2 to >3 m), and is associated with extensive areas of hummocky moraine.

Thickest till deposits (5->10 m) are derived from supracrustal bedrock. Such rock is commonly fine grained and of low metamorphic rank, and it is inferred to have been susceptible to glacial erosion, contributing relatively large amounts of debris to the ice sheet in comparison with igneous and metamorphic rock of the basement complex. The distribution of thick till is generally reflected by the occurrence of

Table 1. Summary of geochemical analyses and analytical methods; Labrador till geochemistry

ELEMENT	SIZE FRACTION	ANALYTICAL METHOD	SAMPLE WT. (g)	ANALYTICAL LAB	DETECTION LIMIT	'BACKGROUND' RANGE
Copper (Cu)	clay	AAS a	0.5	B-C	1 ppm	40-150 ppm
Lead (Pb)	clay	AAS a	0.5	B-C	2 ppm	10-40 ppm
Zinc (Zn)	clay	AAS a	0.5	B-C	1 ppm	40-200 ppm
Nickel (Ni)	clay	AAS a	0.5	B-C	2 ppm	20-120 ppm
Chromium (Cr)	clay	AAS a	0.5	B-C	1 ppm	40-120 ppm
Iron (Fe)	clay	AAS a	0.5	B-C	0.1 wt.%	2-7 wt.%
Manganese (Mn)	clay	AAS a	0.5	B-C	1 ppm	
Uranium (U)	clay	dNA	2.0	B-C	0.5 ppm	2-10 ppm
Uranium (U)	clay	Fl	0.1	B-C	1 ppm	2-10 ppm
Cadmium (Cd)*	clay	AAS a	0.5	B-C	0.2 ppm	
Cobalt (Co)*	clay	AAS a	0.5	B-C	1 ppm	
Molybdenum (Mo)	clay	AAS a	0.5	B-C	1 ppm	
Arsenic (As)	silt and clay	AAS b	1.0	Ch	2 ppm	3-8 ppm
Arsenic (As)	clay	Col	0.1	B-C		
Gold (Au)	silt and clay	FA - ICP - AFS	20	Ch	5 ppb	<5 ppb
Gold (Au)	silt and clay	FA - AAS c	10	B-C	5 ppb	
Gold (Au)	silt and clay	iNA	10	B-C	2 ppb	
Platinum (Pt)	silt and clay	FA - ICP - AFS	20	Ch	5 ppb	<5 ppb
Palladium (Pd)	silt and clay	FA - ICP - AFS	20	Ch	2 ppb	<2 ppb
Beryllium (Be)	silt and clay	AAS d	0.25	B-C	0.5 ppm	2-5 ppm
Cerium (Ce)	silt and clay	XRF	5	B-C	10 ppm	30-200 ppm
Niobium (Nb)	silt and clay	XRF	5	B-C	1 ppm	10-30 ppm
Rubidium (Rb)*	silt and clay	XRF	5	B-C	1 ppm	
Thorium (Th)*	silt and clay	XRF	5	B-C	1 ppm	
Yttrium (Y)	silt and clay	XRF	5	B-C	1 ppm	20-50 ppm
Selenium (Se)*	silt and clay	XRF	5	B-C	1 ppm	
Zirconium (Zr)	silt and clay	XRF	5	B-C	1 ppm	200-1000 ppm
Strontium (Sr)*	silt and clay	XRF	5	B-C	1 ppm	
Tin (Sn)*	silt and clay	XRF	5	B-C	1 ppm	

Analytical methods		Sample preparation
AAS a	Atomic Absorption Spectroscopy	HCl - HNO_3 (1:3) (LeForte)
AAS b	Atomic Absorption Spectroscopy	HNO_3 - Aqua Regia - Hydride Generation
AAS c	Atomic Absorption Spectroscopy	
AAS d	Atomic Absorption Spectroscopy	Aqua Regia
AFS	Atomic Fluorescence Spectrometry	Hf - H_2SO_4 - HCl
AES	Atomic Emission Spectroscopy (ICP)	
Col	Colourimetry	HNO_3 - HCl (Aqua Regia)
FA	Fire Assay	HNO_3 - $HClO_4$
Fl	Fluorimetry	
ICP	Inductively Coupled Plasma Analysis	
dNA	Delayed Neutron Activation Analysis	
iNA	Instrumental Neutron Activation Analyses	
XRF	X-Ray Fluorescence	Pressed Pellet - Lithium metaborate binder Analytical Laboratory

Analytical Laboratory

B-C Bondar-Clegg & Co. Ltd. (Ottawa)
Ch Chemex Labs Ltd. (Vancouver)

(Note: Analyses (Cu, Pb, Zn, Ni, Cr, Fe, Mn, Co, Cd, and Mo) by ICP - AES methods (Chemex) are not included as part of the data base used to construct geochemical maps in this report).

*Indicates no accompanying geochemical map.

Table 2. Descriptions of indicator lithologies that are used to define glacial dispersal trains by field mapping of clasts

Indicator	Bedrock Source (s)	Lithological Character	Size	Topographic Setting	Comments
Porphyritic volcanic rock of the Flowers River Igneous Suite	Quartz feldspar porphyry (Unit 18p) of Flowers River Igneous Suite (FRIS) (Hill,1982)	Porphyritic, volcanic rock comprising quartz and pink feldspar phenocrysts in a red to grey groundmass. Quartz phenocrysts are deeply embayed.	Circular in outline, ~15 km diameter	Highland plateau, 300 to 400 m a.s.l. .	FRIS volcanic rock includes felsite, tuff, porphyry and breccia: only porphyritic rock, which is the main lithology, was used to define glacial dispersal patterns. The volcanic rock and surrounding peralkaline granite are enriched in cerium, lanthanum, niobium, rubidium, yttrium, zinc and zirconium: concentrations of zinc and zirconium within the volcanic rock are two to three times those of the granite.
Snegamook granite	Harp Lake Complex (Emslie, 1980)	Massive, leucocratic, medium- to coarse-grained, pink to red granite.	Elongate, 5 x 20 km.	Forming the southeastern margin of the Harp Lake Highlands, ~300 to 500 m a.s.l. .	Granite lacks metamorphic fabric. Small granite dykes of similar appearance outcrop NW of Snegamook Granite.
Volcanic rock of the Bruce River Group	Sylvia Lake Formation, Bruce River Group (Unit 29c; Ryan, 1984)	Mauve to greenish grey, plagioclase, porphyritic andesite, trachyandesite (latite) and trachyte. Rock comprises up to 40% feldspar phenocrysts to 1 cm in maximum dimension set in a fine grained, mauve groundmass.	Volcanic rock of Sylvia Lake Formation outcrops within a zone 20 km wide and 50 km long: porphyritic rock occurs within a 5 km wide belt along the northern margin of the volcanic zone.	Rugged, hilly terrain, 280 to 360 m a.s.l.	Phenocrysts are subhedral to euhedral and glomerocrysts. Porphyritic volcanic rock also occurs within bedrock of Aillik Group, farther east, but it is distinguished from Sylvia Lake Formation by a more siliceous character (S. Ghandi, pers. comm., 1986) and a schistose aspect (Ryan, 1984).
Amygdular volcanic rock of the Bruce River Group	Bessie Lake Formation of Seal Lake Group (Baragar, 1981) and Sylvia Lake Formation of Bruce River Group (Ryan, 1984), undifferentiated.	Amygdaloidal and vesicular, dark green to purple, mafic volcanic rock, can contain pyroxene and plagioclase phenocrysts. Quartz, calcite, and zeolite occur as vesicle fillings.	1500 to 200 km²	Prominent, elongate ridges having 100 m relief characterize Seal Lake Group; rugged, hilly terrain having relief of 20 to 60 m characterize Bruce River Group .	Seal Lake Group is considered as the dominant source of indicator erratics because it is areally the largest source. Seal Lake Group outcrops within an arcuate belt, south of Kanairiktok River, 150 km long and 15 to 20 km wide. Sylvia Lake Formation defines a belt 50 km long and 10 km wide, east of Seal Lake Group.
Green and blue gneiss of the Red Wine Complex	Red Wine Alkaline Intrusive Suite (Units 13a, b) (Thomas, 1981); Red Wine agpaites, including green gneiss (Unit 6) and blue-black melanocratic gneiss (Unit 7) of the Red Wine alkaline complex (Curtis and Currie, 1981).	Dark (jade) green pyroxene and nepheline gneiss with complex foliation containing pyroxene and nepheline, and massive to foliated, blue-black omphacite and nepheline-bearing gneiss.	Includes two main bodies each of which is about 25 km² in extent, and eight lesser bodies each of which is <5 km² north and west of Letitia Lake	The two main intrusive bodies form prominent hills having >100 m relief. They lie to similar overall elevation, although relief of the northern is greater.	The Red Wine Complex is characterized by distinctive and unusual mineralogy and geochemistry, and is enriched in lead (Miller, 1987). A distinctive, blue titanian pyroxene ferro-omphacite occurs within Unit 7 (Curtis and Currie, 1981) that is used as a heavy mineral indicator for tracing glacial dispersal from the Red Wine Complex.
Porphyritic volcanic rock of Martin Lake Formation	Martin Lake Formation comprises part of the Wakuach Gabbro of the Montagnais Intrusive Suite within the Labrador Trough (Wardle, 1982)	Porphyritic volcanic rock comprising white feldspar phenocrysts, commonly up to 0.5 cm long, within a fine grained, red groundmass.	Outcrop is 1 km wide and 6 km long.	Underlies a low ridge having ~80 m relief within generally low-lying terrain of Labrador Trough.	Subcropping bedrock could be more extensive than mapped, but is expected to be structually confined to a narrow, elongate zone and within 10 km of known source and along strike (R.J. Wardle, pers. comm., 1987).
Nepheline syenite	Nepheline syenite plutons, Superior Province (Fumerton and Barry, 1984)	Coarse, light grey to green intrusive rock containing nepheline, perthite and up to 15% mafic minerals.	Comprises three distinct, equant bodies of 4 to 25 km².	Forms minor hills within a rugged topographic setting with local topographic relief of 10 to 50 m.	Erratics exhibit a distinctive lumpy, etched appearance, with nepheline weathering recessively and perthite standing in relief.

glacially streamlined landforms and ribbed moraine, especially southeast of the Labrador Trough. Thick till, however, can also be associated with other bedrock sources. For example, near 'Strange' Lake in northern Labrador, it is associated with peralkaline granitic bedrock which appears to have been more easily eroded than adjacent gneissic terrain.

Till derived from bedrock of the western Labrador Trough is typically red-brown due to its content of iron-formation, red shale, and slate within finer fractions. Red-brown till is widespread over the Ashuanipi Complex, within the Trough, and southeast of the Trough. Its distribution closely reflects the glacial transport of debris outwards from the Trough along several ice flow directions. Till derived from red sedimentary bedrock of the Seal Lake Group is also red to red-brown, particularly over the Shipiskan Plateau in the northwestern part of the source area. There, red sedimentary bedrock is extensive and little metamorphosed, and it has contributed significant quantities of debris to glacial sediments. Along the eastern margin of the Trough and western Churchill Province, till is grey to dark grey. It is derived from mafic igneous rock of the eastern Labrador Trough, and has been subject to eastward glacial transport, in the direction of regional ice flow.

Table 3. Descriptions of lithological subdivisions applied to pebbles (4 to 5.6 mm)

Lithological Name	Texture	Colour	Comments
Crystalline	Igneous or metamorphic: wide variation in lithology	Light to dark, varied	Broad subdivision, including unidentified clasts. Largely comprising basement rocks of the Shield.
Anorthosite	Coarse grained feldspar	Commonly grey	Sources include the Harp Lake and Michikamau intrusives. Clasts tend to disintegrate easily along grain boundaries.
Sediments (undifferentiated)	Fine grained to granular	Dark grey to grey, white, brown, red.	Includes mudstone, sandstone and quartzite; derived from supracrustal assemblages, notably Labrador Trough, Seal Lake Group, and relatively unmetamorphosed bedrock of the Central Mineral Belt (CMB).
Red sediments	Fine grained to granular	Red to pink	Dominantly sandstone, includes shale; largely derived from Labrador Trough and Seal Lake Group. Can include sources underlying Smallwood Reservoir, and within Moran Lake and Bruce River groups.
Volcanic	Fine grained, porphyritic, amygdular or vesicular	Dark grey to green, reddish	Derived largely from eastern Labrador Trough and bedrock of CMB. Can be difficult to distinguish from other fine grained sedimentary or crystalline rocks, and may be more extensive than mapped.
Iron-formation	Oolitic; banded to massive	Red to dark grey	Derived from the Labrador Trough; commonly contains jasper, can be magnetic, and may be partially recrystallized.

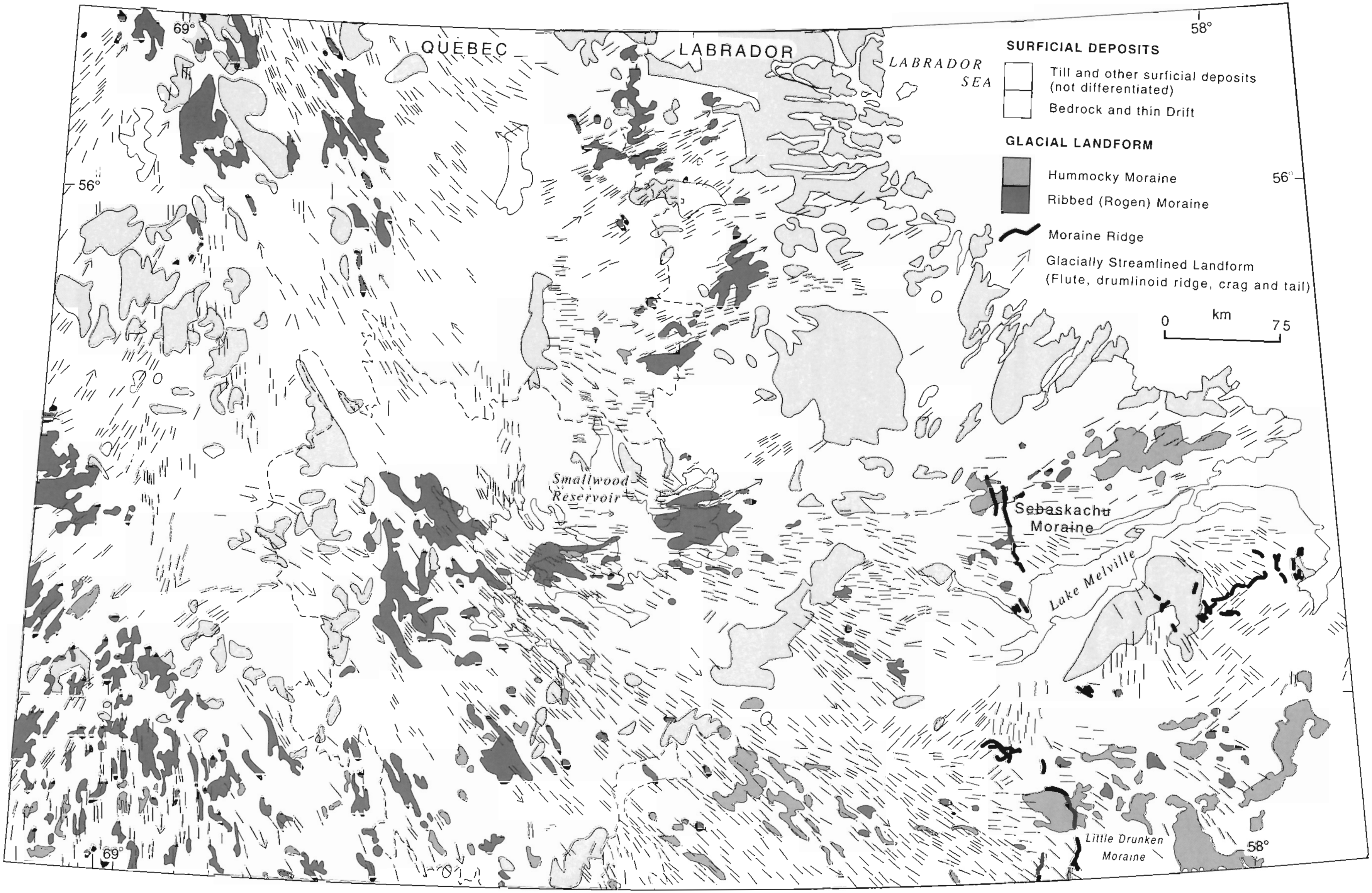


Figure 5. Glacial deposits and landforms of central Labrador. Streamlined landforms outline northward, convergent patterns of ice flow in the northwest part of the study area, and divergent ice flow trending between the southwest and northeast across the remainder. Ribbed moraine and hummocky moraine occur within well defined areas, and are predominant landforms in the area of Smallwood Reservoir. Morainic ridges, including Sebaskachu and Little Drunken moraines, occur to the east.

Along the Trans-Labrador Batholith, north of Lake Melville (Batterson et al., 1987) and near Churchill Falls, large (1 to >4 m) boulders are widespread as scattered erratics and as extensive boulder fields (Fig. 8). Where they form continuous cover, the boulders can present significant problems to mineral exploration. Their large size makes movement in the field difficult, and they obscure underlying bedrock and Quaternary deposits, impeding sampling of surficial sediments. The clasts are largely local, having limited glacial transport, and may overlie a finer-grained till facies, although subsurface information within boulder fields is limited. The origins of the boulders fields have not been determined. Near Churchill Falls they have been described as lags from which finer material has been washed by glacial meltwater (Kirby, 1961).

Glacially streamlined landforms

Glacially streamlined landforms, including fluted, drumlinoid, and crag-and-tail features, are common throughout Labrador (Fig. 9). They vary from tens to hundreds of metres in length, and a few metres to tens of metres in relief. Streamlined landforms occur in groups of tens to hundreds that define areas elongate with the trend of the individual landforms (Fig. 5). They preferentially occur south and east of the southern Labrador Trough, south of Churchill River, and in eastern Labrador within the Lake Melville basin.

Throughout most of Labrador, streamlined landforms indicate the trends of last regional ice flow defined by striae. Two exceptions are known: 1) In the Labrador Trough the landforms are aligned generally north-south and do not record the latest glacial flow toward the northeast that is recorded by faint striae on uppermost outcrop surfaces (Henderson, 1959); 2) Along the western margin of Hamilton Uplands, in central Labrador, streamlined landforms are aligned northeast- southwest, transverse to last directions of ice flow toward the southeast. They are interpreted to record older northeast flow defined from striae, and from crag-and-tail features (Morrison, 1963).

Ribbed moraine

Ribbed moraine occurs as sinuous ridges lying transverse to the last ice flow direction (Fig. 10). The ridges can be a few metres to more than fifteen metres high, and hundreds of metres to more than a kilometre long. In western Labrador, they are 300 to 1500 m long, 60 to 170 m wide, and spaced 200 to 500 m apart (Henderson, 1959, p. 18). The ridges can be asymmetric, having a steeper slope on their down-ice margin. Internal structure and composition of ribbed moraine is poorly known, derived from limited road exposures south of the Labrador Trough and from publications of Ives (1956), Henderson (1959), and Cowan (1968). The landforms are

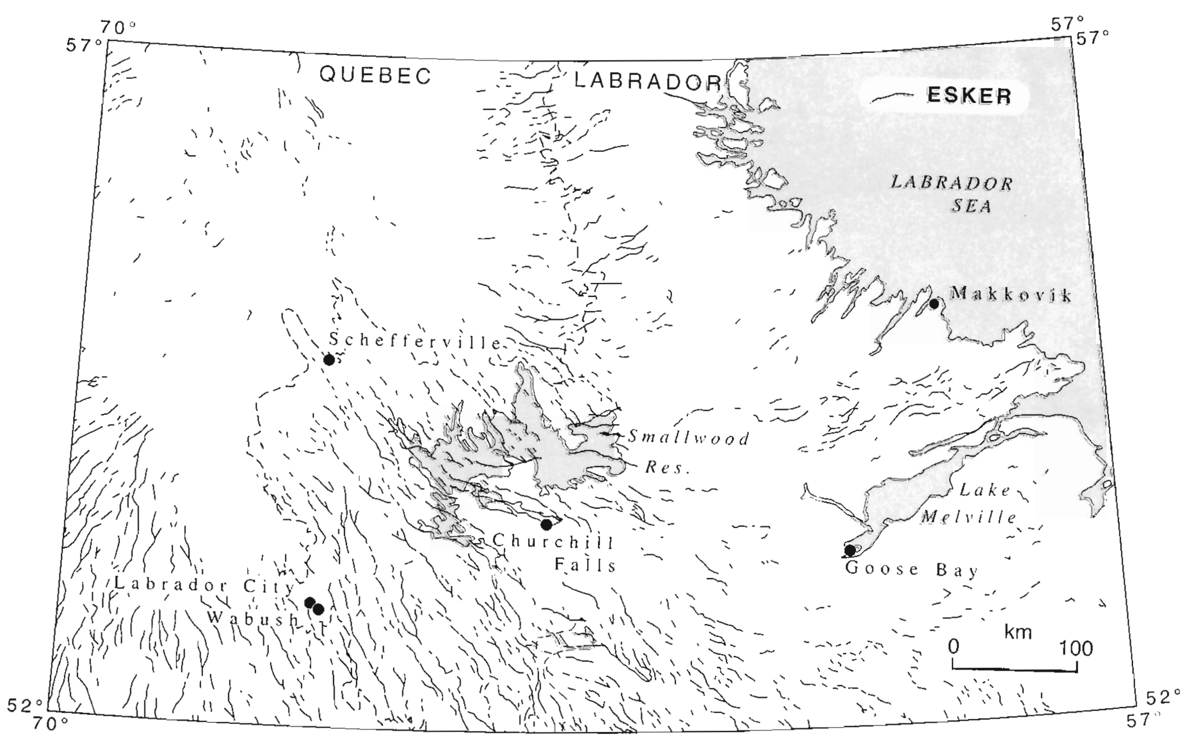


Figure 6. Distribution of eskers within the study area. Eskers are widespread and generally aligned with the trends of glacially streamlined landforms. They can be more than one hundred kilometres long. Eskers are most abundant in the southwest and central parts of the study area.

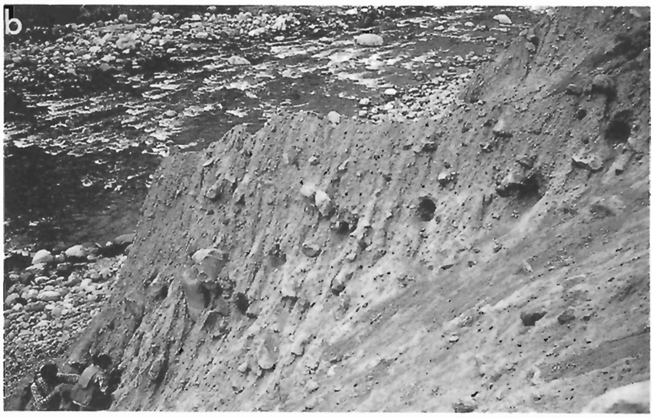


Figure 7. Examples of till. **a**), **b**) It is stony and poorly sorted throughout Labrador. Till composition, colour, and texture are derived from bedrock crossed by the ice. Where clasts are washed clean at the surface, thousands can be rapidly reviewed for indicator rock types. In this study, such field observations have proven an important basis for mapping glacial dispersal trains. GSC 20483-K; GSC 204881-JJ.

Figure 8. Boulder fields cover large parts of the Trans-Labrador Batholith, especially south of Kaipokok River and Smallwood Reservoir. Large boulders (1 to 4 m) can hinder sampling surficial sediments and movement in the field. GSC 203803-G

composed of sandy, poorly-sorted sediments, similar to till in surrounding areas, and are massive to poorly stratified. They are commonly mantled by large, angular boulders.

Ribbed moraine occurs within broad areas of irregular outline that are slightly elongate in the direction of last ice flow (Fig. 5). Within the area of study, it is most common southeast and east of the Labrador Trough where it is associated with till containing significant levels of supracrustal debris (>5 wt. %). Ribbed moraine in northern Labrador has been mapped by Batterson et al. (1985). There, its occurrence is associated with peralkaline granite that may have been susceptible to glacial erosion, in comparison with gneissic terrane of the Churchill Province. Fields of ribbed moraine are commonly crossed by eskers.

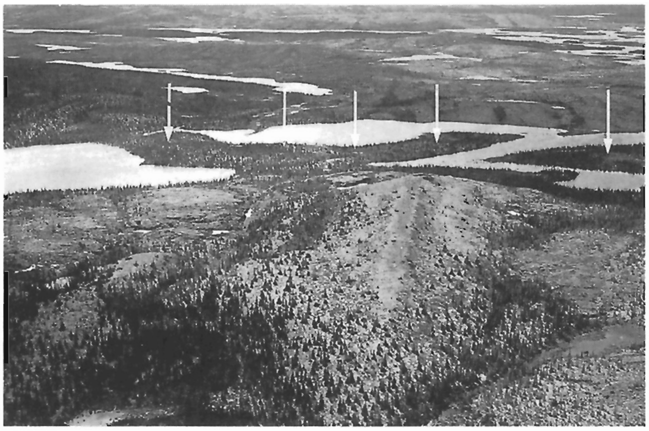


Figure 9. Glacial streamlined landforms. They include crag-and-tail features extending down-ice from bedrock knobs as well as fluted and drumlinoid features. They can be tens of metres high and hundreds of metres to kilometres in length. Most commonly they are aligned with the directions of last regional ice flow indicated by striae. Sebaskachu Moraine (Fig. 5, 11) is indicated by white arrows. Ice flow toward the observer. GSC 205204-Q

Figure 10. Ribbed moraine. It occurs as sinuous ridges lying transverse to ice flow directions as extensive fields (Fig. 5). The ridges are commonly steeper on their down-ice margins (left in photograph), and can be mantled by boulders. GSC 203803-I

Hummocky moraine

Hummocky moraine occurs as irregular mounds a few metres to more than ten metres in relief, and is commonly incised by short meltwater channels. Sediments composing the landforms range from poorly-sorted to well-sorted. Near Churchill Falls, limited exposures indicate that the landforms are composed of sandy till, and can be poorly stratified, containing discontinuous laminae and thin beds of sand. The most extensive areas of hummocky moraine occur north of Lake Melville (Fig. 5).

Morainic ridges and ice-marginal landforms

A major moraine system extends north (Sebaskachu Moraine) and south (Little Drunken Moraine) of the western end of Lake Melville (Fulton and Hodgson, 1979) (Fig. 5, 9, 11). In areas of significant relief (>100 m), across hillsides near the Labrador coast and Schefferville, minor moraines and ice-marginal deposits and landforms (kames, kame terraces, side-hill meltwater channels) define the successive margins of ice within valleys during deglaciation.

The Sebaskachu Moraine is a few metres to ten metres high and tens of metres wide (Fig. 11), and approximately one hundred kilometres long. It was mapped from aerial photographs, and is difficult to recognize from aircraft in the field because if its generally low relief. Boulders are common at its surface, although internal composition and structure are not known. At one location the moraine is crossed by an esker that appears younger than the moraine, although the ridge apparently has not been overridden by ice. If that is correct, the moraine could be of subglacial origin. Near the junction between the esker and moraine, small ice-contact deltas, graded to the approximate level of the moraine crest, occur against the eastern margin of the moraine. The deltas may have formed within minor glacial lakes ponded against the ice front in contact with the moraine. Studies of drift composition, reported in following sections, indicate that the moraine marks the approximate eastern extent of glacial dispersal of iron- formation from the Labrador Trough and of agpaitic gneiss from the Red Wine Complex.

Figure 11. Sebaskachu Moraine. It occurs as a low-lying, bouldery ridge nearly one hundred kilometres long (indicated here by arrows, see also Fig. 5, 9). It appears coincident with the limits of eastward glacial dispersal of iron-formation of the Labrador Trough, and detritus from the peralkaline complex at Letitia Lake. GSC 205204-A

Glaciofluvial deposits and landforms

Glaciofluvial sediments occupy narrow corridors that are typically tens to hundreds of kilometres long and range in width from less than one to two kilometres. They were deposited within ice-contact and proglacial environments, and preferentially occur in low-lying areas, flooring most large valleys. Within the corridors, eskers are commonly central. Sediments typically include poorly-sorted to well-sorted sand, gravel, and boulder gravel. Clasts are commonly rounded to well rounded. Large boulders at the surface of eskers can be angular to subangular, presumably deposited by meltout from the ice tunnel roof subsequent to esker deposition. The sediments are derived from till and other glacial debris, and have been further transported by meltwater. Thus, their compositional relationship with bedrock is correspondingly more remote than that of till.

Eskers are the dominant glaciofluvial landform, forming sharp-crested ridges several kilometres to several hundreds of kilometres long (Fig. 6, 12a). They range in height from 5 m to more than 20 m and are single-crested, although segments having several crests can occur. Bedding is tens of centimetres to a few metres thick, and defined by gross textural differences. Small-scale depositional structures within beds are typically absent. Glaciofluvial transport within eskers is measured in hundreds of metres to a few tens of kilometres, and esker composition can be significantly influenced by input from esker tributaries (Edwards, 1972; Bolduc et al., 1987). The first appearance of indicator debris in eskers can occur some distance downstream from the intersection of esker and source, and glaciofluvial transport further downstream is typically measured in kilometres (>1 to 10 km).

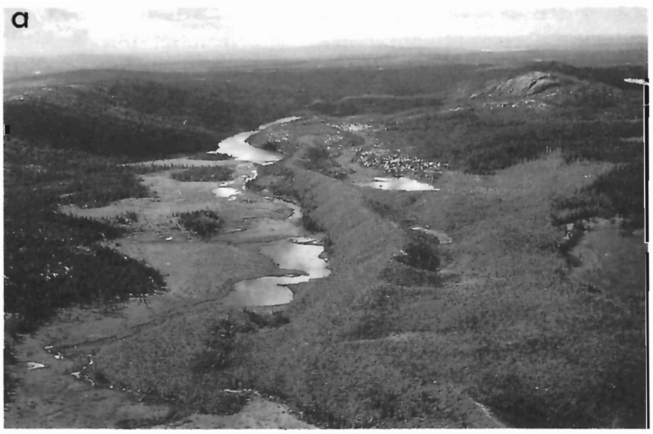
Eskers tend to occupy topographic lows. They can alter direction to cross interfluves at low points, and can diverge around topographic obstructions having relief of more than 50 m. Esker systems are most abundant in western Labrador. They are generally absent within the Lake Melville drainage basin, and terrain flanking much of the Churchill River. Those valleys may have captured meltwater drainage thereby limiting the development of eskers within adjacent terrain.

Generally, eskers are aligned with the directions of last regional ice flow, indicated by streamlined landforms. Notable exceptions occur north and west of Smallwood Reservoir where eskers are oblique to the trends of last ice flow, diverging from them by at least 20°. For much of their length, tributary eskers lie parallel with trunk systems, and change abruptly in direction within their lowermost few kilometres to join with them. At connection points, deposits can display complex geomorphology and can be higher than the trunk esker ridge.

Kames, kame-deltas, and outwash aprons flank esker ridges (Fig. 12b), and were deposited in an ice marginal or proglacial environment on retreat of the ice margin and exposure of esker conduits. Ice contact deposits can occur as nodes, kilometres apart along the esker. Deposits flanking esker ridges are commonly kettled, indicating deposition over ice. Where the margin of the ice retreated from the regional watershed, as in the Wabush area, kame terraces flanking the esker ridge grade to the approximate elevation of low points along the divide. Deposition appears to have been within the glacial lakes indicated by abandoned shorelines on hillsides.

Within valleys, extensive kettled deposits of sand and gravel, and plains crossed by abandoned, braided channels occur (Fig. 13a, b). They have been incised by modern streams and are not subject to modern fluvial reworking. The thickness and extent of the deposits forming the plains indicate they were deposited from meltwater during deglaciation.

a



b

Figure 12. Eskers and related glaciofluvial deposits. **a**) Eskers appear as narrow, sinuous ridges of sand and gravel, several kilometres to several hundreds of kilometres long, and several metres to tens of metres high. **b**) Other glaciofluvial sediments flank the esker ridge and were deposited from meltwater flowing from the esker tunnel in front of the glacier margin. They can extend up to several kilometres away from the esker, and appear light-toned in photographs due to their content of sand and gravel, and to sparse vegetation. GSC 205204-H; GSC 205204-K

Glaciolacustrine deposits and landforms

Prominent shoreline features, including both wave-cut and depositional benches, occur along hillsides within large areas of western Labrador (Low, 1896), including parts of the Ashuanipi Complex, the Wabush region (Harrison, 1963), and the central Labrador Trough (Henderson, 1959). The shorelines are compelling evidence for glacial lakes ponded between the ice margin and the regional watershed during deglaciation, and they indicate that glacial lakes were widespread. The history of glacial lakes in Labrador has not been documented.

In western Labrador, glaciolacustrine sediments are neither widespread nor thick, and till is exposed at the surface throughout most areas of former lake inundation (Henderson, 1959, p. 37). Poorly laminated, stony mud more than 2 m thick, observed in one stratigraphic section near Wabush, is interpreted as glaciolacustrine. Due to its poorly sorted character, the deposit could be mistaken for till where exposure is limited, particularly within extensive, low-lying regions of the southern Labrador Trough. As such, glaciolacustrine sediment could represent problems to mineral exploration and to the interpretation of geochemical analyses and boulder tracing results.

a

b

Figure 13. a) Glaciofluvial deposits occupy extensive areas within valleys, forming kettled, hummocky terrain where they were deposited over ice, and **b**) plains crossed by abandoned, braided channels that are incised by modern streams. GSC 205204-T; GSC 205204-C

In eastern Labrador, glaciolacustrine sediments of limited extent have been mapped within valleys of the Lake Melville drainage basin, including the Churchill River valley (Fulton, 1986a, b). There, they occur as finely laminated mud and sandy mud at elevations above marine limit.

Glaciomarine and marine deposits and landforms

Glaciomarine and marine sediments are extensive and commonly 5 m to more than 20 m thick (Fig. 14a, b). They occur below marine limit along the coast, particularly in sheltered parts, and within the lower reaches of larger valleys. They vary in structure from massive to laminated, and in texture from clayey mud and sandy mud, to coarse sand and gravel. They are rarely fossiliferous. Glaciomarine and marine sediments form extensive, blanket deposits of mud and sandy mud across the floors of Lake Melville-Double Mer basin and Kaipokok River valley (<100 m a.s.l.), among others, where they can be 10 m to more than 20 m thick. Their presence hinders study of bedrock and till in areas below marine limit, and mineral exploration in general.

Red sediments are common within glaciomarine and marine sequences in the lower reaches of Kaipokok and Kanairiktok river valleys, and as part of grey-red bedded sequences along rivers entering western Lake Melville. The red colour is interpreted to reflect a sediment provenance within the Labrador Trough or Seal Lake Group, with the detritus derived from till and transported to the marine environment by meltwater flowing along major valleys. Colour banding can reflect textural variation within sedimentary sequences, with the red hematite component preferentially concentrated within one size fraction, depending on the properties of the bedrock source.

Deltaic landforms graded to elevations at or near marine limit (~100 m a.s.l.) occur within valleys near the coast, particularly near Hopedale and coastal areas north of Lake Melville. They are composed of well-sorted sand and gravel. Where they occur against hillsides and have no direct connection to outwash, the deltas are interpreted to have been deposited against the ice margin within a marine environment. Raised beaches occur on their outer margins, formed during emergence. Beaches are common where surficial deposits provided sufficient material for their construction by wave action with lowering of relative sea level.

Nonglacial deposits

Nonglacial sediments are largely eolian and fluvial, and cover minor areas. Eolian sediments are almost exclusively confined to areas of glaciofluvial and fluvial sediments which provide an abundant source of sand. They appear as sharp-crested, sinuous features on aerial photographs and are interpreted as dunes; the landforms were not visited during fieldwork. Fluvial sediments occupy modern floodplains where rivers can erode thick, pre-existing deposits. The downcut sediments are commonly the older glaciofluvial deposits that are widespread across valley floors. Fluvial deposits are typically unvegetated due to reworking by seasonal floodwaters.

Organic deposits and organic-rich sediments are widespread in fens, bogs, and string bogs, particularly in the southern Labrador Trough, and areas southeast of it (Fig. 15). The deposits can be extensive, blanketing underlying glacial sediments and bedrock. Their thickness is varied, and is estimated at between 1 to 3 m. Large boulders exposed within shallow lakes are common in areas of boggy terrain, indicating that organic accumulations may typically be less than 2 m thick, despite their large extent.

Glacial stratigraphy

Stratigraphic sections of till are few and exposures cut by stream or coastal erosion typically comprise glaciofluvial and marine sediments. Although glacial sediments may have been transported during distinct ice flow events, different tills cannot yet be recognized at surface.

Only in western Labrador is a significant Quaternary stratigraphic sequence known. The sections were exposed by construction and mining activity near Schefferville, Wabush (Gosse, 1989), and Churchill Falls. They include compositionally distinct tills, and intervening waterlaid sediments, some of which contain organic matter. The tills constitute a

Figure 14. Glaciomarine and marine sediments. **a)** They occur as thick (>10 m), blanket deposits near the coast and within valleys below marine limit (typically <100 m a.s.l.). **b)** The sediments vary from sand and gravel to sandy mud. GSC 2048811-PP; GSC 205204-D

Figure 15. Swamps and organic deposits. String bogs are extensive in low lying areas, particularly within and southeast of the Labrador Trough. The organic deposits are not necessarily thick, and large boulders are commonly evident. GSC 205204-B

depositional record of ice flow events (Morrison, 1963; Klassen and Thompson, 1988), although their relationship to the erosional record of striae remains unclear. At Wabush, waterlain sediments between till units are of particular stratigraphic significance. They occur near the geographic centre of the Labradorean ice sheet and were deposited when the ice sheet was either greatly diminished or absent. Thus, they define either a significant interstadial or an interglacial period. Organic debris from one waterlain unit is of interglacial origin, based on paleoenvironmental interpretation of organic remains, and indicates that underlying till is pre-Wisconsinan (Klassen and Thompson, 1988; Klassen et al., 1988). The nonglacial deposits provide the only basis known for establishing a chronology of Quaternary events and for developing correlations outside the region. The sections remain under study.

ICE FLOW TRENDS AND RELATIVE AGES

Ice flow trends and their relative ages were measured from striae at more than 300 sites (Klassen and Thompson, 1990). Although numerous measurements were made at each site, only striae representative of distinct ice flow directions were used to develop ice flow maps. Where minor (<5°) divergence in flow was recognized, a single, average trend was interpreted. In addition to field observations, ice flow directions indicated in published sources (e.g. Henderson, 1959; Hughes, 1964; Taylor, 1979; Fulton, 1986a, b), and derived from review of aerial photographs as part of this study were also incorporated into the database.

To establish ice flow trends characteristic of a site, striae were highlighted on outcrop surfaces with thick crayon. Crayon is effective for marking dirty or wet surfaces, and provides a means of tracking ice flow trends over large exposures, especially where the record could only be seen by close examination. At a site, the distribution, trend, and position of striae were sketched as a summary portrayal of ice flow (Fig. 16). The sketches have proven useful in compilation and interpretation of observations throughout the study area.

Relative age of striae is principally determined by the aspect of striated surfaces, and their exposure to varied ice flow directions (Fig. 17a, b), and by crosscutting relations among striae (Fig. 17c, d). Detailed studies have revealed that a pristine record of older flow events is commonly retained on surfaces that are sheltered from erosion during later flow. Surprisingly, given the regional extent of youngest flow events and scale of erosional landforms in bedrock associated with them (>2 m), the degree of protection need not be great for the preservation of an older record. Distinct striae trends can be inscribed on adjacent stoss and lee surfaces having only slight differences in slope aspect (<10°).

Protected surfaces bearing an older record are found at the down-ice margins of outcrop where they can be obscured by vegetation or surficial sediments and are thus easily overlooked. The initial discovery of older striae was facilitated by road

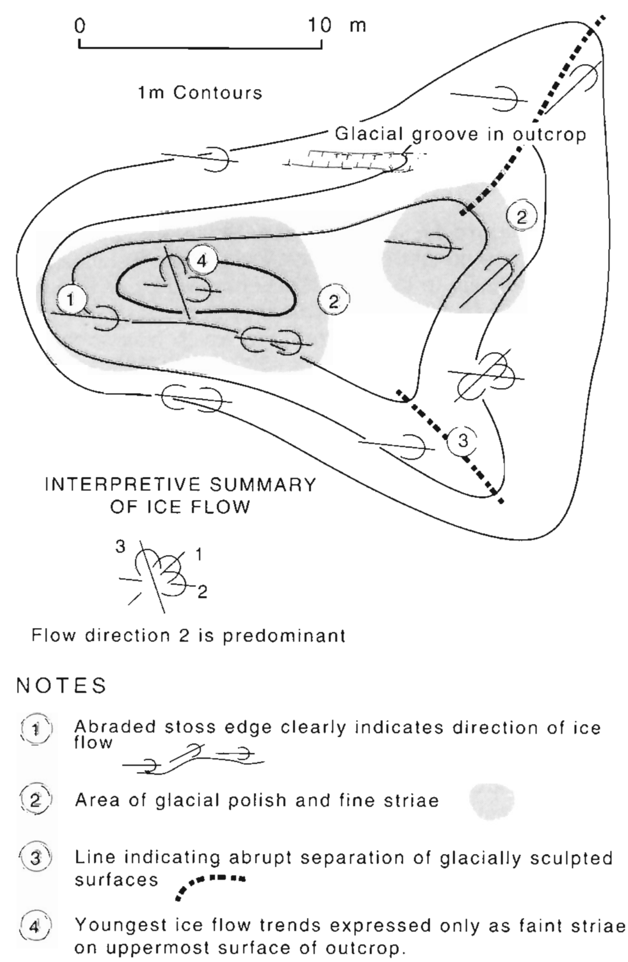


Figure 16. An example of sketch maps of outcrop and descriptive notes used in field notes to summarize the evidence of ice flow. Such maps have proven useful in recording striae and interpreting the relative ages of ice flow events.

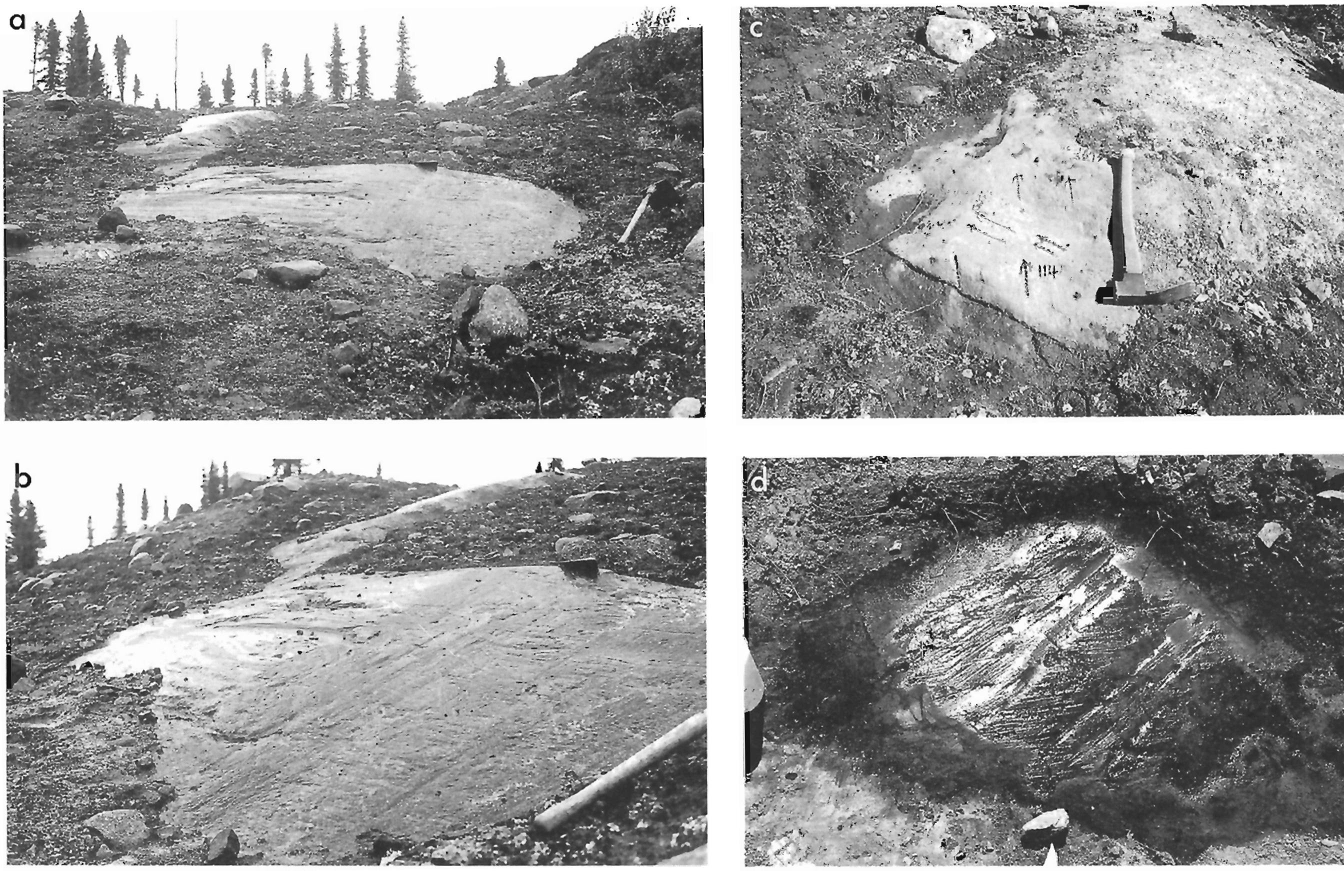


Figure 17. Glacial striae. Striae are common on outcrop throughout Labrador and are an important basis for reconstruction of ice flow events. Relative ages of striae are established by the aspect of striated surfaces relative to ice flow directions, and by crosscutting relations. **a**) Near Churchill Falls, striae trend southeast across the upper surface of bedrock (left to right). **b**) Older striae trending northeast are preserved on the southeastern outcrop face which was sheltered from the erosive effects of later flow (trend indicated by alignment of shovel handle). **c**), **d**) Where distinct ice flow trends occur on the same surface, relative ages are established by crosscutting relations. GSC 203810-B; GSC 203810-C; GSC 204842-Y; GSC 205204-P

construction and mining activities that cleared outcrop in the areas of Churchill Falls and the Labrador Trough. In remote areas, however, extensive excavation by shovel demonstrated that such a record is widespread in Labrador. Similar observations are reported in central and western Quebec by Bouchard and Martineau (1985) and Veillette (1986), and are illustrated by Prest (1983).

Youngest ice flow directions

The youngest directions of regional ice flow are outlined by the orientations of glacially streamlined landforms, including drumlinoid, and crag-and-tail hills (Fig. 9), and by striae on uppermost bedrock surfaces (Fig. 17a-d). For the most part, youngest striae define the most prominent erosional record, and indicate the same ice flow trends as the depositional record of glacial landforms (compare Fig. 5 and 18). In some areas, however, youngest striae are only faintly expressed on uppermost bedrock surfaces. Generally, faint striae are restricted in their areal extent, and they are interpreted to be the product of short-lived, late glacial ice flow events. Near the residual centre of the ice sheet in western Labrador (Ives, 1960; Kirby, 1966) youngest, faint striae trend northeast, crosscutting a more prominent record of regional north-south ice flow indicated by both striae and large scale glacial landforms. In eastern Labrador, faint striae can indicate topographic influence on ice flow directions.

Older ice flow directions

Striae defining older directions of ice flow are widespread and present coherent patterns over large (>10 000 km^2) areas (Fig. 18). Unlike the landform record, which can be interpreted from aerial photographs, striae predating the youngest directions of ice flow are known only through field study (Henderson, 1959; Morrison, 1963; Kirby, 1966; Klassen and Bolduc, 1984). In some areas three or more older events can be determined from striae that indicate >90° change in flow direction, including reversal of flow in western Labrador. East of Churchill Falls, streamlined landforms aligned northeast-southwest are transverse to last direction of ice flow toward the southeast (Fig. 5) (Prest et al., 1968). They are an exception in the landform record because they appear to be the product of ice flow toward the northeast, a direction and relative age indicated by older striae throughout the central study area (Fig. 17a, b, 18).

Among surfaces bearing older striae, no difference in weathering, such as iron stain, was recognized that could indicate nonglacial conditions between glacial flow events. In the absence of such evidence, and as the simplest interpretation, the different events are presumed to have occurred under continuous ice cover during the Wisconsin Glaciation. Evidence for pre-Wisconsin glaciation, seen in sections at Wabush, is not recognized from the evidence of striae and drift composition.

REGIONAL VARIATIONS IN DRIFT LITHOLOGY

Supracrustal erratics, including sedimentary rock, iron-formation, and volcanic rock (Table 2) are widespread in till (Fig. 19a-e). As pebbles, they occur in significant concentrations (5 wt. %) well outside of the Labrador Trough and Central Mineral Belt, the two largest sources. Labrador Trough debris has been glacially transported in all directions, defining prominent glacial dispersal trains extending southwest and southeast from the Trough. In eastern Labrador the Central Mineral Belt is the most important bedrock source of supracrustal erratics, although iron-formation (Fig. 19d) indicates that some part, likely small, could also be Trough-derived. Across most of the study area, regional dispersal trains of supracrustal debris are preferentially elongate toward the southeast in the general direction of last regional ice flow (Fig. 19a, b).

Within till overlying the Harp Lake Complex, north of the Central Mineral Belt, erratics of sedimentary rock (Fig. 19a, b, c) could have originated with either the Seal Lake Group or Siamarnekh Formation. If they originated with the Siamarnekh Formation, their distribution and abundance would indicate that the Formation could be more extensive west of the Harp Lake Highlands than mapped.

'Supracrustal' debris mapped in northern Labrador, near 'Strange' Lake (Fig. 19a, b) is likely derived from quartzite of the basement complex comprising the Churchill Province. Due to the small size of the pebbles, debris from that source cannot be distinguished from supracrustal sources. In that area no debris from the Labrador Trough or any other supracrustal source was recognized, despite intensive search. The presumed basement source is located near the George River, at the approximate western (up-ice) occurrence of the debris (Fig. 19a).

Anorthosite is common (>5 wt. %) northeast of Smallwood Reservoir in till overlying and down-ice from several large sources, including the Michikamau anorthosite, Harp Lake Complex, and Nain Igneous Complex (Fig. 19f). Glacial transport of anorthosite, however, appears more limited than from supracrustal sources. From the Harp Lake Complex, for example, concentrations decrease from more than 30 wt. % to

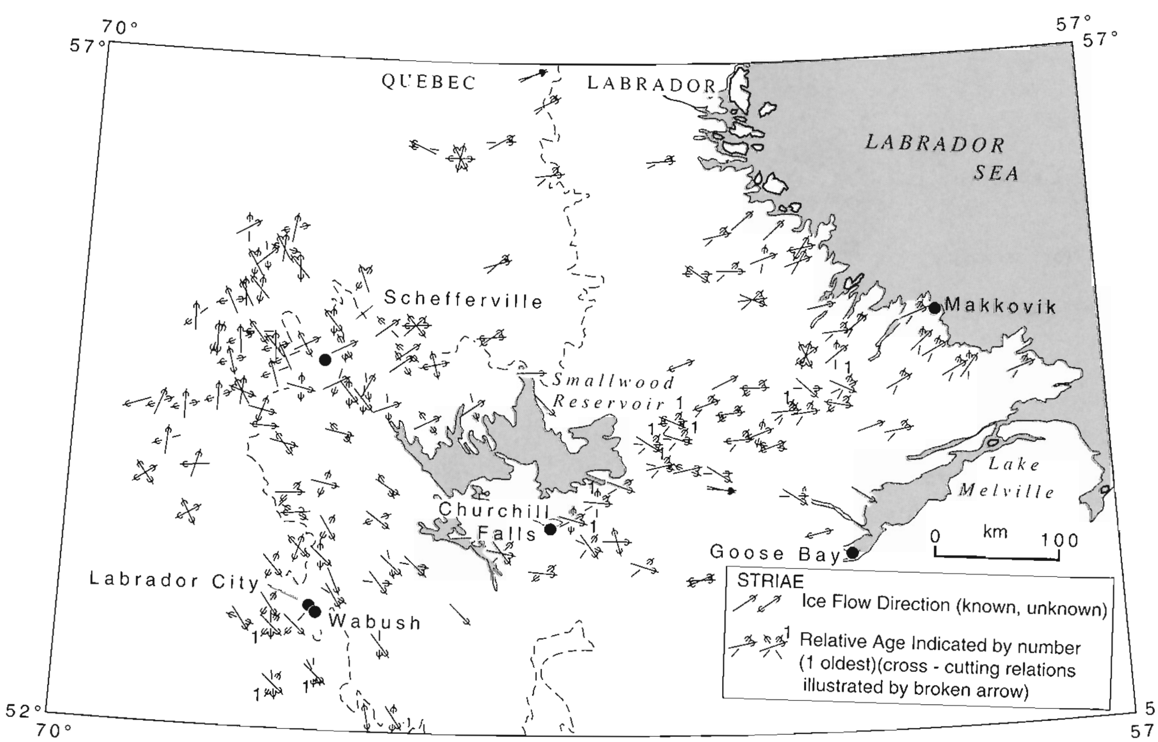


Figure 18. Summary of ice flow trends and relative ages indicated by striae. The map indicates the distribution and relative abundance of field observations.

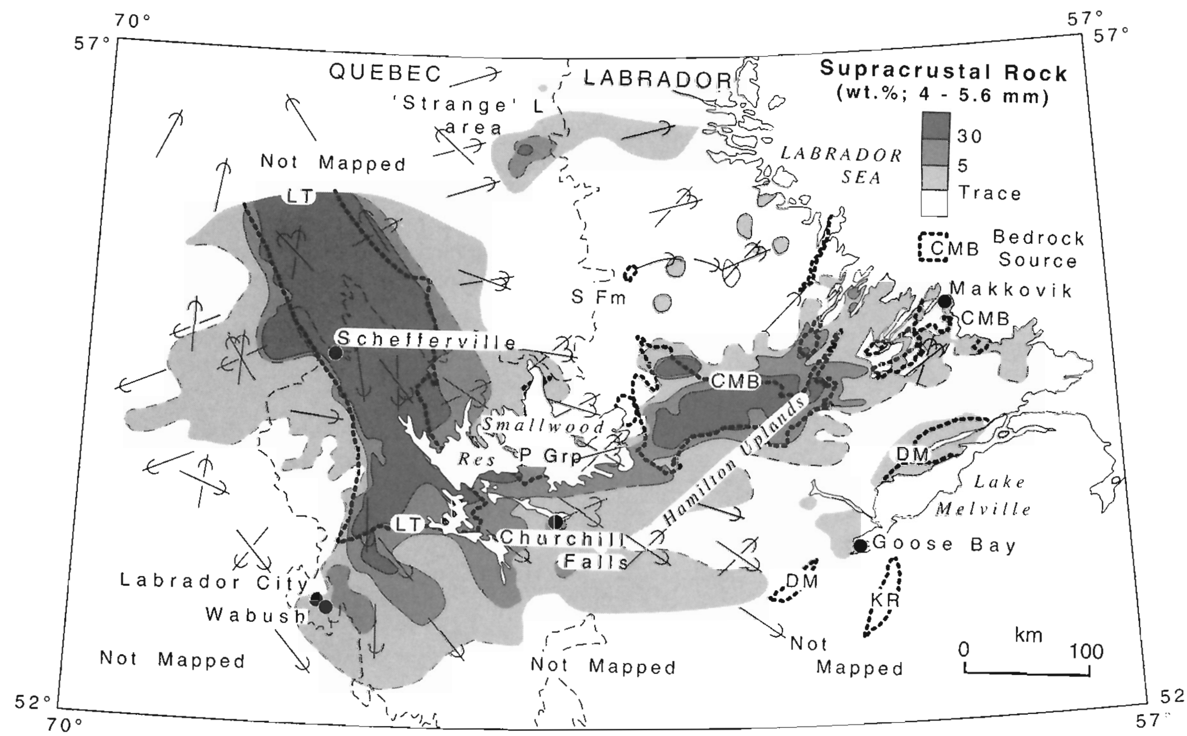
trace concentrations 10 km down-ice from its eastern margin. Presumably anorthosite erratics are easily comminuted to less than pebble size during glacial transport. In the field anorthosite was observed to fracture easily along grain boundaries.

LOCAL SCALE GLACIAL DISPERSAL TRAINS

Indicator erratics (Table 3) derived from seven distinctive bedrock sources define glacial dispersal trains extending tens to more than a hundred kilometres down-ice (Fig. 20). As reflected by their shape and internal, compositional zonation, the trains are the net product of glacial transport in several ice flow directions. As determined in the field, variation is qualitatively described by the terms: not found, rare, present, common, and abundant. They are described in order of increasing distance from the ice sheet margin along the Labrador coast, where ice flow history is relatively simple, to the area of ice divide(s) within the Labrador Trough, where ice flow history is relatively complex.

Flowers River volcanic porphyry

Erratics of porphyritic volcanic rock derived from the Flowers River Igneous Suite (Hill, 1982) define a ribbon-shaped dispersal train. The margins of the train are linear, and extend more than 40 km down-ice to the Labrador coast. They are aligned east-northeast with the last direction of ice flow (Fig. 21a). The train is slightly greater than outcrop width



BEDROCK SOURCES

BLG	Blueberry Lake Group	LT	Labrador Trough
CMB	Central Mineral Belt	M	Michikamau Anorthosite
DM	Double Mer Formation	M Mtn	Mealy Mountains
HLC	Harp Lake Complex	NIC	Nain Igneous Complex
IF	Iron Formation Fm	P Grp	Petscapiskau Group
KR	Kenamau River Fm	S Fm	Siamarnekh Formation

Figure 19. Distributions of indicator erratics in till (pebble fraction) at the regional scale. Indicators include: **a)** supracrustal debris (undifferentiated); **b)** sedimentary rock; **c)** red sedimentary rock; **d)** iron-formation; **e)** volcanic rock; **f)** and anorthosite. Till lithology defines glacial dispersal trains, indicating that far-travelled (100 km) debris can be a significant component (5 wt. %) of till. Lithological analyses provide an important basis for provenance studies and for interpretation of till geochemistry.

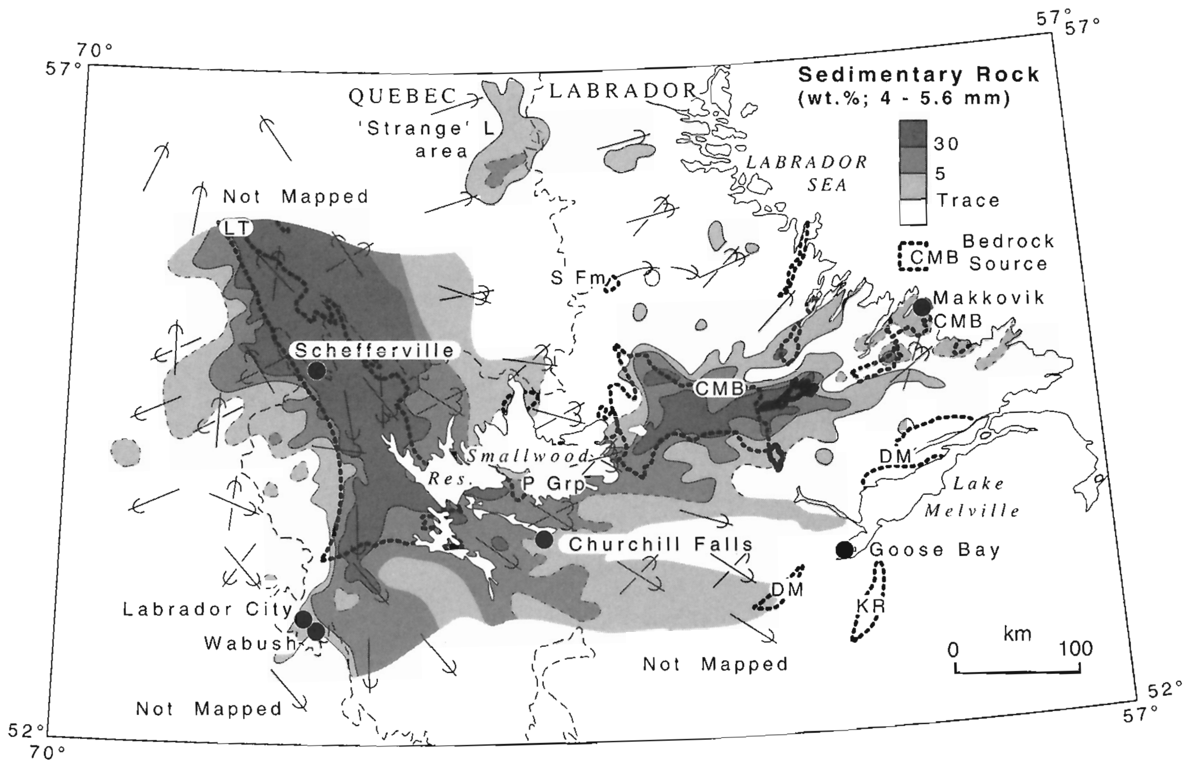


Figure 19 b

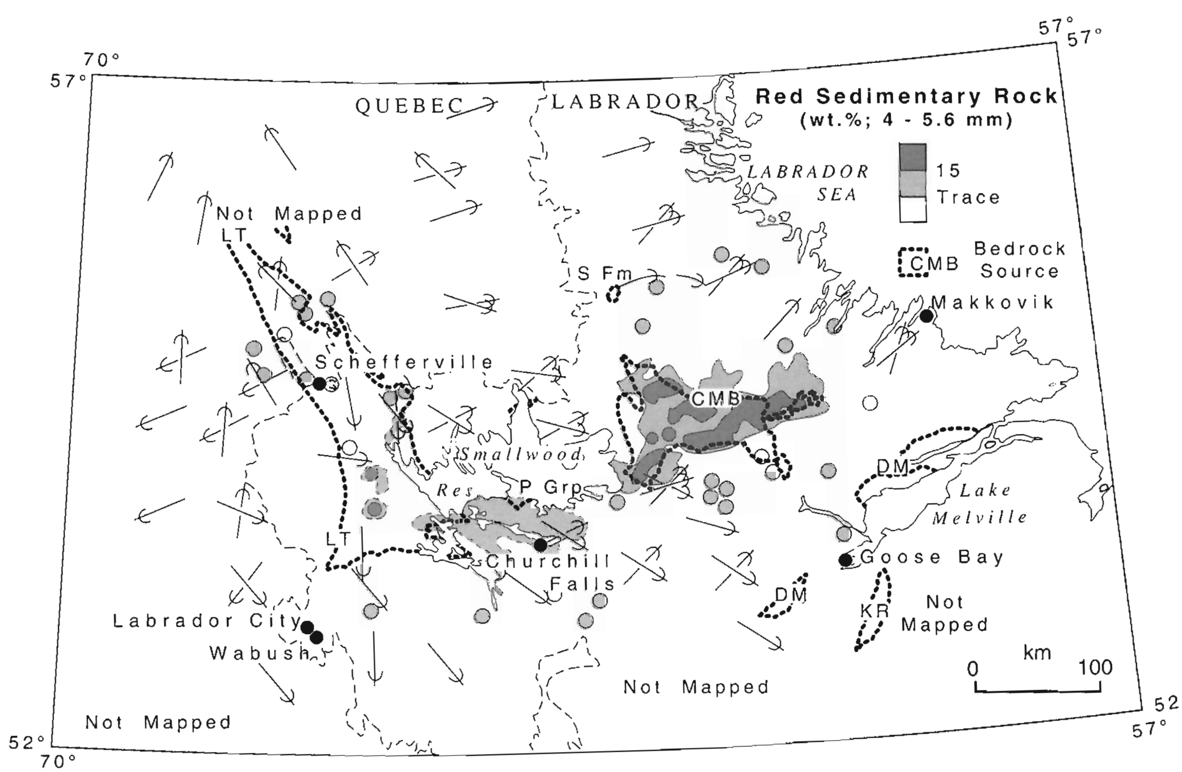


Figure 19 c

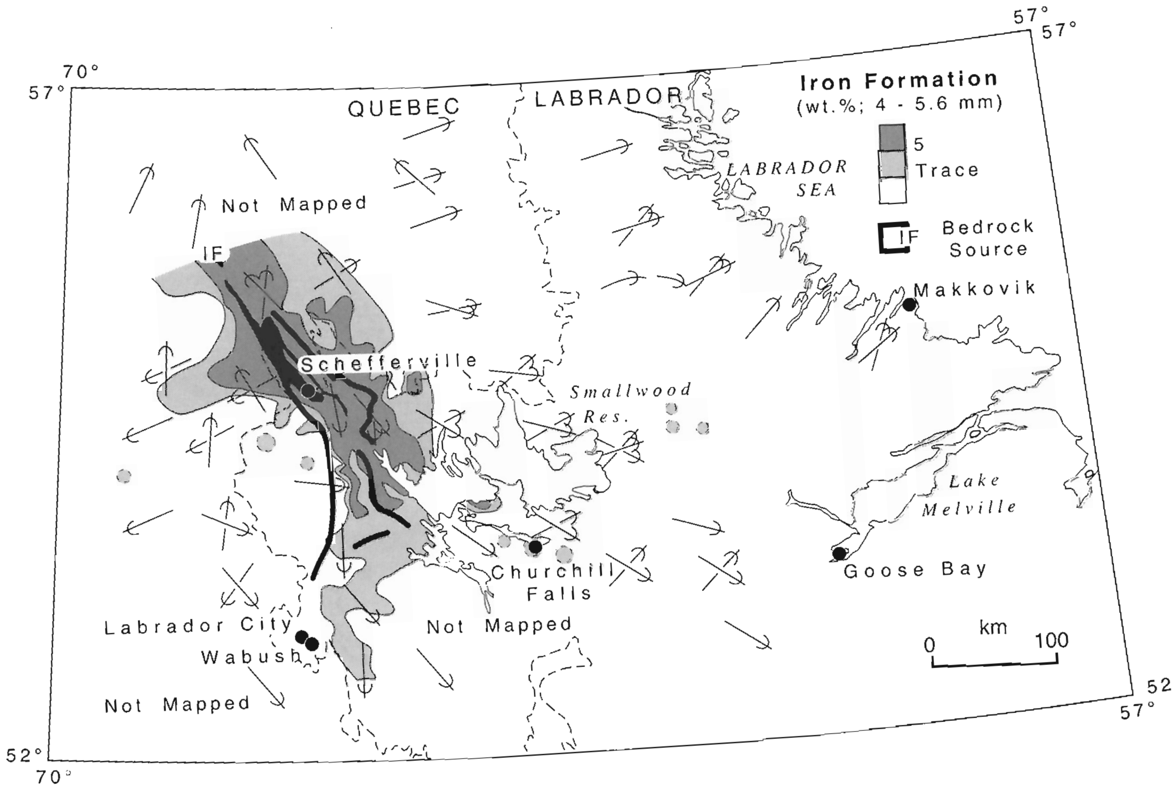


Figure 19 d

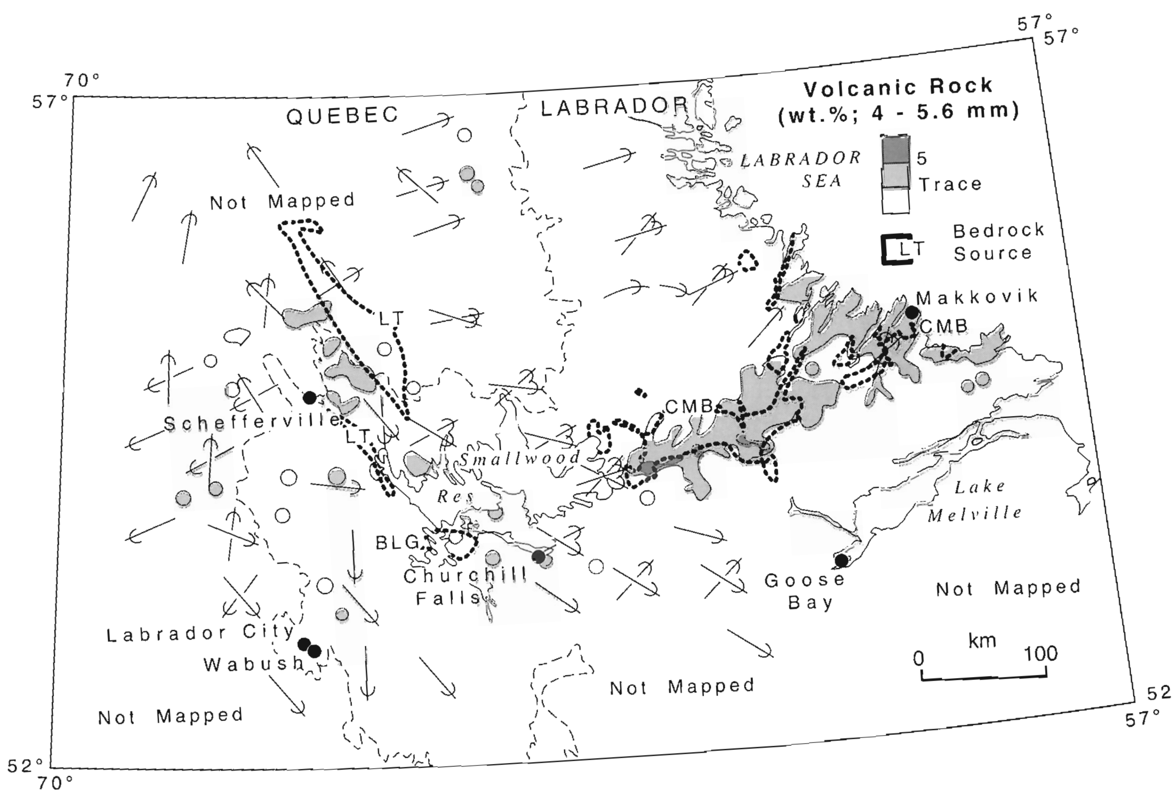


Figure 19 e

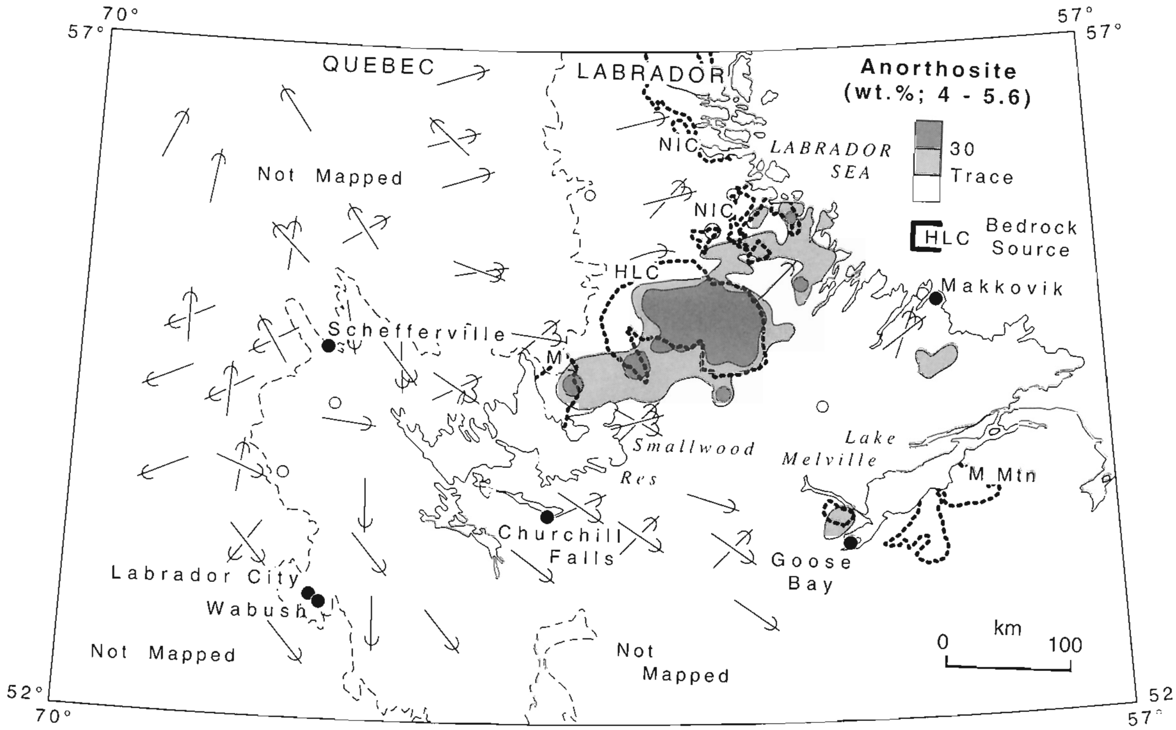


Figure 19 f

(15 km wide) throughout its length, although a 10 km wide core, defined by abundant debris, occupies the central part of the train and narrows down-ice. The northern margin of the train diverges toward the northeast as the result of either transport along the direction of older flow, or erosion of an unmapped bedrock source.

Snegamook granite

Erratics derived from the Snegamook granite (Emslie, 1980) at the southeastern margin of Harp Lake Complex define a fan-shaped dispersal train extending more than 80 km northeast (Fig. 21b). The train formed as the net product of glacial transport in two directions, to the northeast and to the east-northeast, and the bounding margins of the fan are aligned in those directions. Within the dispersal train, there is a two-pronged core where indicator debris is common. The northern core extends about 60 km northeast from the source, and the southern about 25 km to the east-northeast.

Bruce River porphyry

The distribution and relative abundance of erratics derived from the Bruce River Group is not well known, particularly to the east and south (Fig. 21c). As portrayed, the dispersal train extends 100 km to 120 km from the source. A broad core where indicator debris is present extends 60 km east, aligned generally in the directions of latest ice flow, although its orientation and outline are not well known. The northern margin of the train, however, is well defined from field observations. It is sinuous, curving to the north-northeast about 30 km from the source, and then northeast (see also Batterson et al., 1988). The nonlinear character of the margin probably results from glacial erosion of a dispersal train originally extending directly northeast from the source. Presumably the erosion occurred during later events directed more eastward. Porphyritic erratics discovered near the northwestern end of Lake Melville could reflect either glacial erosion of an unknown source, possibly volcanic rock of Blueberry Lake Group southwest of Smallwood Reservoir, or glacial transport from the Bruce River Group along flowlines not defined by striae.

Seal Lake and Bruce River Group volcanic rock

Erratics of green amygdaloidal volcanic rock are widespread, although their distribution is best known across the Harp Lake Highlands (Fig. 21c). The northern margin of the dispersal train is well defined and linear, trending northeast across the Highlands from northernmost volcanic source in the direction of regional ice flow indicated by striae.

Red Wine Complex

In the Letitia Lake area, erratics of blue and green agpaitic gneiss derived from the Red Wine Complex (Curtis and Currie, 1981; Thomas, 1981; Hill and Thomas, 1983) are used as indicators of glacial transport (Fig. 21d). They are widely

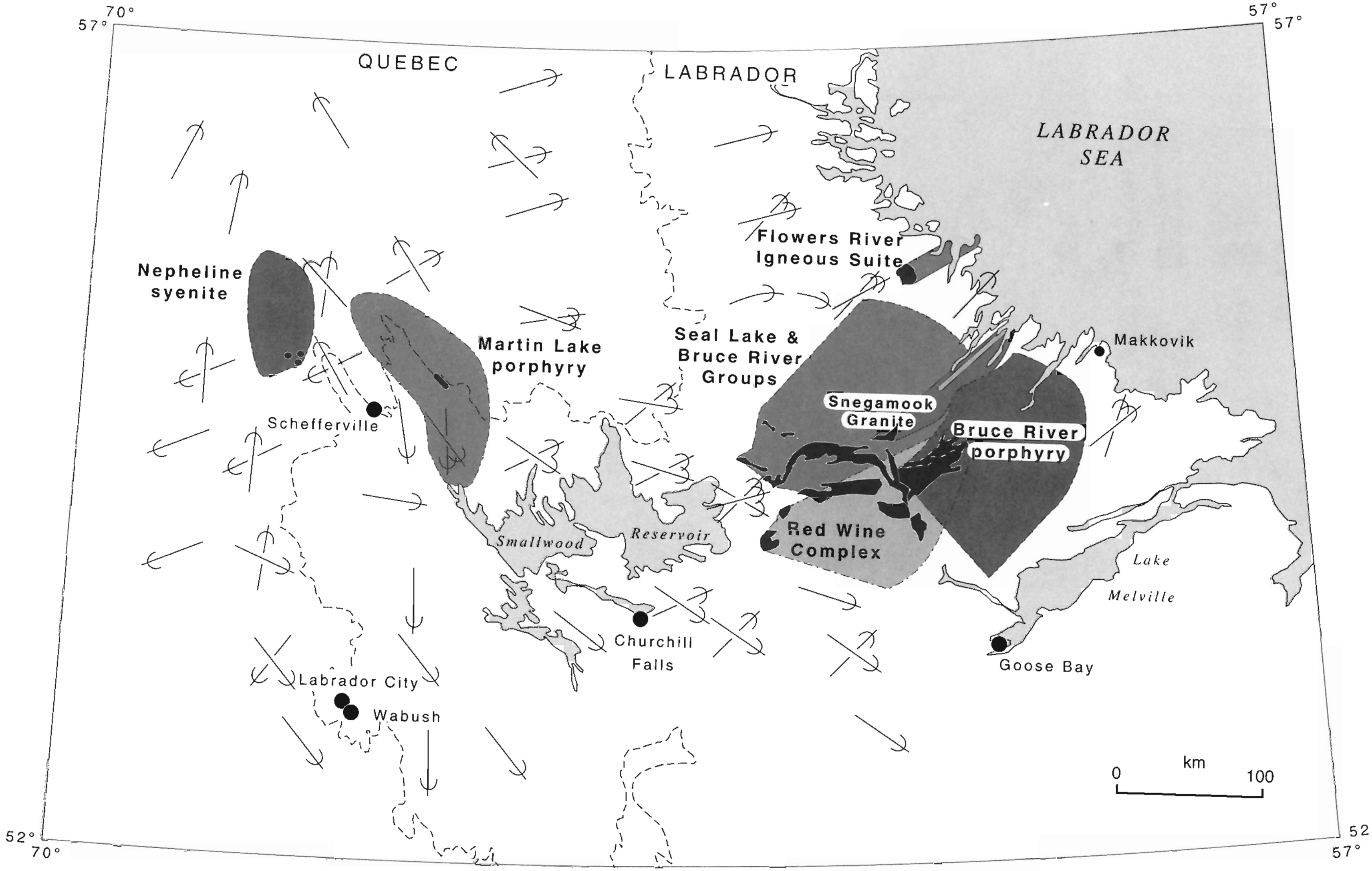


Figure 20. Indicator erratics derived from six distinct bedrock sources define glacial dispersal trains in central Labrador. The trains vary from narrow ribbons of outcrop width near the ice sheet margins, where ice flow has been relatively simple, to broad fans and patches near the locations of former ice divides in western Labrador, where ice flow has been most complex. Data are derived from field mapping of clasts (see Fig. 21 a- for detail of dispersal trains).

distributed, occurring more than 200 km from their bedrock source, and clearly indicate glacial transport in several distinct ice flow directions. Glacial dispersal trains from the Red Wine Complex also have geochemical, lithological and mineralogical signatures, discussed in a subsequent section. The indicator erratics are derived from two plutons, referred to as 'northern' and 'southern', which are the most important with regard to glacial transport, and

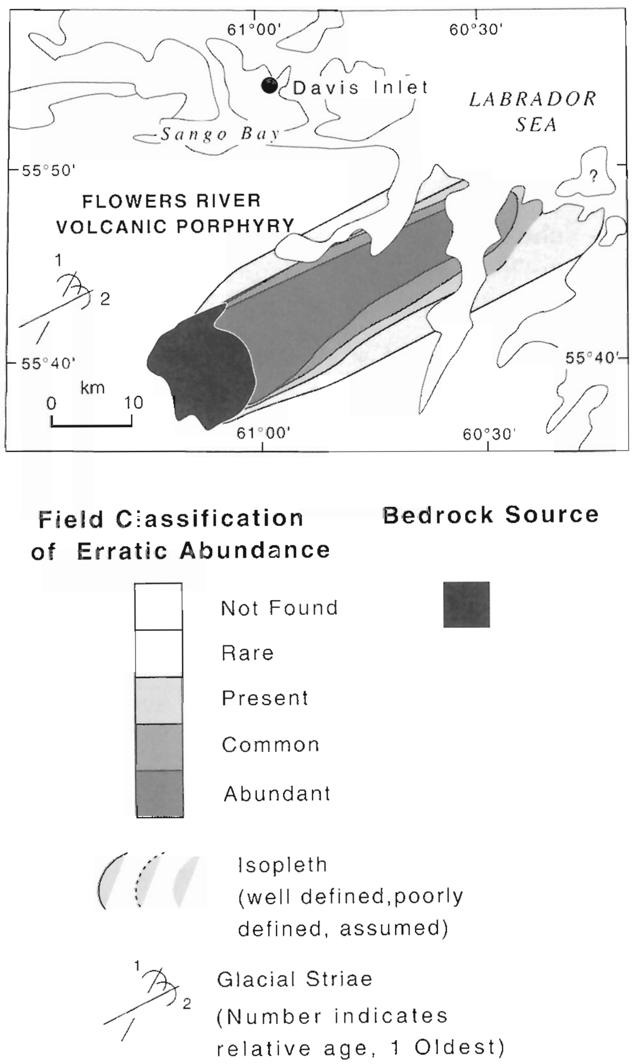


Figure 21. Compositional variation within local scale glacial dispersal trains. Indicator erratics include: **a**) volcanic porphyry of Flowers River Igneous Suite; **b**) Snegamook granite; **c**) volcanic rock of Bruce River and Seal Lake groups; **d**) agpaitic gneiss of the Red Wine Complex; and **e**) porphyritic rock of Martin Lake Formation and nepheline syenite. Compositional variations are qualitatively characterized through field observation of clasts. The effects of glacial transport and erosion during succeeding glacial events is evident by variation in the shape and orientation of the dispersal trains, and compositional zonation. The latest direction of regional ice flow is a principal control on drift composition. Dispersal trains formed during earlier ice flow events can be modified by erosion and redirection of debris during later events.

other, smaller bodies near Letitia Lake (Curtis and Currie, 1981). Although both plutons lie at similar elevations, relief of the northern is greater.

Agpaitic gneiss erratics define ribbon- and fan-shaped glacial dispersal trains. The ribbon train is linear and narrow, originating 140 km northeast of its source, and extending a further 70 km northeast to the coast. Indicators are rare throughout most of the ribbon, although they are common (>1 wt.%) at the hilltop site located at its up-ice 'head' (Shilts, 1976). Erratics from the southern pluton (K. Currie, pers. comm., 1987) occur within the ribbon more than 200 km northeast of their source. That direction of glacial transport is defined by older striae throughout central Labrador. No indicators have been found between the head of the ribbon train and the bedrock source, despite intensive search. Their absence in that region is presumed to be the result of glacial erosion during later ice flow events.

The dispersal fan originates at the bedrock source and extends up to 100 km down-ice. The margins of the fan trend east-northeast and east-southeast, and are aligned with two directions of regional ice flow indicated by striae. They are linear and well defined, and their trend is independent of topography. The southern margin, for example, lies directly across the Hamilton Uplands 300 m higher than the source.

Within the dispersal fan, indicators are present within a broad, elongate zone extending 75 km to 100 km east to east-southeast from the sources, and within scattered patches to the east-northeast. A core in which they are common is 20 to 30 km wide and extends as an elongate arc 70 km southeast from the southern pluton. In detail, it follows the latest direction of ice flow which was topographically influenced. The arc curves around the northern end of the Hamilton Highlands, following the valley of Red Wine River. Indicator debris is abundant in till overlying both sources, at sites scattered within the arcuate core, and at one site on the eastern (down-ice) margin of the Hamilton Highlands. Of the two sources, the southern pluton

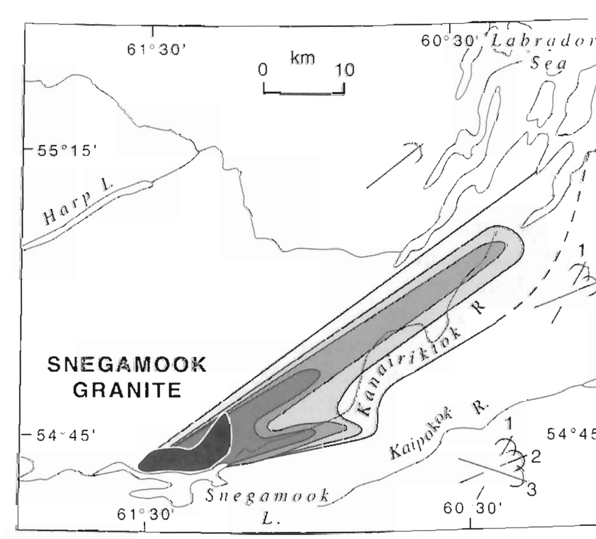


Figure 21 b

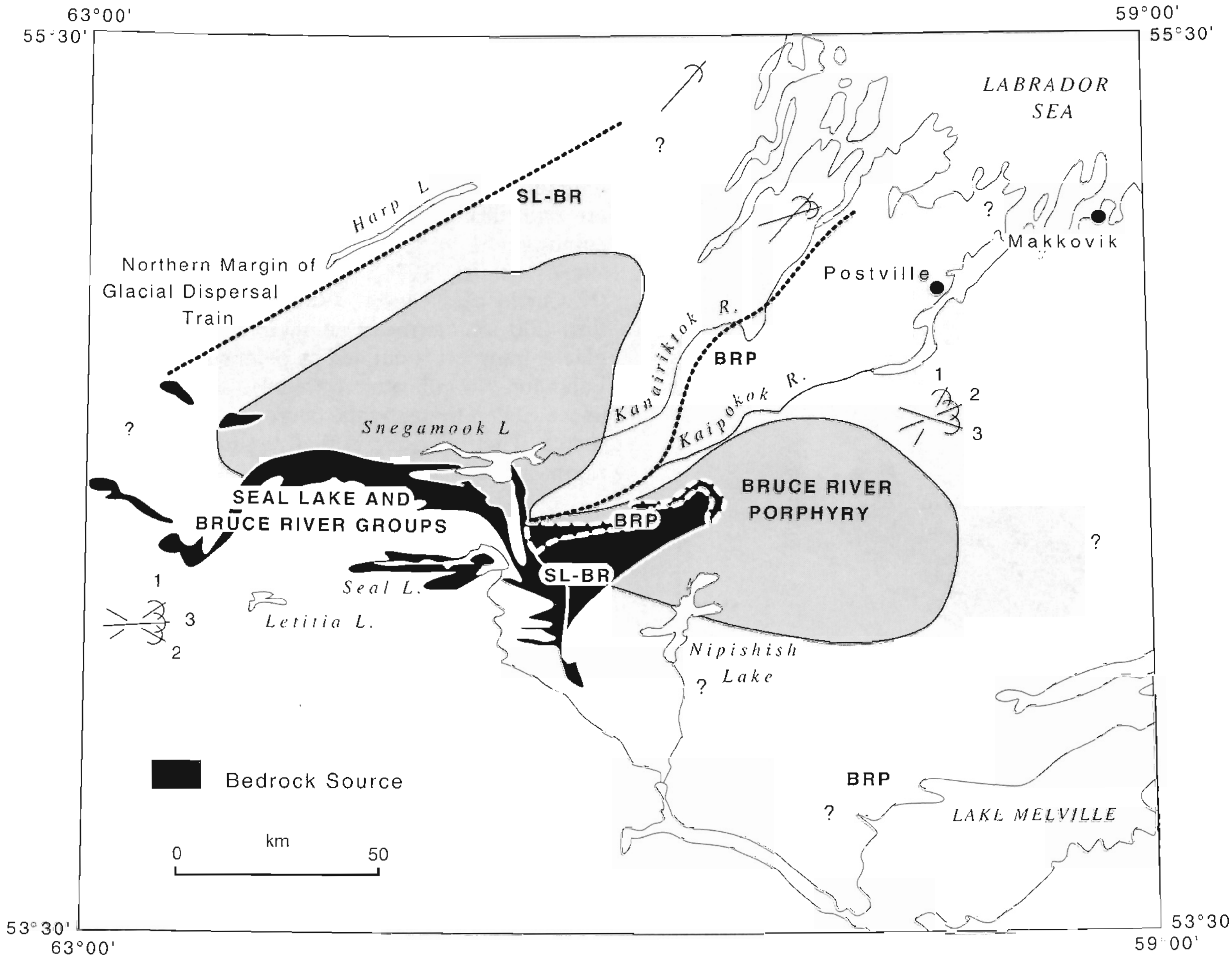


Figure 21 c

appears to have contributed greater amounts of debris to the glacier, and is inferred to have been more easily eroded by ice.

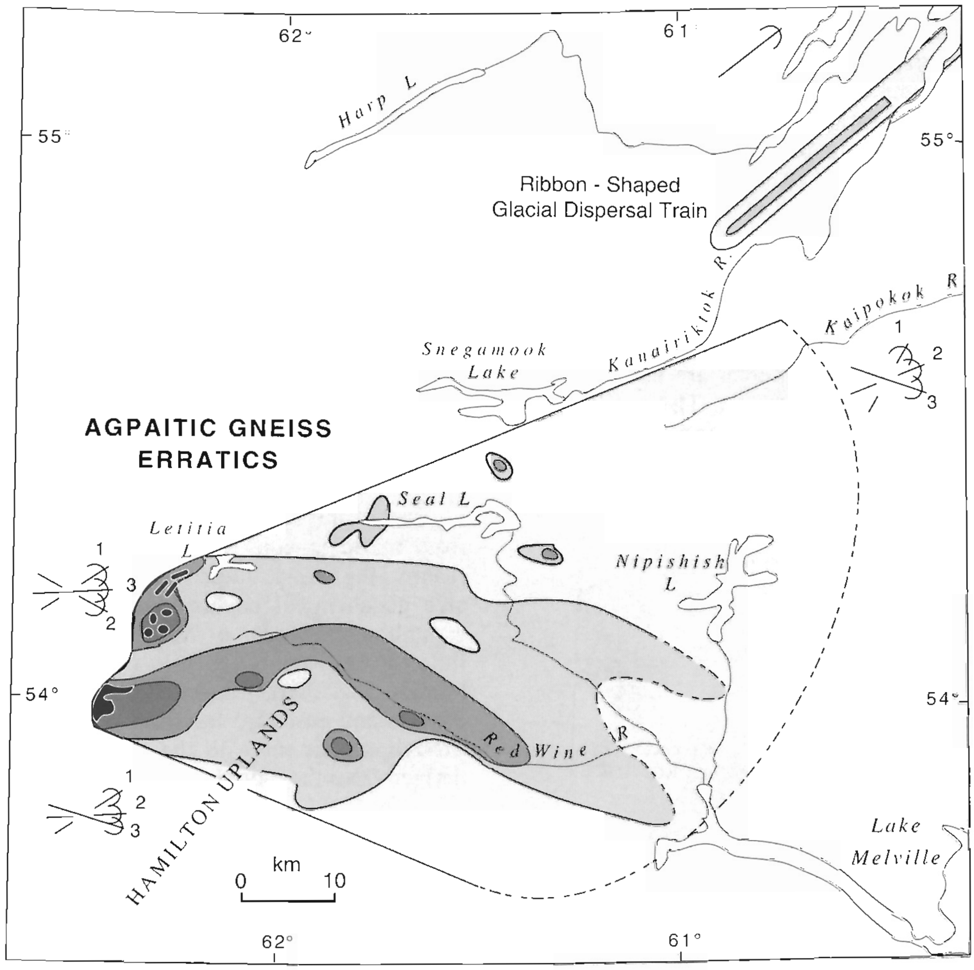
Martin Lake porphyry

Within the Labrador Trough, erratics of red, porphyritic volcanic rock define an elongate train centred about its source. It is 40 to 50 km wide, and extends 120 km northwest of the source, and 65 km southeast (Fig. 21e). Net dispersal to the west and east is not known as well as it is to the northwest and southeast, and it is likely more extensive than shown. Indicator debris is common within a core less than 10 km wide extending 65 km northwest and 30 km southeast of the source, in the directions of regional ice flow. The glacial dispersal train defines glacial transport in all directions about the source, and reflects its location near one or more dispersal centres of the Labradorean Ice Sheet, where change in ice flow direction has been greatest.

Glacial dispersal of Martin Lake porphyry is large in comparison with the source. Although the source could be more extensive than mapped, it is confined structurally to a narrow northwest-southeast trending zone (R.J. Wardle, T. Birkett, pers. comm., 1987). Either the source is significantly more extensive than shown, or it was easily eroded, allowing the erratics to be readily traced over significant distances, albeit at low concentrations.

Nepheline syenite

West of the Labrador Trough, nepheline syenite debris defines a broad, fan-shaped glacial dispersal train opening generally towards the northwest. The outer sides of the fan are aligned with two older ice flow directions defined by striae, and trend southwest and north (Fig. 21e). The central part of the train is generally elongate north-northwest in the direction of last ice flow, and extends 60 km down-ice from the source. A core where indicator debris is common extends 5 to 10 km down-ice from the bedrock source, and is two-pronged, similar to the dispersal train of Snegamook granite (Fig. 21b). The northwest orientation of the fan is distinct from dispersal trains elsewhere in Labrador that face eastward because the syenite source is located west of the ice divide(s).



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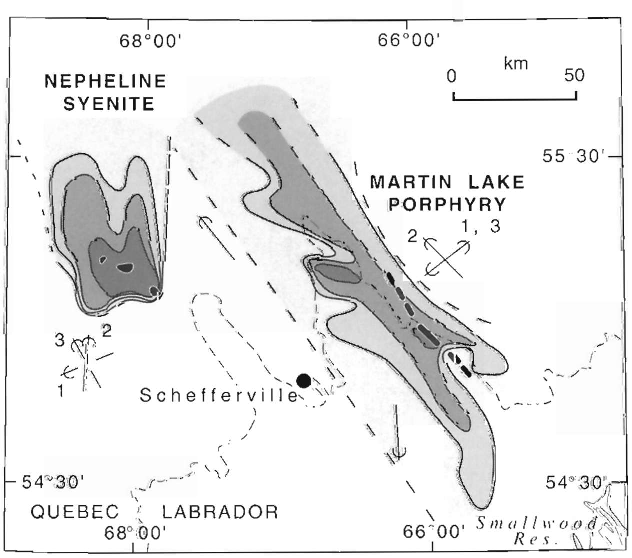

Figure 21 e

REGIONAL VARIATIONS IN TILL GEOCHEMISTRY

Geochemical maps and summary descriptions of till geochemistry are presented in Appendix 2 (Fig. A2-1 to A2-19). In large part, the geochemical patterns indicate the distribution of major geological units, and of supracrustal and peralkaline intrusive rocks in particular. Not only were those sources subject to preferential glacial erosion, but they are compositionally distinct from crystalline basement rock, allowing them to be traced in drift by both lithological and geochemical analyses, even at extremely low concentrations. Within the regional geochemical patterns, the effects of glacial transport cannot be reliably distinguished from compositional variation in bedrock without additional information concerning ice flow history and till lithology. Lithologic analyses constitute a sound geological basis for characterizing drift provenance.

Regionally, the relations among bedrock composition, glacial transport, till lithology, and till geochemistry are best shown in western Labrador where there are marked variations in ice flow directions and in bedrock composition. In comparison with basement rock, the Labrador Trough is enriched in iron, manganese, lead, and zinc, and it is depleted in chromium. Glacial dispersal trains of Trough debris (Fig. 22a) are clearly reflected by elevated concentrations of iron, manganese, lead, and zinc (Fig. 22b-f). Within these dispersal trains, the composition of underlying crystalline bedrock cannot be easily distinguished due to either the volumetric dominance of transported Trough debris, or to the large geochemical differences (contrasts) between bedrock and transported material, or both.

Where supracrustal debris is a minor component of drift, as over the southern part of the Ashuanipi Complex (Fig. 2, 22a), geochemical levels are low with little variation, and the effects of glacial dispersal are not obvious from the shape of geochemical contours. There, till geochemistry likely reflects the gross composition of underlying crystalline bedrock.

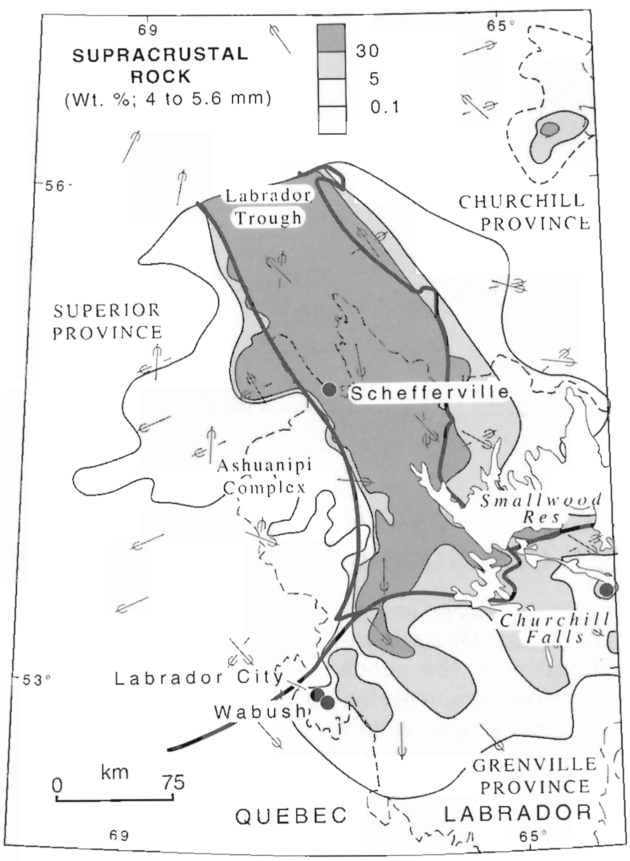

Figure 22. Till lithology and geochemical patterns in the western part of the study area. The diagram illustrates marked changes in ice flow and glacial transport directions, and resulting compositional variations in till. Glacial dispersal trains of **a)** supracrustal debris extend outward from the Labrador Trough and can be geochemically defined by greater concentrations of **b)** iron, **c)** manganese, **d)** lead, and **e)** zinc. Over the basement complex west of the Trough the zone of eastward ice flow is indicated by geochemical depletion. **f)** East of the Trough chromium defines northeast glacial transport from mafic sources, whereas west of the Trough it reflects the composition of underlying crystalline bedrock modified by chromium-poor debris from the Trough. (Bedrock units are given by Appendix 2, Fig. A2-1).

Till overlying the Ashuanipi Complex is enriched in chromium compared with the Trough (Fig. 22f). To the north, where supracrustal debris is present in significant concentrations, the extent to which chromium concentrations have been subdued or otherwise masked by the chromium-poor transported material is not known. The relatively low chromium concentrations (120 to 200 ppm; Fig. 22f) that characterize the central core of the supracrustal dispersal train west of Schefferville (Fig. 22a) are indicative of some masking effects.

Eastward glacial transport into the southern part of the Trough is reflected by both increased concentrations of crystalline pebbles (Fig. 22a) and by elevated levels of chromium (Fig. 22f). There, chromium analyses reflect glacial history and provenance of transported debris, not the composition of underlying bedrock.

East of the Trough, till enriched in chromium is derived from mafic igneous rock of the southern Doublet Group (LPmv, Fig. A2-1, Appendix 2), and defines a more extensive geochemical pattern extending farther east over the crystalline basement of the Churchill Province. Although lithological evidence for eastward glacial transport is not well known (Fig. 22a), till geochemistry likely reflects glacial erosion and eastward transport of mafic bedrock from the Trough, consistent with the distribution of green-grey till derived from the Doublet Group.

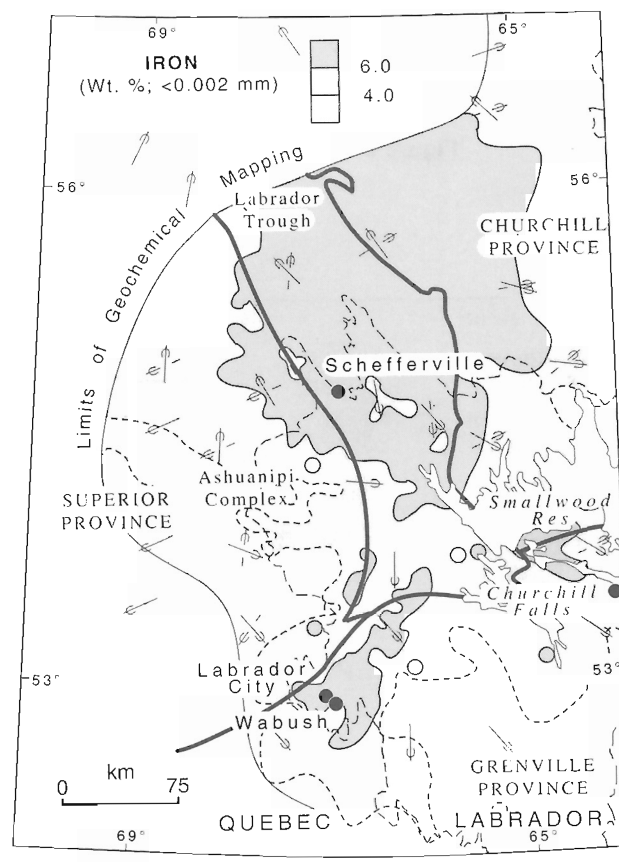

Figure 22 b

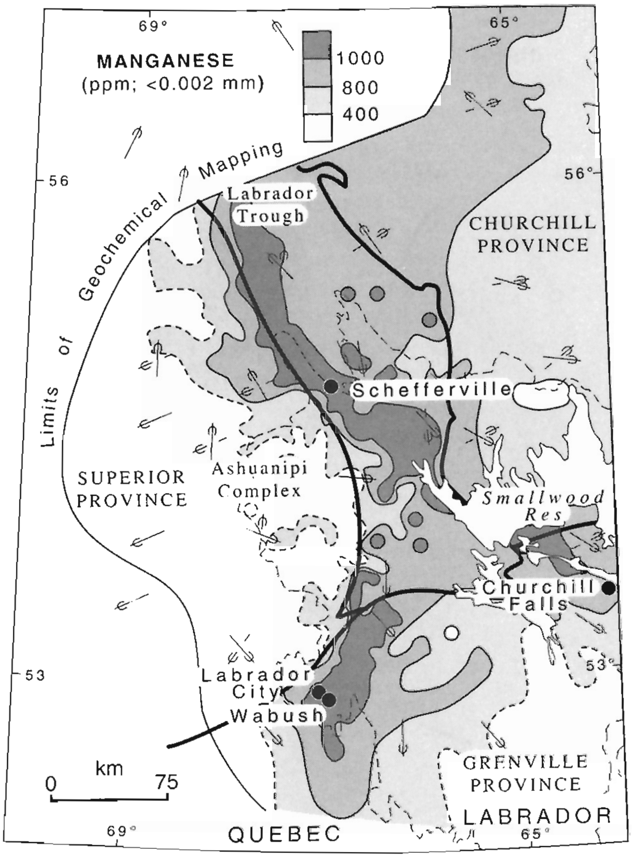

Figure 22 c

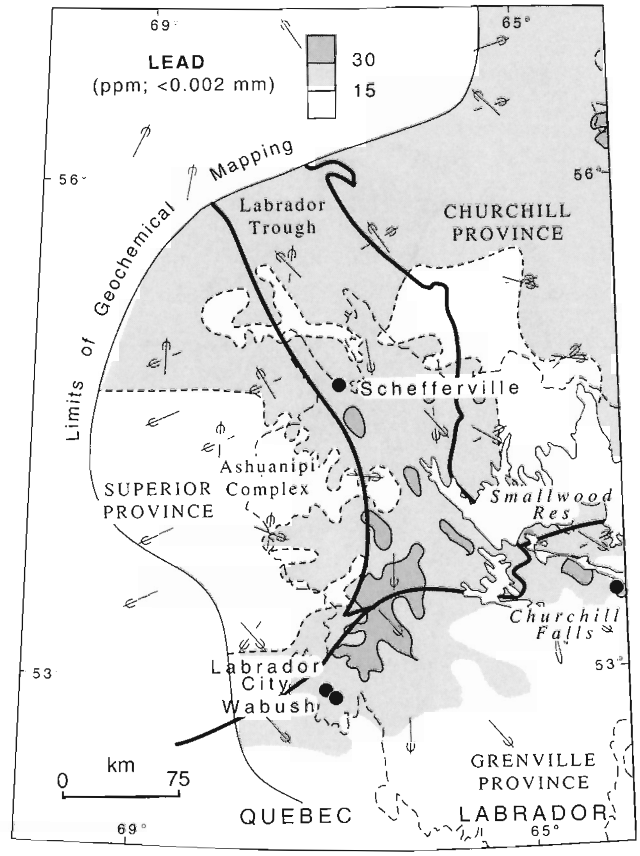

Figure 22 d

Where till is geochemically distinct from adjacent terrain up-ice, its composition can be inferred to relate to underlying bedrock. For example, till in the southernmost Labrador Trough, northeast of Labrador City-Wabush, is anomalous in several elements, including copper, lead, zinc, and uranium. The anomalous concentrations are attributed to glacial erosion of a bedrock source within the southern Trough where they appear to originate, and the extent of till having those characteristics would indicate a large bedrock source.

GLACIAL DISPERSAL NEAR FLOWERS RIVER AND LETITIA LAKE

In the Flowers River and Letitia Lake areas sample density was increased to provide more detailed characterization of drift geochemistry and to illustrate the effects of glacial transport at local scale. Both areas are underlain by peralkaline intrusive and volcanic rocks that are well suited as indicator sources.

Letitia Lake

In the Letitia Lake area, interpretation of glacial dispersal from peralkaline rock, including the Red Wine Complex, Arc Lake Intrusive Suite, and volcanic rocks of the Letita Lake Group (Hill and Thomas, 1983), is based on field mapping of clasts (Fig. 21d), pebble lithology (Fig. 23a), sand mineralogy (Fig. 23b), and geochemical analyses of silt and clay (Nb, Y) (Fig. 23c, d) and of clay (Pb, U) (Fig. 23e, f). Indicator pebbles and heavy minerals are derived from agpaitic gneiss of the Red Wine Complex, the northern and southern plutons in particular (Curtis and Currie, 1981), whereas the peralkaline complex as a whole is considered as a single source for geochemical dispersal.

Coarse clasts

Agpaitic gneiss erratics mapped in the field (Fig. 21d) define ribbon- and fan-shaped glacial dispersal trains, recording transport of more than 200 km in three directions of ice flow. The erratics and their distribution are discussed in a preceding section.

Pebbles

Agpaitic gneiss pebbles (Fig. 23a) define a fan-shaped glacial dispersal train originating at the bedrock source, similar to that defined by field mapping of indicator erratics (Fig. 21d). Pebbles of green gneiss are more easily recognized than blue gneiss (Curtis and Currie, 1981), and the dispersal pattern emphasizes that rock type. The fan is defined by indicator pebbles at low (trace to 1 wt. %) concentrations, and not all sites within the fan contain indicators. It extends eastward to

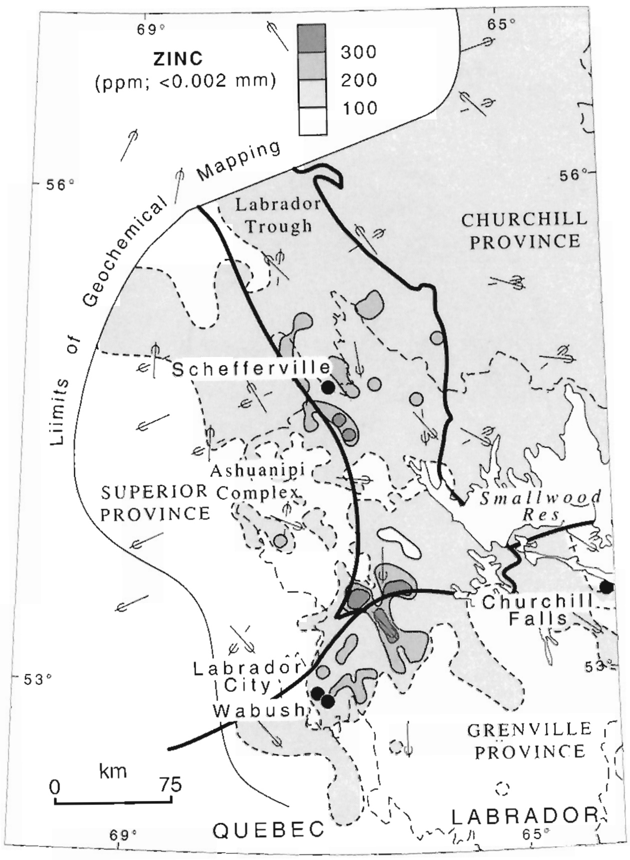

Figure 22 e

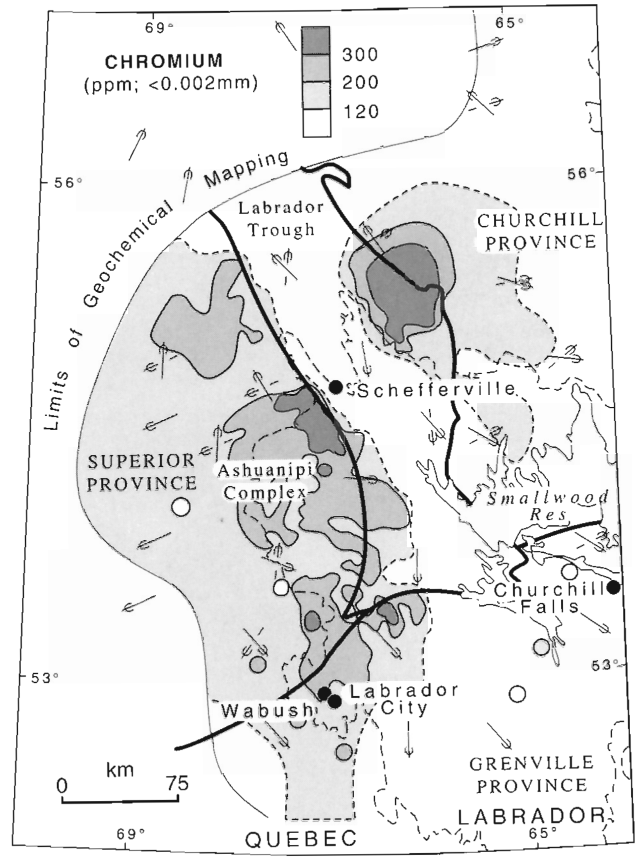

Figure 22 f

Nipishish Lake, although its down-ice extent is less than defined by erratics mapped in the field. Within the fan, indicator pebbles (1 to 2 wt.%) clearly define a zone approximately 45 km wide extending 100 km east to east-southeast, and several isolated occurrences north of it. Concentrations greater than 2 wt. % define narrow core zones that extend 10 km and 25 km east-southeast of the northern and southern plutons.Outside the fan, indicator pebbles occur only at the 'head' of the ribbon train defined by coarse clasts (Fig. 21d).

Heavy mineral fraction

Blue aegirine (titanian ferro-omphacite; s.g. 3.3: Curtis and Currie, 1981, p. 25) is an indicator mineral (Fig. 23b). Although present at low concentrations, it is widespread in till and readily identified, remaining as a record of glacial transport despite postglacial weathering. Another blue mineral (titanium-rich aegirine; s.g. 3.15) also occurs within bedrock, but would not occur in the heavy mineral fraction, unless as a contaminant. At low concentrations (<0.1%), blue aegirine defines a broad fan opening towards the east that is more or less coincident with the dispersal fan defined by erratics (e.g. Fig. 21d, 23a), and isolated patches outside the fan, 120 km and 170 km northeast of the source. The southern margin of the fan is linear and well defined, and the northern curved and irregular, indicating that it could have been subject to erosional modification during succeeding glacial events. The scattered occurrences to the northeast, outside the fan, are interpreted as erosional remnants of a dispersal train originating with regional ice flow toward the northeast (Fig. 21d, 23a).

Within the fan, blue aegirine at concentrations greater than 1% defines a 25 km wide core that originates with the northern pluton source, generally curving around the northern end of the Hamilton Uplands and extending more than 100 km down-ice. The indicator mineral is 3-12 wt. % near the northern source and within an elongate zone 30 km farther down-ice, and it remains 2-3 wt. % more than 80 km down-ice. In comparison with the southern pluton, the northern could either have a greater concentration of the heavy mineral or could have been subject to preferential glacial erosion, or both, leading to the definition of those zones within the glacial dispersal fan. Similarities in the dispersal of pebbles (2-3 wt. %) from northern and southern plutons (Fig. 23a) would indicate mineralogical differences between sources.

Till geochemistry

Peralkaline rocks of the Letitia Lake area are geochemically distinct from bedrock of adjacent regions by their elevated concentrations of zirconium, yttrium, niobium, lanthanum, thorium, lead and zinc, and low concentrations of nickel and chromium (Baragar, 1981, Thomas, 1981, p. 31; Miller, 1988, Tables 5, 6). Bedrock sources of Nb-Be and of Y mineralization occur within peralkaline syenite of the Arc Lake Intrusive Suite and nearby volcanic rocks of the Letitia Lake Group west and north of Letitia Lake, and at one site to the southeast (Thomas, 1981; Miller, 1987, 1988). Volcanic bedrock of the Letitia Lake Group is also commonly mineralized with disseminated pyrite, and contains both lead and zinc sulphides in veins (Brummer, 1960; Thomas, 1981). Uranium is also reported at elevated levels within the Letitia Lake Group as well as within the Arc Lake Intrusive Suite and the Red Wine Complex (Thomas, 1981).

Glacial dispersal from the peralkaline complex can be geochemically defined by niobium (>20 ppm) (Fig. 23c) and yttrium (>40 ppm) (Fig. 23d). Geochemical dispersal trains appear as broad, elongate zones that extend 40 km to 80 km east. Till directly overlying the bedrock sources contains >40 ppm niobium and >60 ppm yttrium.

A zone characterized by lead concentrations of >30 ppm extends up to 50 km east from the peralkaline complex, and is preferentially developed over and down-ice of volcanic bedrock of the Letitia Lake Group (Fig. 23e). That bedrock is elongate along the path of ice flow, and likely contributed a proportionally greater volume of debris to the ice than did other peralkaline sources. Paleoweathered volcanic rock of the Letitia Lake Group is known to be geochemically enriched in lead (A. Thomas, pers. comm., 1987), and differential glacial erosion of that bedrock unit could have further contributed to the enhancement of the northern part of the dispersal train. Till containing >60 ppm lead forms core zones extending 10 km down-ice of the bedrock sources.

Uranium does not clearly define glacial dispersal from the complex, although anomalous concentrations exist in till overlying, and up to 20 km east of the northern pluton (Fig. 23f). The southern pluton is not reflected by uranium,

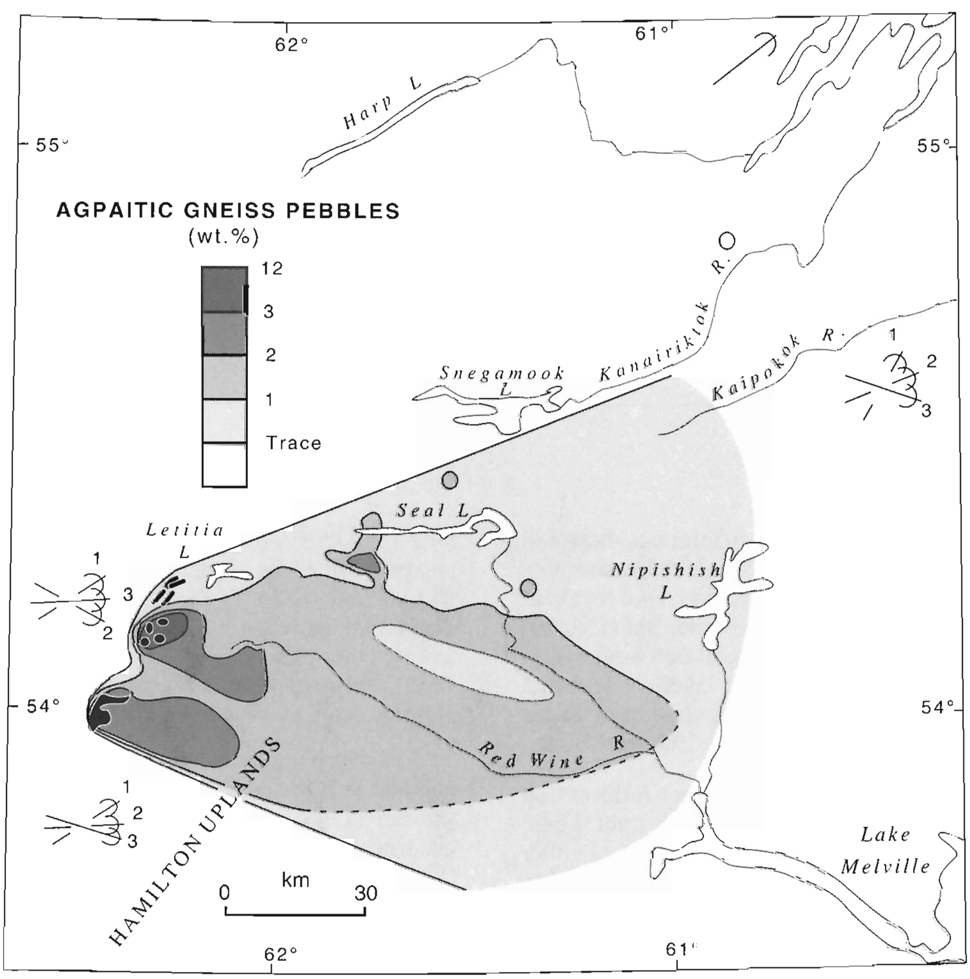

Figure 23. Lithological, heavy mineral, and geochemical indicators of glacial transport from the peralkaline Red Wine complex near Letitia Lake. Analyses of **a**) pebbles, **b**) heavy minerals, **c**) niobium, **d**) yttrium, **e**) lead, and **f**) uranium define glacial dispersal trains – those shown by geochemical analyses are most restricted in their definition and down-ice extent. Heavy mineral analysis provides the best definition of glacial transport, and its dispersal train is comparable to that indicated by field mapping of indicator erratics (Fig. 21d). Bedrock source(s) indicated by white outline and by dashed outline.

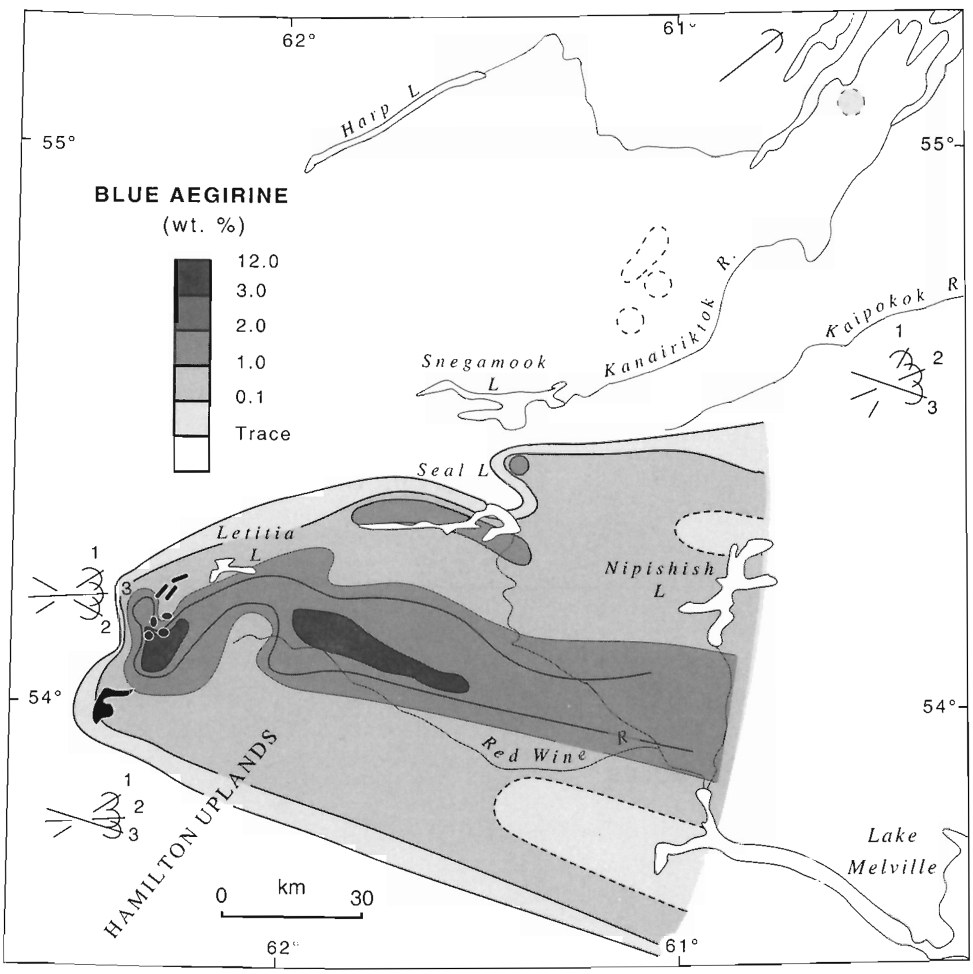

Figure 23 b

possibly indicating compositional differences between plutons. Net dispersal patterns from the peralkaline complex are difficult to define against the high background levels of uranium in till derived from the Trans-Labrador Batholith and other bedrock sources of the Central Mineral Belt farther east. East of the Letitia Lake Group, elevated levels of lead and uranium are most likely related to glacial erosion of Bruce River and Moran Lake groups of the Central Mineral Belt.

The ribbon train defined by erratics is not reflected by geochemical analyses, even at the head of the train where erratics comprise 1 wt. % of pebbles. The absence of either mineralogical or geochemical evidence of dispersal within the finer size fraction indicates that the coarse erratics were likely transported englacially, and that they did not serve as a continuing source of indicator debris to the fine fraction by glacial comminution during transport.

Flowers River

The Flowers River Igneous Suite consists of felsic volcanic rocks intruded by peralkaline granite. The granite comprises a batholith and several smaller satellitic plutons that outcrop over 1570 km^2. To the west, the area is underlain by granitic and gabbroic rocks of the Nain Igneous Complex. Peralkaline and volcanic rocks of the Igneous Suite are geochemically distinctive; enriched in niobium, yttrium, lead, and uranium, among other elements, and they are depleted in nickel (Hill, 1982). Those geochemical characteristics are reflected at the regional scale by till geochemistry (Fig. 24a-e).

Till overlying the northern and eastern parts of the Suite contains the greatest concentrations of niobium (Fig. 24a) and yttrium (Fig. 24b), and smaller areas can be identified elsewhere that are also enriched. Niobium, yttrium, lead (Fig. 24c), and zinc (Fig. 24d) define a glacial dispersal train that originates near the eastern margin of the volcanic centre. The train extends northeast 10 km to 20 km outside the peralkaline complex, lying across gneissic terrain of the Nain Province. Its geochemical attributes are distinct from till derived from basement sources allowing it to be readily traced. Elsewhere over the Igneous Suite, smaller areas of geochemical enrichment occur near Sango Bay although their shape does not as strongly reflect glacial transport.

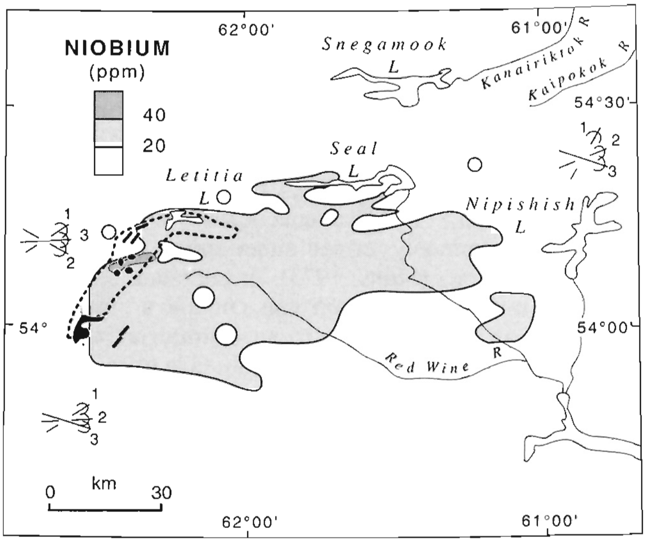

Figure 23 c

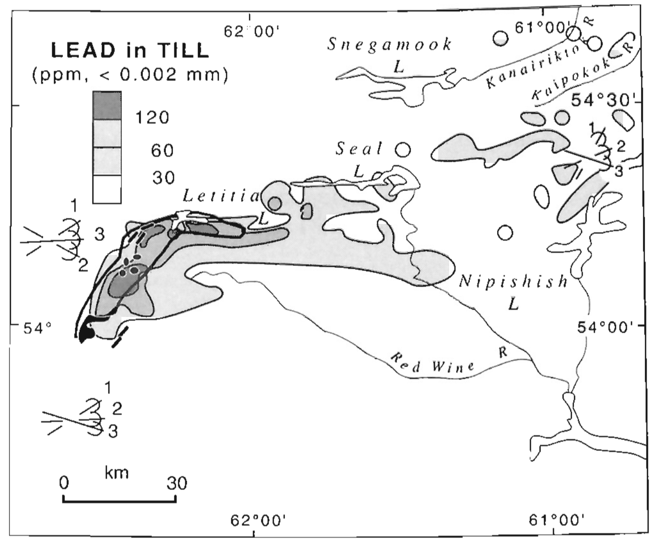

Figure 23 e

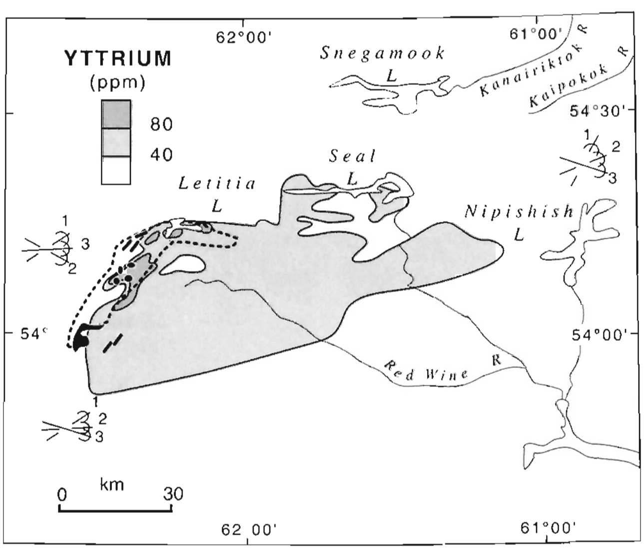

Figure 23 d

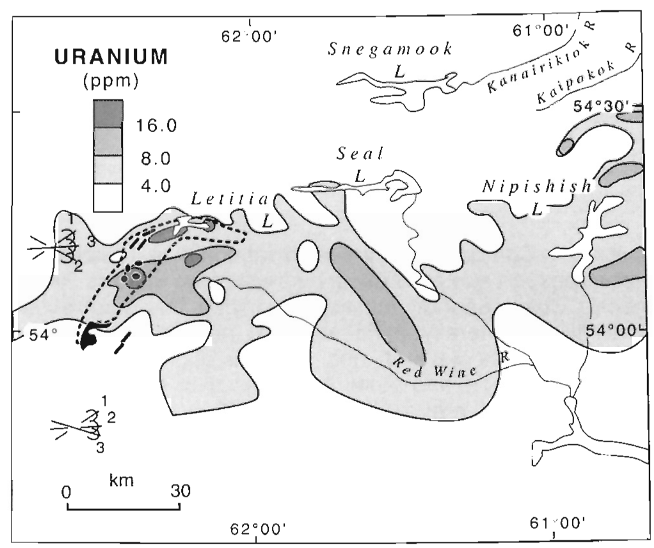

Figure 23 f

Most of the Igneous Suite is overlain by till containing low concentrations of nickel (<20 ppm) (Fig. 24e). The greatest concentrations occur to the south, where till is also relatively depleted in niobium, yttrium, and lead. The geochemical characteristics indicate that till there is most likely derived from crystalline bedrock to the west, up-ice. Thus it can be inferred that the geochemical expression of bedrock along the western and southern margins of the peralkaline complex is masked by the glacially transported debris derived from gneissic terrain up-ice.

POSTGLACIAL WEATHERING AND TILL GEOCHEMISTRY

There are few studies of Labrador soils, so that the following descriptions are not strictly based on the Soil Classification of Canada (Canada Soil Survey Committee, 1978) which incorporates laboratory analytical results within pedogenic definitions. Instead, they are descriptive and intended as a working guide to geochemical sampling as part of exploration in Labrador.

Generally, soils of Labrador are podzolic, meaning that they are acidic and that parent materials have been subject to strong leaching and horizonation (McKeague et al., 1983; Wang et al., 1989) (Fig. 25). Podzols occur within areas of boreal forest cover, and bright oxidation colours and well-defined colour differences among soil horizons are typical of well drained sites with sandy sediments (Fig. 26a). In comparison, at wet or poorly drained locations soil colours imparted by secondary iron, manganese, and organic compounds are not as bright, and colour differences among soil horizons are not clearly defined (Fig. 26b). At the latter sites mottling is common, indicating periodic change from oxidizing to reducing conditions. Where reducing conditions are prolonged, a grey horizon lacking oxidation colours can occur. Reducing conditions are most commonly found at shallow (<50 cm) sites within the lowermost 1 cm to 3 cm of sediment overlying bedrock. They are associated with water ponded at the bedrock surface where oxygen is lacking. Where there is marked fluctuation in near-surface water tables, soil structure within the B horizon can be cemented by

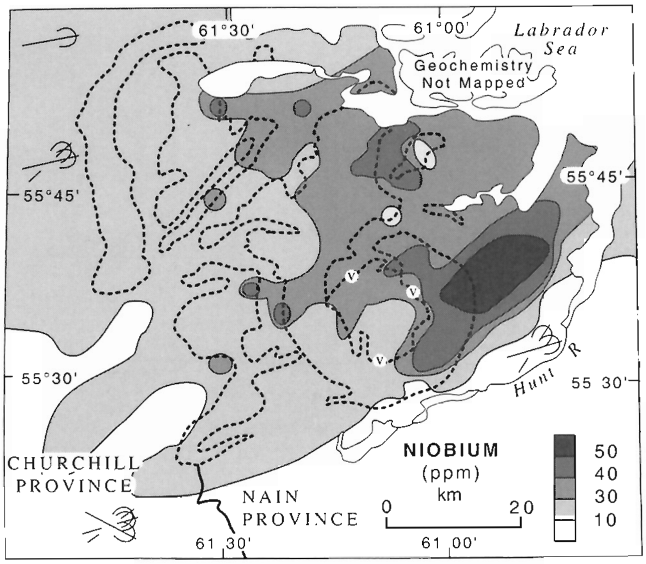

Figure 24. Compositional variation within till as it relates to glacial transport and peralkaline bedrock of the Flowers River Igneous Suite (dashed outline). Overlying the peralkaline rocks, till is generally enriched in **a**) niobium, **b**) yttrium, **c**) lead, and parts of it in **d**) zinc, and **e**) is depleted in nickel. Across the southern and western margins of the Igneous Suite the geochemical properties of till most closely relate to crystalline terrain up-ice (west), and the compositional expression of underlying bedrock is masked.

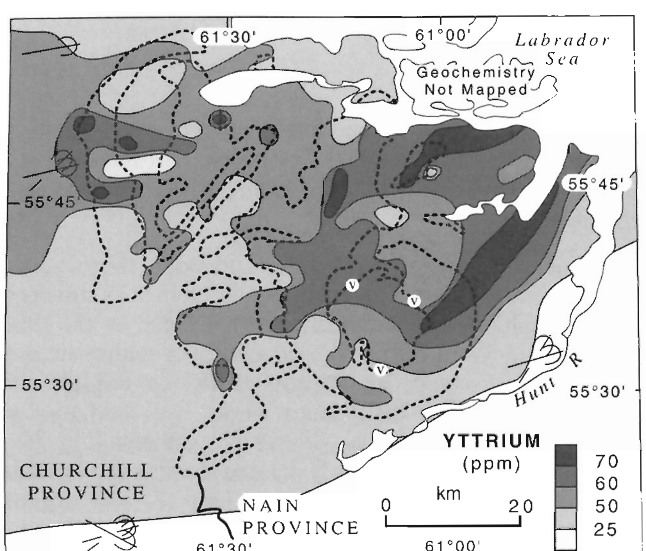

Figure 24 b

compounds presumed to include secondary iron, manganese and amorphous alumina complexes, and organic matter, in varying combinations.

At exposed locations, on hilltops or above treeline, soil circulation resulting from periglacial processes prevents development of stable soil profiles. Circular patches free of vegetation, <0.5 to >1 m in diameter, occur in those locations, and they are commonly termed either sorted or nonsorted circles, or mudboils (Shilts, 1973). In Labrador, sediments subject to mudboil formation can contain a significant admixture of fine-grained organic material and are geochemically weathered despite the absence of soil profile development and despite limited colour change imparted by secondary iron and manganese oxides.

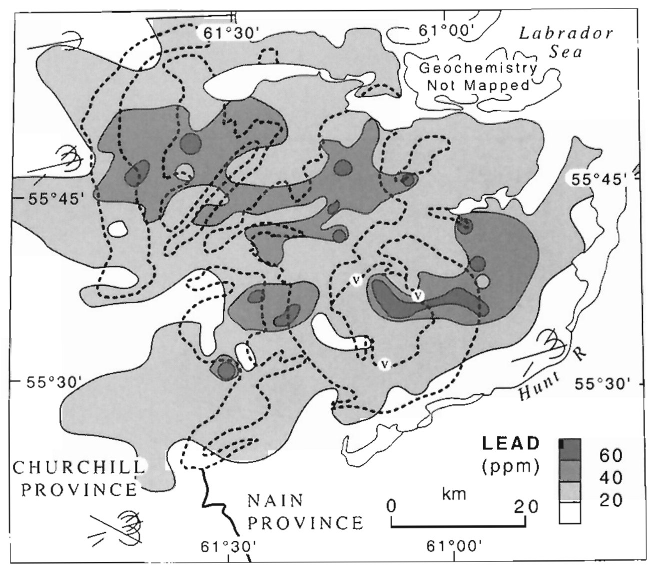

Figure 24 c

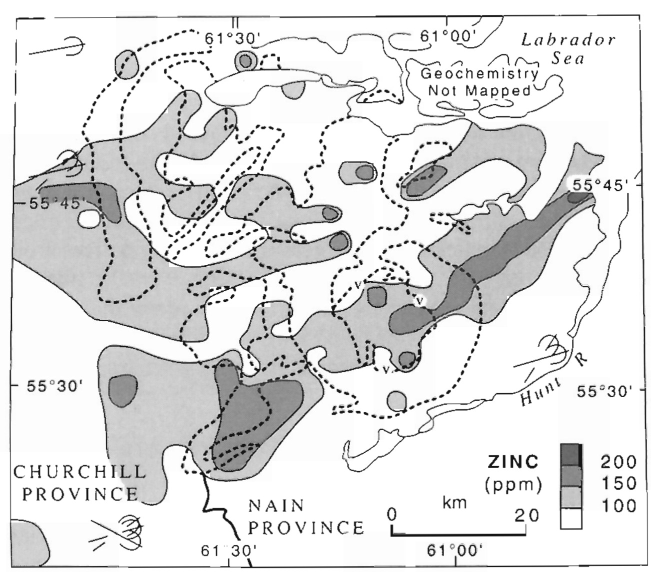

Figure 24 d

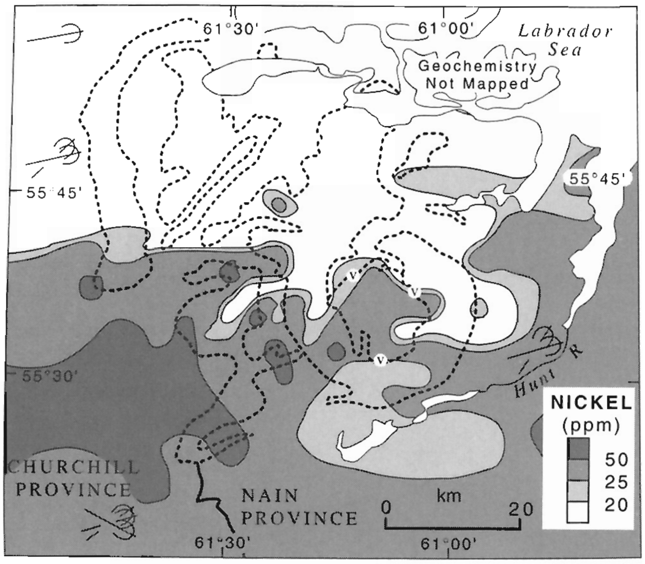

Figure 24 e

To determine postglacial weathering effects, samples were collected from soil profiles in till derived from distinct bedrock terrains, and at sites with diverse drainage and vegetation. They represent the range of soils commonly encountered. From the work, a strategy can be defined for geochemical sampling within the solum and for determining the most appropriate size fraction for geochemical analyses. Soil profiles discussed in the following text are presented in Appendix 3.

At each site, pits were dug either to bedrock or to depths of about 1 m, and samples were collected from soil horizons at intervals of about 5 cm to 10 cm. For eastern soil profiles, geochemical analyses were made of clay (<0.002 mm), silt and clay (<0.063 mm), and granule (2 to 4 mm) fractions, and of sand (0.250 to 0.063 mm) (total; heavy mineral (s.g. >3.3)) fractions. For western profiles, analyses were made of the clay (<0.002 mm), silt (0.002 to 0.063 mm), and sand (0.063 to 0.250 mm) (total; heavy mineral (s.g. >3.3)) fractions, as well as the <2 mm fraction. Organic carbon analyses were also done on the clay fraction (eastern) and on the <2 mm fraction (western) by determination of weight loss on combustion in a LECO furnace.

With two exceptions (Emben profile of the eastern group, and Pedon 7 of the western group) the soil profiles are developed within till <1 to 2 m thick that is interpreted to have been compositionally uniform at the time of deposition. The till appeared massive within the walls of sample pits, having no significant variations in texture or depositional structure that could indicate facies variations. Geochemical analyses of the pebble fraction, which is interpreted to have been least subject to chemical weathering, further indicates little variation with depth and supports the interpretation of a compositionally uniform parent material. Eastern soil profiles were developed in till near mineralized (U) showings, and some element levels are anomalous with regard to regional trace element levels.

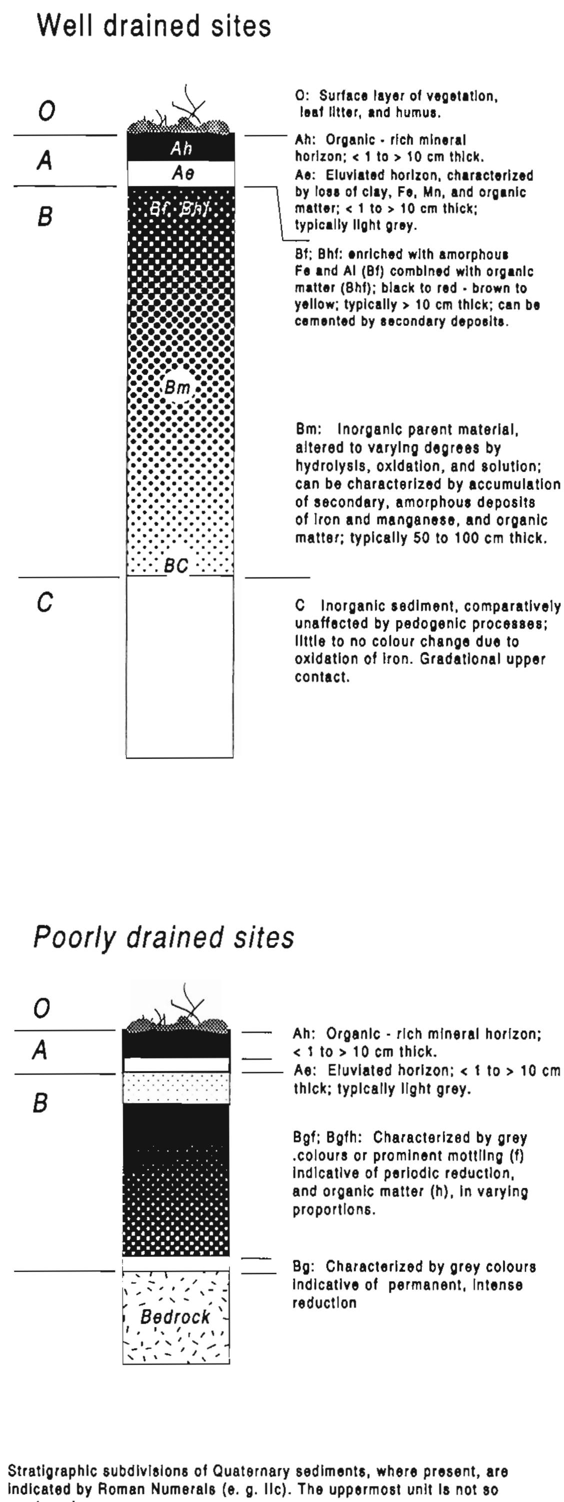

Figure 25. Schematic diagram illustrating the principal characteristics of podzolic soils at well drained and at poorly drained sites, and usage of soil terms and stratigraphic indicators. Shading indicates the relative degree of iron stain within the B horizon.

Figure 26. Soils typically have an organic-rich surface layer, overlying a light coloured zone of intense oxidation and leaching, in turn overlying a zone of oxidation and accumulation. **a**) Colours are brightest and horizonation best developed at well drained sites. **b**) At wet or poorly drained sites, soil colours are comparatively subdued, and mottling is common. GSC 203803-R; GSC 203803-Q

Comparison among size fractions

Trace element concentrations vary inversely with grain size, and clay contains notably greater amounts than any of the coarser fractions analyzed.

Within western profiles, geochemical concentrations of the <2 mm fraction were greater than either the sand or silt fractions, and they likely reflect the geochemistry of the clay component within that fraction. An exception is represented by Soil Profile 7 where chromium concentrations are greatest within sand. The sand could contain fragments of slate and shale derived from the Attikamagen and Menihek formations, which contain greater concentrations of chromium than other rocks within the Trough (Fryer, 1977).

Comparison among soil horizons

There are well defined differences among horizons in organic matter, iron, and manganese that are secondary in origin and related to postglacial weathering (Appendix 3, Fig. A3-1 to A3-8). Within all fractions, trace element concentrations increase generally with depth, and soil profiles are generally similar in shape. The clay fraction contains the greatest concentrations of trace and minor elements and organic matter, and displays the greatest variation among soil horizons.

1. Organic carbon: Carbon concentrations are greatest within either the Ae or upper B horizons below which they decrease with depth. The rate of change with depth is greatest within the upper part of the B, and it decreases rapidly lower within the profile. Samples within the C horizon contain some organic carbon (<2 wt. % in the clay fraction and <1 wt. % in the <2 mm fraction), likely from either roots or the downward movement of finely divided organic material with water. The carbon profiles appear similar to those of iron.

2. Iron: Well drained, sandy soils are characterized by bright oxidation colours whereas poorly drained soils appear dull brown and reddish-brown and lack well defined colour horizonation. Differences in soil colour closely match the distribution of iron, which is least within the Ae horizon, and greatest within the uppermost part of the B, below which it decreases with increasing depth. The rate of change in iron with depth is greatest through the B horizon, below which it decreases. Iron can be concentrated to a significant degree within the B horizon where it can be 5 to 10 wt. % greater than within the upper part of the C. It is depleted from reducing horizons.

3. Manganese: Manganese concentrations are least within the Ae horizon, and generally increase with depth, unlike iron. Within the Ae horizon, manganese levels are typically less than 100 ppm, whereas near the base of the profiles levels they are commonly 1000 ppm, and can be much greater (6000 ppm),

depending on parent material composition, moisture, and redox conditions. Within well drained soils manganese has been removed from the Ae and B horizons, and levels within the C are interpreted as the best approximation of original parent material available within the sample pit. For poorly drained soils, however, there can be accumulation of manganese within the reducing horizons near the base of profiles (e.g. Appendix 3, Burnt Lake, Leslie Lake soil profiles). The relative importance of secondary processes appears to be closely controlled by site moisture and drainage.

4. Trace elements: Within all size fractions most trace metal concentrations are least in the Ae and generally increase with depth toward the C. The rate of change with depth is greatest within the uppermost part of the B horizon, and it decreases with depth. Concentrations are typically greatest within the upper C horizon. In most profiles, however, there is little geochemical difference between adjacent samples within the lowermost B and upper C horizons.

Below the A horizon, geochemical differences can be greatest where reducing horizons (Bg) occur at the contact with underlying bedrock. Reducing horizons are sites of geochemical enrichment for copper, lead, zinc, nickel, and uranium. For chromium they can be sites of either depletion or enrichment (e.g. Appendix 3, Burnt Lake, Leslie Lake soil profiles).

In contrast with the other trace elements, lead and chromium levels can be greatest within the Ae horizon, and markedly greater than within the underlying B horizon. Where no reducing horizon is present, chromium and lead concentrations generally decrease with depth within the B and C horizons. Anna Lake 1 is an exception and there the concentrations of both trace elements increase with depth (e.g. Appendix 3, Anna Lake 1 soil profile).

Heavy mineral fraction

Trace elements within the non-magnetic heavy mineral fraction were analyzed within three profiles, including Anna Lake 1, Anna Lake 2, and Emben. The recovery of heavy minerals decreased towards the surface due to weathering, and not enough concentrate was available for analyses of the upper Anna Lake 1 profile. For the heavy mineral fraction, trace element concentrations are similar to those of the silt and clay and the pebble fractions. Within the Anna Lake 2 and Emben profiles, however, uranium concentrations are greatest within heavy minerals, in comparison with other fractions. Those profiles are located near bedrock containing uranium and lead mineralization, and uranium-bearing heavy minerals likely occur within them.

Within heavy minerals, concentrations of iron, lead, chromium, and uranium are generally greatest within the uppermost B horizon, and least within the Ae. In contrast with the silt and clay, and clay-sized fractions, trace element concentrations do not increase generally with depth. The peak in iron concentration characteristic of the upper part of the B is not matched by manganese, which occurs lower in the heavy mineral profile. The iron enrichment indicates either production of secondary heavy minerals within the B, such as limonite or goethite, or the removal of other more labile constituents by weathering. The association between trace element levels and iron could be due either to scavenging by secondary iron, or to concentration as other elements are removed by weathering.

INTERPRETATION AND DISCUSSION

In glaciated terrain drift prospecting is based on the use of glacial sediments as a record of bedrock composition modified only by the mechanical processes of glacial erosion, transport, and deposition. Thus, the basis for effective mineral exploration lies with understanding glacial history and processes of glacial sedimentation. From that background, the origins of sediments containing indicators of mineralization can be determined, and the most likely pathways of glacial and nonglacial dispersal from the bedrock source can be geologically traced. Methods of exploration can be simple, based on mapping the distribution of mineralized boulders exposed at the surface, or complex, based on tracing geochemical, mineralogical, or lithological indicators through change in stratigraphic unit, sediment type, and transport direction (e.g. Sauramo, 1924; Shilts, 1976, 1984; Coker and DiLabio, 1989).

This report presents both a practical and conceptual basis for mineral exploration in central Labrador by defining: 1) directions and distances of glacial transport characteristic of different parts of the region; 2) the relative importance of regional ice flow events as controls on drift composition; 3) regional variations in drift composition as a function of glacial history and bedrock composition; 4) the shape, orientation, and compositional variations within dispersal trains; and 5) a geochemical, mineralogical, and lithological basis for analyses of glacial sediments. Most of the work relates to geological diversity at regional (tens to more than hundreds of kilometres) and local (kilometre to tens of kilometres) scales, and it provides a context for mineral exploration which is commonly carried out at detailed (hundreds of metres to kilometre) scales.

Ice flow history

Streamlined landforms (Fig. 5) define coherent patterns of regional ice flow that are divergent outward from the southern Labrador Trough, trending between southwest and east-northeast, and that are convergent northward towards Ungava Bay (e.g. Glacial Map of Canada, Prest et al., 1968). The term 'coherent' is used to describe ice flow patterns that appear logically connected, consistent with flow within an ice sheet. The zone separating convergent and divergent fields of flow has been interpreted as the location of a major ice divide, which has been variously referred to as the Nouveau Quebec, Labrador, and Labrador-Quebec ice divide (Flint, 1971, Fig. 18-7; Hillaire-Marcel, 1981; Dyke et al., 1982) (Fig. 27). Flow patterns are most complex and varied in western Labrador, an area where a residual centre of the ice sheet remained until late glacial time (Ives, 1960). In areas of significant relief, for example north of the Harp Lake Highlands, southwest of

Lake Melville, and south of the Mealy Mountains, directions of last ice flow appear to have been topographically controlled, and they can diverge from regional trends.

The striae record has proven to be most important for deciphering glacial history, representing the erosional record of ice flow throughout a substantial period, likely all, of the last glaciation. Despite their small size and delicate nature, striae associated with events of different ages provide evidence of ice flow directions not evident from glacial landforms, and of relative ages of ice flow events. Similar observations on the complexity of the striae record and on its importance to glacial history have been reported elsewhere in the eastern Canadian Shield (Prest, 1983; Bouchard and Martineau, 1985; Bouchard and Marcotte, 1986; Veillette, 1986) and in the Maritime Provinces (Stea et al., 1989). They indicate that complex ice flow could be more the rule than the exception within large areas of the Canadian Shield.

There are significant constraints on the interpretation and usage of striae for the reconstruction of glacial history. They can be used to determine the trend and less frequently the sense of ice flow, as well as relative age (e.g. Prest, 1983). They provide, however, no direct measure of either duration of ice flow or glacial transport distance associated with it. Nor do they constitute a basis for distinguishing glacial events of different ages that are characterized by similar ice flow directions. Furthermore, the record is commonly incomplete or otherwise obscured by surficial cover at any one site. Striae trends and relative age relationships, however, were found to be consistent throughout large areas. Exceptions are most likely to occur on valley floors, where topographical control of ice flow can be important, and near the residual mass of the ice sheet in western Labrador.

To describe ice flow history, a series of ice flow events are defined from the evidence of striae having the same relative ages, glacially streamlined landforms, and distances and directions of glacial transport defined by indicator erratics (Fig. 27). Erratics of iron-formation derived from the Labrador Trough have proven to be the main key to unravelling glacial history (Fig. 28). The events serve as a working guide to the discussion of glacial dispersal trains and their origins, and their interpretation in terms of ice divides and glacial history is considered preliminary. The emphasis of this report is on their use as a practical guide to modelling glacial dispersal trains and to describing the most likely pathways of glacial transport in different parts of the study area.

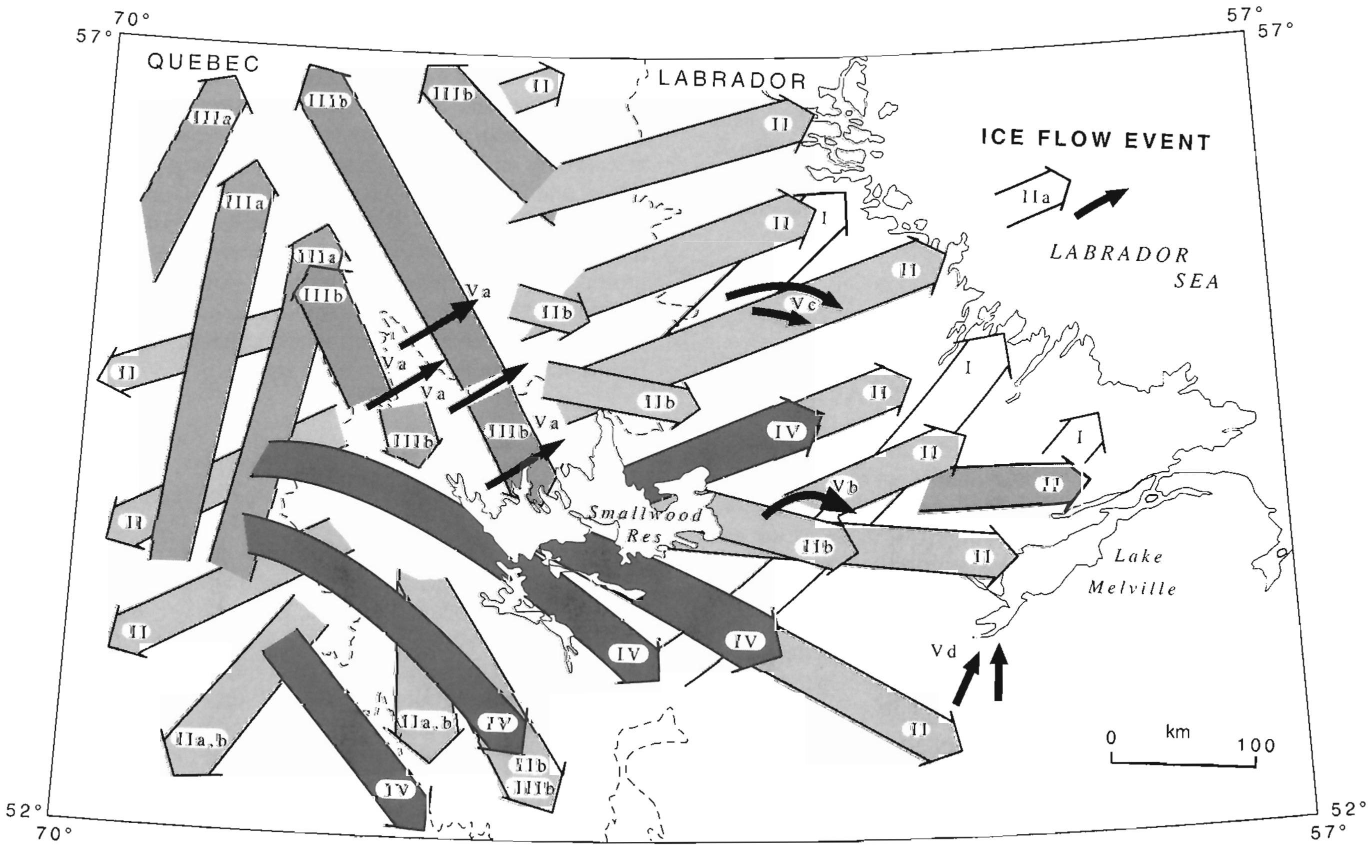

Figure 27. Summary of ice flow events interpreted from striae, glacially streamlined landforms, and drift composition. The Events characterize large scale movements within the Labradorean ice sheet, although they are not necessarily contemporaneous, nor are they of equivalent duration.

Major events are associated with coherent patterns of ice flow affecting large areas, and glacial transport distances of more than 100 km. Minor events record the topographic influence of highlands and valleys on ice flow directions. The areas affected by different Events are inferred from: 1) the extent of striae that either have common trends or define a coherent pattern of ice flow; and 2) transport distances and directions recorded by indicator erratics. The events are not necessarily equivalent in either extent or duration of ice flow. In the absence of stratigraphic (depositional) evidence it is difficult to define distinct events from the striae (erosional) record if they had similar ice flow trends. They are named from oldest (EI) to youngest (EV). Lowercase letters (e.g. EIIa) are used to identify changes in ice flow direction that are interpreted as part of one Event, related either to change in either the magnitude or configuration of an ice divide, or both.

Event I (EI)

Striae associated with EI flow trend northeast, and occur within an elongate belt extending more than 300 km northeast to the coast. In central Labrador, their trend is nearly at a right angle to those of later events (Fig. 17a, b). Near the coast, in the north part of the study area, they trend about ten degrees north of last flow directions. The principal compositional evidence for Event I is the ribbon train of agpaitic gneiss derived from the Red Wine Complex. That train is aligned northeast, parallel with the trend of EI striae. It originates 140 km from its bedrock source, and extends a further 70 km to the coast. Glacial transport of the gneiss can only be the product of northeastward ice flow. Additional evidence of significant (>50 km) northeast glacial transport is derived from the northeast trend of the northern margins of the dispersal fans of volcanic rock (Fig. 21c), and Snegamook granite (Fig. 21b).

Together, the widespread occurrence of EI striae and the significant distance of northeast glacial transport indicate that Event I was of regional extent and could have affected all of Labrador. Evidence for EI flow, however, has not been recognized in western Labrador and eastern Quebec. There, EI flow directions could have been similar to later (EII) trends, and thus difficult to distinguish. Event I is associated with an ice divide located southwest of Churchill Falls, likely north of the St. Lawrence River, much farther south than during later events. A similar conclusion is given by Morrison (1963). The southern location of the divide indicates that EI is distinct from later events which are related to a divide more central in Labrador-Quebec, and as such it could be either early or pre-Wisconsinan in age.

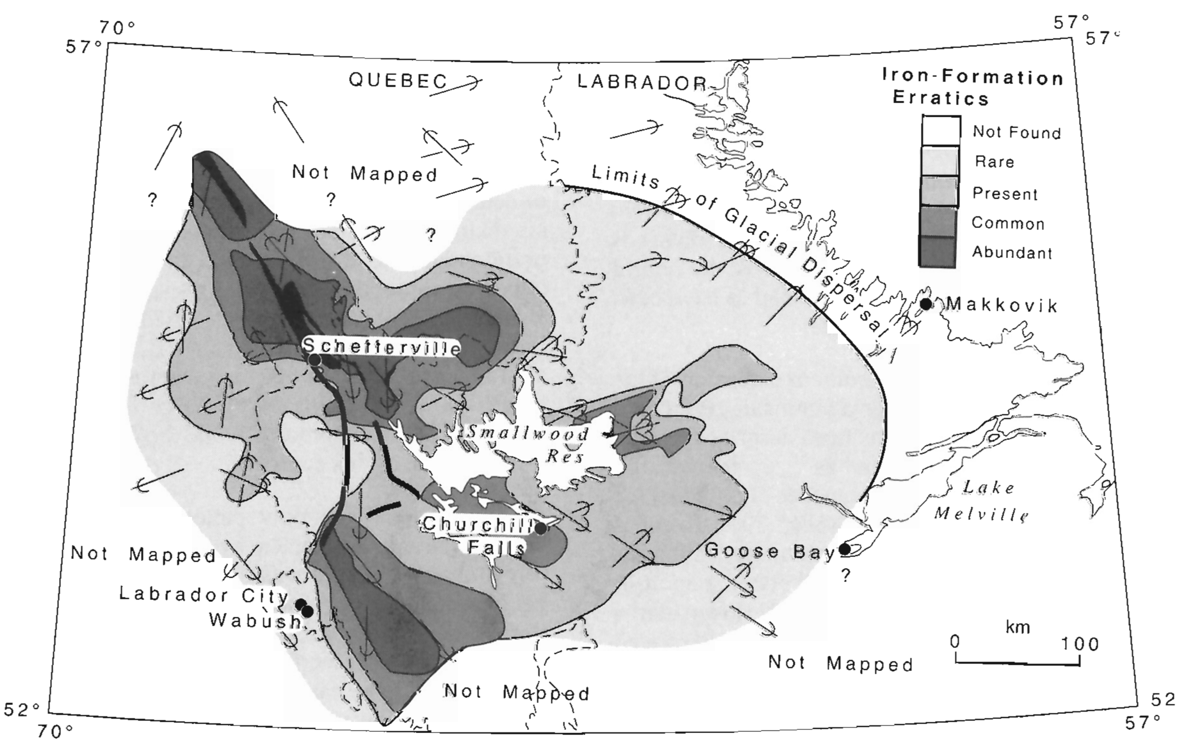

Figure 28. Glacial dispersal of iron-formation of the Labrador Trough based on qualitative review of erratics in the field. Iron-formation is distinctive and can be readily identified, even at low concentrations. It has been the main compositional evidence for defining glacial transport associated with distinct glacial Events (Fig. 27).

Event II (EIIa, b)

Streamlined landforms and striae associated with Event II flow define ice flow directions ranging from southwestward to east-northeastward, and they are youngest throughout most of the study area. The evidence for Event II is widespread as older striae within areas affected by events III and IV. From drift composition, EII is associated with glacial transport of more than 200 km outward from the Labrador Trough. Over the Ashuanipi Complex west of Schefferville, erratics of iron-formation derived from the Labrador Trough occur 100 km west of their source, and their distribution farther west across central Quebec is not known (Fig. 28). They can only be the product of the southwest ice flow shown by striae associated with Event II, and they cannot be the result of glacial transport during later events (EIII, EIV) when ice flow was directed north and east toward the Trough. Iron-formation erratics also occur more than 150 km northeast of Schefferville in the upper drainage basin of the George River, and they can only be the result of northeast glacial transport. Later flow (EIII) was directed from the George River Basin toward the north and north-northwest, and the erratics cannot be attributed to that later event. In the Goose Bay area, 300 km southeast of the Trough, erratics of iron-formation are the product of regional ice flow toward the southeast, an interpretation that is consistent with the well defined record of southeast flow indicated by glacial landform and striae along the Churchill River, and the apparent magnitude of flow that they represent. Transport of those erratics could be related either to event II or IV, or both.

Ice flow associated with Event II is interpreted to originate at an elongate ice divide extending northwest-southeast across central Labrador-Quebec and located more or less along the axis of the Labrador Trough (Fig. 27). Assuming glacial erosion beneath ice divides is minimal, glacial transport directly outwards from the Trough towards the southwest and northeast could indicate either lateral migration of the divide, or two separate glacial events. The simpler interpretation, one event (EII) characterized by lateral migration of an ice divide is recognized here. Flow towards the southeast across the central and eastern part of the study area is interpreted to have been along the axial extension of the ice divide.

The EII ice divide could be the southern extension of the Payne Centre identified on the Ungava Peninsula (Bouchard and Marcotte, 1986). The Centre has been described as "...a persistent central area of flow...", and as "...a segment of a larger feature referred to as the New Quebec (Labrador) Ice Divide." (Bouchard and Marcotte, 1986, p. 297). Event II likely characterizes the Wisconsinan maximum, although there are no radiocarbon dates available to either support or deny that interpretation. The divergence of EII flow patterns outward from the southern part of the Trough is interpreted as the product of flow from the southern extremity of that elongate divide.

Event II can be subdivided into an early main phase (EIIa) and a later, lesser phase (EIIb). From the southern Labrador Trough, EIIa flow was outward along radial, divergent flow paths. East of the Smallwood Reservoir, EIIa flow was superseded by flow that shifted clockwise toward the southeast (EIIb). In the Wabush region, there was a corresponding counterclockwise shift from south-southwest to south. Between those areas ice maintained southeast flow from the Trough. The shifts in ice flow are restricted to relatively small areas, and they are interpreted as contemporaneous. It is proposed that the clockwise and counterclockwise changes in ice flow direction on either side of the Churchill River are the result of decrease in the magnitude and southern extent of the ice divide controlling EIIa flow. As the divide diminished, there was less divergence in ice flow across central Labrador and an apparent focusing of ice flow issuing from the southern end of the divide located within the Labrador Trough (EIIb).

Event III (EIIIa, b)

Event III flow is characterized by east-northeast flow from the Ashuanipi Highlands (EIIIa) and by later north-northwest flow from the upper basin of the George River (EIIIb). The relative ages of EIIIa and EIIIb flow are clearly established by crosscutting relations among striae. South of the Labrador Trough, flow toward the south and southeast cannot be distinguished from either EIIb or EIV flow and there is no clear evidence for distinguishing separate glacial events, especially EIII.

Compositional evidence of succeeding ice flow directions within the area affected by Event III is derived from glacial dispersal trains of nepheline syenite and Martin Lake porphyry (Fig. 21e). The dispersal train of syenite is the net product of glacial transport toward the southwest (EIIa), north (EIIIa), and northwest (EIIIb). Distance of glacial transport is greater than 20 km to the southwest, and is greater than 50 km to the north and northwest. Near Ungava Bay, 150 km north of the study area, glacial transport of 60 km has been recorded (Drummond, 1965) during northward flow that is likely related to Event III on the basis of similar transport direction. Erratics of porphyritic rock of Martin Lake Group are distributed in all directions about their source, and occur preferentially to the northwest and southeast. Those two opposing directions of glacial transport likely result from change in the location of an ice divide operative within the Labrador Trough during Event III. Whether the divide migrated southward or northward across the bedrock source is not known. There is no evidence for southward glacial transport of syenite indicators, and the divide was most likely located south of that source.

The regional ice flow patterns that converge toward Ungava Bay, as illustrated by the Glacial Map of Canada (Prest et al., 1968), are part of Event III. On the Ungava Peninsula, northwest of the study area, they are interpreted to result from a late glacial ice divide named the Caniapiscau centre from which ice flow was north toward southwestern Ungava Bay (Bouchard and Marcotte, 1986). Flow from the Caniapiscau centre is younger than that of the Payne, although both are associated with segments of the New Quebec Ice Divide. Northward ice flow of EIII was possibly in response to calving of the ice sheet at the mouth of Hudson Strait and may have occurred subsequent to the maximum of the Wisconsin Glaciation.

Event IV (EIV)

Event IV is characterized by flow toward the east and east-southeast originating from the southern part of the Ashaunipi Complex. At its up-ice head, the area affected by Event IV is narrow and well defined. It is characterized by prominent northeast- to east-trending striae and glacially streamlined landforms, and they are distinct from adjacent regions where ice flow was toward the south-southwest and north. Where mapped, EIV is youngest, and EIV striae crosscut those associated with EII and EIII.

East of the Ashuanipi Complex, glacial flow patterns that appear to be part of Event IV diverge to the east and southeast. Across the Smallwood Reservoir they trend eastward, and from the southern end of the Labrador Trough southeastward. The area affected by EIV flow is characterized by well defined fields of glacially streamlined landforms (Fig. 5). Within the Reservoir, the eastward trend of the landforms contrasts with the regional southeast patterns of Event II. The down-ice extent of EIV flow is not well known because flow directions merge with those of other flow events, and the geological record of EIV cannot be easily distinguished. The easternmost limit could be marked by Sebaskachu Moraine, north of Lake Melville. That moraine appears coincident with the limits of glacial dispersal of Labrador Trough iron-formation and of peralkaline debris from the Red Wine Complex.

Event IV affected a narrow, well defined zone within the Labradorean Sector, and could be the product of 'fast ice' (ice stream) active during late glacial time.

Event V (EV a, b, c, d)

Minor events of ice flow are recorded only by faint striae within relatively small parts of the study area. Faint striae typically occur on the most exposed bedrock surfaces, crosscutting an older striae record that remains prominent. Event V includes: 1) northeast ice flow in the Labrador Trough (Va); 2) east-southeast flow curving around the northern margin of the Hamilton Uplands (Vb); 3) ice flow curving around the northern margin of the Harp Lake highlands (Vc); and 4) northeast ice flow into western Lake Melville (Vd). Events Vb, Vc, and Vd were topographically controlled, and could relate to either EII or late stages of EIV flow. Flow patterns associated with Vd converge on the western end of Lake Melville and may have been initiated by drawdown towards the lake basin (Region 7, Fulton and Hodgson, 1979).

Event V ice flow occurs in several distinct areas, and is interpreted as late glacial. In eastern Labrador it records the influence of large scale topographic relief on ice flow. It seems likely that additional evidence for this type of flow will be found by more detailed study. Such flow has been recorded within valleys in the eastern-central part of the study area (Batterson et al., 1987), although it is not shown here due to the small scale of the valleys and limited extent of ice flow within them.

Glacial erosion and transport

The distance of glacial transport and concentration of debris resulting from glacial erosion are affected by: 1) the mechanical properties of the rock and its resistance to glacial erosion and comminution; 2) the areal extent and topographic setting of the source; 3) the position of the debris within the ice sheet – whether it is carried at the base where there is an abundance of clasts for abrasion, or above the base within clean ice; and 4) geographic location of the source within the context of the ice sheet and its divides, and related variations in the duration of glacial transport and ice velocity (e.g. Dreimanis and Vagners, 1969; Perttunen, 1977; Boulton, 1984; Puranen, 1988). In Labrador, distance of glacial transport ranges to hundreds of kilometres, although the bulk of debris has undergone limited transport of less than one to a few kilometres and is of local origin. The latter conclusion was also reached for eastern Labrador (Batterson et al., 1987), and for Shield terrain of Fennoscandia (e.g. Linden, 1975; Perttunen, 1977; Peltoniemi, 1985; Salminen and Hartikainen, 1985; Salonen, 1986a, b).

Far-travelled (10 to >100 km) debris can occur in significant concentrations (>5 wt. %) within regional dispersal trains originating with supracrustal sequences, and sedimentary bedrock in particular. Those bedrock sources cover large areas, are compositionally distinctive, and were more easily eroded than crystalline terrain (e.g. Fig. 19a-g). In addition, supracrustal rock is more readily ground to finer fractions than crystalline rock, and that preferential comminution further contributes to its geochemical expression in till. Other sources, such as anorthosite, contribute relatively little debris to regional dispersal trains, and they are compositionally dominant only within till directly overlying the bedrock source (Fig. 19f). Anorthosite fractures easily, and is readily ground to sand and finer fractions during glacial transport. Thus, as clasts, glacial dispersal trains of anorthosite are limited in their down-ice extent.

Despite their susceptibility to glacial erosion and their distinctive compositional characteristics, the expression of supracrustal and peralkaline sources within till can be subdued or otherwise modified by glacially transported debris, especially along their up-ice margins. Within 10 km to 20 km of the western (up-ice) margin of the Seal Lake Group, for example, supracrustal debris comprises <0.1 wt. % of the pebble fraction whereas elsewhere over the source terrain and areas farther down-ice, it is >30 wt. % (Fig. 19a, b, c). Masking effects can also be geochemically defined. Over the southern and western margins of the Flowers River Igneous Suite the predominantly crystalline provenance of till is reflected by low concentrations of niobium and yttrium, and high concentrations of nickel. There, the geochemical characteristics of the underlying peralkaline bedrock are effectively masked (Fig. 24a, b, f). Eastward glacial transport of crystalline debris into the southern Labrador Trough during Event IV is reflected by both till lithology (Fig. 19a, 22a) and geochemistry (Fig. 22b, c, d, e, f). There, the increase in the concentration of crystalline pebbles is closely matched by a decrease in iron, manganese, lead, and zinc concentrations, and increase in chromium.

Clasts entrained above the basal, debris-rich zone of the ice sheet may not be subject to glacial comminution and can be transported significant (>100 km) distances. The ribbon train derived from the Red Wine Complex originates at a topographically prominent hilltop site 140 km northeast of its source. There, indicator debris is surprisingly abundant given the distance of glacial transport: erratics are characterized as present by field mapping (Fig. 21d), and comprise up to 1 wt. % of pebbles (Fig. 23a). Although heavy mineral indicators are not found at that site, they occur within the train and at several sites between the head of the train and the bedrock source (Fig. 23b). The ribbon train, however, is not defined by geochemical analyses of the silt and clay (Fig. 23c, d, e, f), suggesting that the coarse clasts did not act as a continuing source of debris for the finer fractions through comminution during glacial transport and that they could have transported englacially. Deposition may have been initiated when debris within the ice was brought into contact with the hilltop that marks the head of the train. Similar topographic effects were described within a dispersal train originating at 'Strange' Lake, northern Labrador (Batterson, 1989b).

The effects of topographic relief can also be reflected within the regional patterns of glacial dispersal. East of Churchill Falls, for example, till is typically continuous and >2 m thick, and contains >2 wt. % supracrustal pebbles to the western (up-ice) margin of the Hamilton Uplands (Fig. 19a). The distribution of iron-formation (Fig. 28) indicates that the pebbles are part of a regional dispersal train extending southeast >100 km from the Labrador Trough. In contrast, till overlying the Uplands is thin and discontinuous, and supracrustal debris is rare within it. The change in till composition and thickness is coincident with the edge of the Uplands, and indicates that they could have acted as a barrier to further glacial transport toward the southeast. Along the up-ice margin of the Uplands, glacial landforms aligned northeast-southwest are associated with Event I flow. Their preservation could also indicate the influence of the Hamilton Uplands on large-scale ice flow and glacial erosion.

Ice flow patterns that diverge around highlands (e.g. Harp Lake Highlands (EVc) and Hamilton Uplands (EVb)) and that follow the trend of large valleys (e.g. Lake Melville basin (EVd)) record topographic effects and are presumably late glacial, related to flow within a thinning ice sheet. Such flow has also been reported within valleys of eastern Labrador (e.g. eastern Central Mineral Belt; Batterson et al., 1987). Where ice flow has been topographically influenced, drift composition can be distinct from nearby areas that may have been affected only by regional events. Ice flowing along valley floors can alter the transport direction and change the relative abundance of indicator debris by addition of local material. Thus, at detailed and local scales till on valley floors can be distinct from till on highland areas that remained unaffected by late glacial flow. The arcuate character of core zones within the dispersal fan agpaitic gneiss, for example, is likely the result of ice flowing around the northern margin of the Hamilton Uplands along the valley of the Red Wine River (EVb) (Fig. 21d, 23b).

The preservation of older striae on sheltered surfaces indicates that at small scales glacial erosion of a bedrock source could vary with change in ice flow direction, as ice encountered surfaces having different slope aspect. Thus, glacial erosion can be dependant on the shape and relief of outcrop as well as on the exposure of different bedrock surfaces to ice flow. Preferential erosion would occur on stoss sides. In some areas, however, striae on outcrop having tens of metres of relief cover both stoss and lee sides without change in trend. There, the potential for erosion of different outcrop surfaces appears independent of the surface aspect relative to ice flow direction. The foregoing suggests that there is significant variation in the ability of the ice sheet to erode outcrop. The differences in erosional characteristics could be significant to mineral exploration, particularly at detailed scales of investigation.

Glacial dispersal patterns and ice flow history

At the regional scale, the glacial events differ in terms of their capability to erode and transport debris. The differences are best described in western Labrador by comparison of areas affected by events EII, EIII, and EIV. Over the Ashuanipi Complex, drift is characterized by the widespread occurrence of supracrustal debris derived from the Labrador Trough. Between the northern and southern parts of the Complex, differences in the concentrations of Trough debris are interpreted to result from differences in the erosional characteristics of events III and IV. It is assumed the composition of drift resulting originally from EII flow was similar across the entire Complex, an interpretation consistent with the large area of source terrain crossed by ice during Event II and the apparent regional uniformity in southwest (EII) ice flow.

Within the zone of EIII flow over the northern Ashuanipi Complex, erratics of iron-formation are common to abundant (Fig. 28), and till contains 5 to 30 wt. % supracrustal debris up to 40 km west of the bedrock source within the Labrador Trough (Fig. 19a). The Trough debris can only be the result of southwest glacial transport during Event II, and glacial dispersal patterns are elongate in that direction of ice flow. The high concentrations of supracrustal debris and southwest orientation of dispersal trains indicate that glacial erosion of bedrock and pre-existing (i.e. EII) glacial deposits was minimal during Event III. Although erratics of nepheline syenite provide clear evidence for northward transport during EIII, it is not determined whether that is the result of redirection of debris entrained within the ice during EII, or of continued bedrock erosion, or both.

In contrast, within the zone of EIV flow over the southern Ashuanipi Complex, till contains less than 1 wt. % supracrustal debris and is grey, reflecting the crystalline provenance of its finer fractions. The low levels of Trough debris contrast with the area of EIII flow to the north where significant quantities of Trough debris remain. The compositional boundary between areas is well defined and abrupt, and it is coincident with the marked break in ice flow trends outlined by striae and glacially streamlined landforms. Event IV was erosional over the southern part of the

Complex, having largely erased debris transported southwest during Event II. That characteristic is further indicated by pronounced glacial streamlining of crystalline bedrock.

Within the southern Trough, increased concentrations of crystalline debris record the reversal of ice flow and eastward to southeastward glacial transport from the Ashuanipi Complex during Event IV. There is no clear evidence, however, of the erosional character of EIV ice within the southern Trough. The occurrence of thick Quaternary stratigraphic sections near Wabush indicates that erosion of pre-existing surficial deposits was not complete. East of Smallwood Reservoir Trough debris defines two prominent dispersal trains 20 km to 30 km long extending east-northeast, in the direction of last ice flow (Fig. 28). The debris could not have been transported there along flowlines associated with either event II or III, which extend from the southern Trough southward to south-eastward across central Labrador. The trains are attributed to the initial erosion and transport of Trough debris to the south and southeast during EII, and to later redirection of that debris towards the east-northeast during EIV. The abundance of Trough debris along the southern margin of the Harp Lake Complex, more than 200 km from its bedrock source, is inferred to indicate that there was little or no deposition of debris during Event IV. The EIV ice appears to have changed from erosive near its up-ice head over the Ashuanipi Complex, to non-erosive (transporting) across central Labrador.

Iron-formation also defines a prominent glacial dispersal train that trends southeast from its southernmost bedrock source (Fig. 28). The size and definition of the train, however, do not appear compatible with the narrow width of bedrock crossed by the ice during southeastward flow (EIV). The dispersal train is interpreted to have formed as the net result of glacial erosion and transport toward the south-southwest (EIIa) and south (EIIb, EIIIb) by ice flowing more or less along the length of the source, and by later redirection of that debris towards the southeast (EIV).

Local scale models of glacial dispersal trains

Differences in the shape and orientation of glacial dispersal trains (e.g. Fig. 20) are compelling geological evidence that drift is the composite product of glacial erosion, transport, and deposition during succeeding glacial events. Near the margins of the Labradorean Ice Sheet, along the Labrador coast, glacial history has been relatively simple, with either little or no change in ice flow direction. There, glacial dispersal trains appear as ribbons of outcrop width, streamed down-ice from their bedrock source in the direction of ice flow. The margins of the ribbon trains are parallel and compositionally well defined, and greatest debris concentrations occur within a central core. With no significant shift in glacial transport direction, succeeding events could have reinforced the compositional record of earlier glacial transport through continued erosion of the source. Re-entrainment of glacial debris transported earlier would increase the net distance of glacial transport.

With distance inland from the coast toward the geographic centre of the ice sheet, ice flow history becomes increasingly complex, and can be represented by four or more distinct directions of ice flow. It is most complex, including reversal of flow direction, near the location of one or more ice divides in the Schefferville region of the Labrador Trough. With increase in the complexity of ice flow, glacial dispersal trains change from narrow to broad fans opening down-ice from their bedrock source, to patches centred more or less about the source. The fans are the net result of glacial erosion and transport during multiple events, and their outer margins are aligned with the two most divergent directions of flow.

Throughout central Labrador glacial dispersal fans open toward the east, although west of ice divide(s) in the Labrador Trough region they open toward the west. Trains centred about their source, shown by Martin Lake porphyry (Fig. 21e), could be characteristic of glacial dispersal trains near ice divides (e.g. Stea et al., 1989). The dispersal train is elongate in the two directions of last regional ice flow (EIIIa, EIIIb), although its eastern and western margins are poorly known and glacial dispersal in those directions could be more extensive than shown. Glacial transport toward the northeast during the last ice flow (EVa) does not appear to have been significant. The distribution of Martin Lake porphyry, and of Trough debris in general, indicates that glacial erosion and transport in the regions of ice divides can be significant. That contrasts with theoretical models that indicate little or no glacial erosion near ice divides (e.g. Boulton, 1984; Boulton and Clark, 1991). It is not known whether there was actually significant erosion beneath the Labradorean ice divide(s), or whether glacial dispersal trains are the result of change in their location, or both. The authors prefer the interpretation of change in divide location.

Zonation within glacial dispersal trains can reflect the sequence of glacial transport and erosion associated with different ice flow events. The latest ice flow direction appears generally to be the most important control on the definition, shape, and orientation of zones. Core zones defined by abundant debris originate at the bedrock source, extending as ribbons down-ice in the direction of last ice flow (Fig. 21a-e). They would be most easily detected during exploration because of their compositional definition. Core zones produced during older events have been variously subject to differential erosion during succeeding events, and are more weakly expressed and irregular in outline.

The compositional definition and length of zones within dispersal trains are related both to the length of outcrop crossed by ice in the direction of ice flow and topographic setting of the source. For the Flowers River Igneous Suite, the core zone occupies the central part of the ribbon train, and is three to four times the length of outcrop crossed by the ice (Fig. 21a). Two cores originate with the Snegamook granite (Fig. 21b) that extend one to two times outcrop length from the source in the directions of EI and EIIa ice flow. The core associated with earlier northeast flow is longer and does not appear to have been modified by later ice flow.

From the southern pluton of the Red Wine Complex, a core zone extends twice outcrop width down-ice in the direction of last ice flow (EIV or EVb) (Fig. 21d). It comprises the head of a more extensive zone where indicator debris is common that appears as an arcuate ribbon following the valley of the Red Wine River around the northern Hamilton Uplands. The zone of common debris is related to the last event (EVb) when ice flow was topographically controlled. No dispersal core originates with the northern source, although indicator debris is abundant within one outcrop length of it. Throughout the dispersal fan, sites characterized by abundant debris occur as isolated patches. Two occur within the arcuate ribbon of common debris, and others outside that ribbon east-northeast of the source. The latter occurrences are interpreted as erosional remnants of a more extensive core zone that is presumed to have originated with older flow toward the east-northeast. At the smaller scales of investigation typical of mineral exploration, such patches could appear to terminate up-ice with no apparent connection to a bedrock source.

Analyses of drift composition

Different size fractions of till represent different bases for tracing glacial dispersal trains (e.g. Linden, 1975; Peltoniemi, 1985; Salminen and Hartikainen, 1985; Puranen, 1988). The choice of size fraction can significantly influence the portrayal of glacial dispersal trains, especially by geochemical analyses. Near the bedrock source, indicator debris preferentially occurs within cobbles and boulders. With comminution during glacial transport, the indicator component becomes finer grained, and concentrations of indicator debris within all size fractions decrease with transport distance as new material is added to the ice (Peltoniemi, 1985, p. 71). Although the finest fractions of till may be the farthest-travelled, indicator debris can be distributed at such low concentrations that maximum dispersal patterns cannot be geochemically detected.

The most appropriate fraction for analyses is determined by the properties of the indicator element or mineral that is sought by exploration and by the goals and scale of the exploration program. Minerals that can contain indicator elements vary widely in structure, size, and distribution within bedrock. They also vary in their resistance to physical modification during glacial transport, and to physical and chemical weathering during postglacial time. Consequently, there is no one size fraction, mineral type, or analytical method suited for all exploration purposes.

In Labrador, field mapping of clasts has proven to be the best method for defining glacial transport and for mapping dispersal trains. At sites where clasts were washed clean at the surface, literally thousands could be quickly checked, and indicators could be recognized at extremely low concentrations. The use of clasts requires that the indicator debris be sufficiently distinctive that it can be easily recognized, either visually or by rapid field methods. The method, however, requires access to washed debris, which can be difficult within the extensive boreal forest of the Canadian Shield. Laboratory analyses of pebbles obtained by washing till samples is less sensitive because fewer clasts are typically available for examination (<100), and the basis for defining glacial dispersal trains at low concentrations is thereby limited (compare Fig. 19d and 28). The smaller size of the clasts further limits the ability to recognize indicator properties. Nevertheless, pebble analysis is quantitative, and it provides a more reliable basis for mapping compositional variation within trains than qualitative field estimates of relative abundance.

Indicator minerals resistant to weathering can be used to define glacial dispersal at low concentrations. The glacial dispersal train defined by blue aegirine from the Red Wine Complex, for example (Fig. 23b), is similar in extent to that based on analyses of coarse clasts (Fig. 21d), and can be traced farther down-ice than by geochemical analyses (Fig. 23c, d, e, f). Up to thousands of sand grains can be rapidly reviewed in the laboratory for trace amounts of indicator minerals, and that fraction appears suitable for drift prospecting studies where resistate indicator minerals occur. In contrast, sulphide minerals are absent from the near-surface zone due to oxidation, and review of the heavy mineral fraction for those minerals would be inappropriate for mapping glacial dispersal from a sulphide source.

Till geochemistry and geochemically defined glacial dispersal trains

Till geochemistry reflects glacial dispersal of the finest size fractions. It has been described as "...a micro-variation of boulder tracing – as a method of searching for infinitesimal 'boulders'" (Kauranne, 1959), and geochemical patterns based on analyses of unweathered till can be considered as a direct reflection of bedrock composition, modified only by the mechanical processes of glacial erosion, transport and deposition. Thus, "... pedogeochemical anomalies may be dealt with just like boulder fans." (Kauranne, 1959, p. 7).

Geochemical properties of till vary markedly among size fractions due to differences in mineralogy. Minerals released from bedrock are partitioned into different size fractions according to their resistance to abrasion and comminution during glacial erosion, transport, and deposition (e.g. Dreimanis and Vagners, 1969; Linden, 1975; Eriksson, 1973; DiLabio, 1979, 1988; Shilts, 1984). The geochemical properties of minerals vary as the result of differences in their structure; their igneous and metamorphic history; and their response to weathering in the surficial environment. Consequently choice of size fraction is important to the portrayal of till geochemistry. At detailed scales of geochemical exploration, the choice of size fraction becomes less important as levels of indicator debris increase within all size fractions with proximity to source (e.g. 'head' and 'tail' of dispersal trains; Shilts, 1976), and there is greater compositional contrast between the dispersal train and areas outside it.

For this report, clay-sized material has been routinely analyzed to portray geochemical properties and regional geochemical variations in till. That fine fraction is enriched in phyllosilicates such as clay minerals, mica, and chlorite, and it typically contains less quartz and feldspar than coarser size fractions (Linden, 1975; Haldorsen et al., 1989). Metal levels are commonly much greater within clay-sized than within coarser fractions (Eriksson, 1973; Shilts, 1973, 1977).

Regional geochemical patterns (Appendix 2: Fig. A2-2 to A2-19) clearly relate to the occurrence and distribution of major lithological units and terranes, including the Labrador Trough; Ashuanipi Complex; peralkaline rocks in the Strange Lake, Flowers River, and Letitia Lake areas; and the Bruce River and Aillik groups of the Central Mineral Belt. All those sources are compositionally distinctive and to varied degrees have been more deeply eroded during glaciation than crystalline basement rocks. The effects of glacial transport from those sources, however, cannot be readily established from the form and orientation of geochemical contours. Till lithology and ice flow history are the keys to distinguishing the effects of glacial transport from those caused by variation in bedrock composition on till geochemistry. Lithological analyses provide an unequivocal basis for defining: 1) distance and direction of glacial transport characteristic of the bulk of glacial debris; 2) till provenance; and 3) variation in the relative contributions of different bedrock sources.

Glacial dispersal trains defined by geochemical analyses can differ from those defined by analyses of clasts or minerals. Glacial transport from the Red Wine Complex, for example, can be defined 20 km to 40 km from the source by geochemical analyses (Fig. 23c-f), and more than 100 km by lithological and by mineralogical analyses (Fig. 23a, b). Within the finest fraction subject to geochemical analysis, indicator minerals could have undergone more limited glacial transport than within coarser fractions, or they may occur at such low concentrations that they cannot be distinguished from background variations. If glacial transport is more restricted, it implies that coarse clasts are transported within the ice, above the basal zone of comminution, and are not a continuing source of debris to the finer fractions (e.g. Puranen, 1988, p. 30).

Where a bedrock source has either, for its areal extent, contributed proportionally greater amounts of debris to the ice than other bedrock types, or is compositionally distinctive, or both, its glacial dispersal train can mask the geochemical expression of bedrock down-ice. Supracrustal and peralkaline intrusive rock sources, for example, have a disproportionate influence on analyses results because they are both geochemically distinctive and more easily eroded. The erosional products of fine grained supracrustal sources such as slate, shale, and volcanic rock are preferentially concentrated within the finer size fractions subject to geochemical analysis. The geochemical expression of crustal debris in till is further enhanced by the relative resistance of crystalline debris to glacial reduction to clay-size.

The definition of smaller sources within regional glacial dispersal trains depends on the proportions of, and the geochemical contrasts between, local and far-travelled debris. Glacial erosion of compositionally distinctive terrane can lead to the formation of trains that appear either geochemically enriched ('positive' dispersal train) or depleted ('negative' dispersal train) (Klassen and Shilts, 1977; Shilts, 1984). The geochemical expressions of a bedrock source depends on its context within larger trains and the geochemical properties of those trains.

Till derived from supracrustal bedrock can be either geochemically enriched or depleted in comparison with deposits derived from the basement crystalline complex. In western Labrador, positive (Fe, Mn, Pb, Zn) dispersal trains extend southwest of the Labrador Trough, masking the geochemical expression of crystalline bedrock. There, the signature of exploration targets could be subdued and thus not recognized within the context of transported debris having greater geochemical concentrations and ranges. The Trough, however, is relatively impoverished in chromium and it cannot be a source for the relatively high levels of chromium that characterize the Ashuanipi Complex. Thus, chromium concentrations reflect the composition of crystalline bedrock, although they are presumed to be diminished by chromium-poor debris originating within the Trough.

Both positive and negative geochemical dispersal trains also originate with peralkaline bedrock sources which are characteristically enriched in lead, yttrium, niobium, cerium, and zirconium, and depleted in nickel and chromium. At local scales, eastward glacial transport from the basement complex across the southern and western margins of the Flowers River Igneous Suite can be defined by low levels of niobium and lead, and by elevated levels of nickel (Fig. 24a, c, e). The geochemical overlap of that transported debris can be defined 5 km to 20 km down-ice. Thus, geochemical differences within specific lithologic terrains, such as the Flowers River Igneous Suite, must be interpreted within the context of background variations resulting from glacial transport from other sources. The differences could be significant in comparison among satellitic plutons of the Igneous Suite and to interpretation of their relative mineral potential.

The significance of regional till geochemistry to mineral potential of bedrock and to mineral exploration remains equivocal within the large areas of Labrador where till lithology is poorly known and little detailed mapping of bedrock has been done. Given the generally low sample density (1 to 5 per 100 km^2) it is unlikely that dispersal trains originating with small scale sources of mineralization can be distinguished at the regional scale by anomalous results. Where glacial transport is either limited or there is little geochemical contrast between transported debris and bedrock, geochemical patterns can relate to compositional variation within underlying bedrock. In such a circumstance, till geochemistry can be interpreted in terms of bedrock genesis, metamorphic history, or metallogenic models. Geochemical differences within and among bedrock units indicated by till can represent a basis for establishing a strategy for mineral exploration, allowing focus of exploration effort to be established among and within lithologic terrains.

Soil weathering and till geochemistry

Physical and chemical soil-forming processes alter the geochemistry of parent materials, resulting in zonation in what may have originally been a uniform glacial deposit. The effects of weathering vary with depth, and geochemical properties are significantly changed within a metre of surface, and likely deeper. Weathering effects can extend several metres or more below surface (Shilts and Kettles, 1990; Shilts and Smith, 1989). Therefore, the position of a sample within a soil profile can be critical to the interpretation of geochemical data.

Soil development depends on diverse factors such as the composition and structure of parent materials, climate (e.g. rainfall, temperature), topography (e.g. drainage, mass movement processes), and vegetation (e.g. root activity and depth), and there are marked differences in soils and soil development among sampling sites (e.g. Wang and McKeague, 1986). Compositional variation within a glacial deposit, however, can also be "primary", related to processes of glacial erosion, transport, and deposition and the stratigraphy of glacial deposits (Shaw, 1985; Shilts, 1978). Stratigraphy and banding of debris within glacier ice (DiLabio and Shilts, 1978, 1979) can be preserved within glacial sediments, recording different bedrock origins and transportation histories. Furthermore, till can comprise ablation and meltout facies that can differ in composition (e.g. Batterson, 1989b).

The principal geochemical features of Labrador soils are as follows: 1) concentrations of trace elements (Cu, Zn, Ni) are least in the Ae horizon and generally increase with depth through the B and upper C horizons; 2) vertical variations in trace elements generally follow the distribution of manganese and likely result from the removal of those elements from both A and B horizons during soil formation; 3) lead and chromium can be concentrated within the Ae horizon, and can decrease with depth. As such they are notable exceptions, and; 4) within the upper C horizon trace element concentrations vary least with depth and are generally greater than within overlying horizons. Those conclusions are generally supported by analyses of podzolic soils elsewhere in Canada (Presant, 1971; Govett, 1973; McKeague et al., 1979; McKeague and Wolynetz, 1980, Table V, p. 304). They contrast with reports that indicate the B horizon to be one of trace element accumulation (Levinson, 1974, p. 94).

The marked geochemical variations with depth indicate that soil development is an important concern for exploration, particularly at detailed scales of investigation. Unweathered parent material provides the most reliable basis for exploration because geochemical analyses can be interpreted in terms of mechanical processes of glacial transport. Weathering effects, however, extend at least a metre below surface, and likely much deeper, making unweathered material effectively inaccessible without mechanical means such as backhoe or drill. Consequently, a strategy for geochemical exploration is to sample the least weathered part of the soil profile as the nearest approximation of parent material, including either the lower B or upper C horizons. Within well drained profiles, the BC and C horizons commonly occur 50 cm to 100 cm below surface.

Plots of zinc versus manganese illustrate a near-linear relationship between those two elements within the A, B, and upper C horizons (Fig. 29a, b). Variations in the slope of the zinc-manganese line, which are evident in comparisons among profiles, are interpreted to reflect both parent material composition and weathering effects. Levels of other trace elements also vary with manganese concentration, although the relationship is more weakly expressed.

Logistical constraints related to time, expense, and sample access have meant that samples in the regional collection are all from the near-surface, and as such have been subject to post-glacial weathering. Within the regional collection, background levels of manganese vary little, although samples derived from the Labrador Trough are an important exception. Manganese concentrations less than 250 ppm are interpreted to reflect weathering, and to indicate decrease in the concentrations of other trace elements due to soil development. In the Labrador Trough, where parent materials can contain significant quantities of manganese, levels below 500 ppm reveal

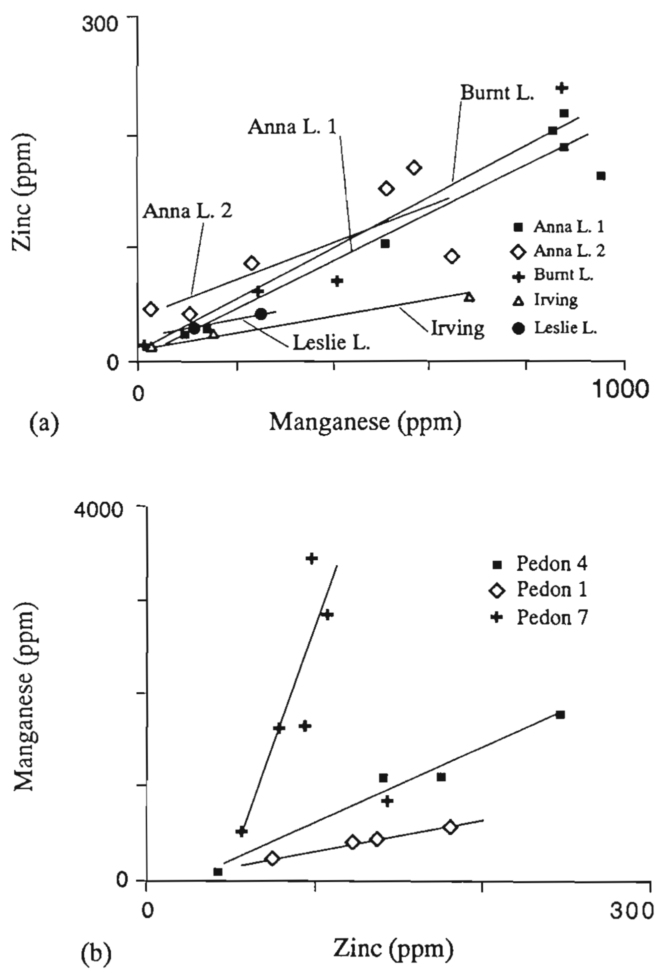

Figure 29. Direct variation between manganese and zinc within the soil profile result from weathering. Manganese concentrations have proven useful in characterizing changes in trace element geochemistry by weathering. Plots for **a**) eastern and **b**) western profiles are shown.

weathering effects. In many cases it was found that manganese provided a more reliable measure of weathering than field observations of sample colour and oxidation state.

Within podzolic soils of the Eastern Townships of Quebec, there is an inverse relationship between geochemical profiles of heavy minerals and of clay (Shilts, 1977; 1984; Shilts and Kettles, 1990; Shilts and Smith, 1989). The relations are interpreted by those authors to indicate that within 3 m of surface either clay-sized phyllosilicates or secondary oxides and hydroxides, or both, have scavenged some of the metal released by weathering of labile sulphide minerals. Within the few Labrador profiles for which the two types of analyses are available there is no inverse relationship between the geochemistry of heavy minerals and clay that could support such an interpretation. Furthermore, in the uppermost B horizon there is no increase in trace element concentration in the clay-sized fraction associated with the accumulation of iron, indicating that trace elements are not fixed or scavenged by secondary iron compounds.

RECOMMENDATIONS FOR MINERAL EXPLORATION

Exploration by drift prospecting is based on knowledge of glacial history and ice flow direction, as well as the geological origins of the glacial sediments sampled as part of the exploration program. Drift composition is the geological result of interplay among numerous factors, including: 1) bedrock structure and composition; 2) topographic setting of the bedrock source; 3) glacial history; 4) processes of glacial erosion, transport and deposition; and 5) soil forming factors, particularly in areas of boreal forest. Thus, drift prospecting is fundamentally a study in Quaternary geology, requiring knowledge of glacial processes of erosion, transport, and deposition. There is no single method of exploration that can be applied everywhere.

Mineral exploration is most commonly carried out at scales that are much smaller than represented by this report, and the shift in geological focus associated with that change in scale is emphasized in the following recommendations. The work, and derived conclusions, are based entirely on till. The use of other glacial and nonglacial sediments in exploration remains for further study. The following are the principal recommendations for mineral exploration in central Labrador:

1. Prepare a surficial geological map of the area of investigation as a basis for the design of a sampling program and focus on the geological origins of the glacial sediments sampled.

Till is the surficial sediment that bears the most direct compositional relationship with bedrock, and it is widespread as a surficial deposit in Labrador. The use of till as a sample medium in exploration is recommended. Other sediment types, however, can also be extensive, and they can be predominant at the scales typical of exploration. They include glaciofluvial deposits which are common across valley floors, and glaciomarine and marine deposits, which blanket extensive coastal regions below the marine limit (<100 m a.s.l.). Non-till sediments are derived primarily from till. They have been subject to further physical and chemical alteration, making their relationship with bedrock more obscure.

2. Establish the history of ice flow with reference to the regional characterizations presented here, and by detailed review of striae within the area of exploration. The work allows the range of ice flow directions to be established as well as determination of the most likely direction of glacial transport.

At local and detailed scales, ice flow directions can vary significantly from regional characterizations. Such variation is most commonly due to topographic effects. Ice flow can be channelled within valleys, affecting the composition and glacial transport direction of drift on valley floors. Drift on adjacent highlands can remain unaffected, being the geological product of regional scale events. All aspects of the striae record should be sought by systematic examination of outcrop surfaces, and ice flow directions within all parts of the area of investigation determined.

3. Establish the regional and local context of glacial dispersal trains that lie across the area of study, as outlined in this report. Such a context provides a basis for distinguishing the presence and relative proportions of local and far-travelled debris, and for separating the effects of glacial transport from variation in bedrock composition in geochemical patterns.

Drift composition can change significantly, even at small scale, as the result of large scale glacial dispersal patterns and the context of an area within dispersal trains. Both 'positive' and 'negative' dispersal trains, defined by their relative geochemical characteristics, can occur, and they affect the expression of underlying bedrock. Mapping all aspects of till composition, including the type, distribution, and relative proportions of all rock types, not only indicator erratics, as part of exploration programs, provides an important geological basis for interpretation of geochemical results.

4. Trace indicators of mineralization within surficial deposits to locate their bedrock source. This requires recognition of the geological origins of the glacial sediment containing the debris. The indicators should be systematically mapped according to the type of glacial sediment in order to define the shape of their dispersal train and to determine their bedrock source.

Models of ribbon- and fan-shaped glacial dispersal trains, presented here, provide a general basis for establishing the most likely pathways of glacial transport, as well as the compositional variation within those trains. Sampling transects should be oriented at approximate right angles to ice flow directions, and located successively farther up-ice to locate the head of the train. There can, however, be significant small-scale effects related to topography and to the exposure of the bedrock source to the ice sheet that affect the location, shape, and orientation of dispersal trains. Thus, the head of dispersal trains may not always originate at the bedrock source, and the principal alignment of dispersal trains can be in directions other than that of latest ice flow. The latest direction, however, is generally the most important control on drift composition and glacial transport.

5. Sampling patterns should be structured with regard to ice flow history and variation in ice flow directions.

To improve the chances of intersecting a glacial dispersal train originating with an indicator source, sampling patterns typically follow transects oriented at right angles to ice flow direction. Sample sites are more closely spaced along transects, compared with distances between transects. Spacing varies according to the size of the area investigated and of the target sought. The complex dispersal patterns identified in Labrador indicate the need to consider geographic position within the former Labradorean ice sheet to account for variation in the ability of the ice sheet to erode and transport debris, and in the shape and orientation of glacial dispersal trains resulting from change in ice flow direction. Near the location of former ice divides, for example, there is potential for transport in any direction whereas near the ice sheet margins transport is principally in one direction. Compositional variations within dispersal trains indicate that the latest direction of ice flow is generally the dominant control on drift composition. Within the overall pattern of glacial dispersal, the shape and orientation of core zones where debris is most abundant commonly reflect latest ice flow directions.

6. Glacial processes of deposition become increasing concerns with a decrease in the scale of investigation. In some regions, such as the Labrador Trough, there can be vertical compositional variation within till, making the compositional relationship with underlying bedrock that much more obscure. The differences can relate to different ice flow events and till stratigraphy, as in western Labrador (e.g. Gosse, 1989), or to facies change within a till unit (e.g. Batterson, 1989b). Although exploration commonly attempts to trace the distribution of indicator debris at the surface, the character of vertical compositional and stratigraphic change, if any, must also be determined.

7. The erosional products of bedrock are not uniformly distributed among size fractions, depending on the characteristics of the source, and on the processes of glacial erosion, transport, and deposition.

Softer sources, such as slate, shale, and mafic igneous rock, are preferentially eroded and tend to occur within the finer size fractions most commonly subject to geochemical analyses. As such, they can have a disproportionate influence on results of geochemical analyses . In contrast, crystalline bedrock resists glacial grinding and the erosional products tend to remain within coarser fractions.

Coarse debris can be transported above the basal zone of the ice sheet where there is little comminution during ice flow. Clasts transported within the ice may not serve as a continuing source of indicator debris to the finer fractions by glacial comminution during transport, and may be transported farther. In such circumstance, geochemically defined patterns of glacial dispersal can be more restricted in extent than defined by analyses of either clasts or sand-sized minerals.

8. Most sediments sampled as part of surficial exploration were weathered during postglacial time, and their mineralogical and geochemical properties have been altered from those of parent materials. Samples should be collected from the least weathered part of the soil profile, and care should be taken to sample at a constant position within soil horizons.

From this study, sediment within the upper C or lower B horizons would appear to be the best approximation of parent material accessible to exploration by manual methods. Sampling of that part of the soil profile represents the best compromise between the advantages of sampling unweathered material and the constraints of time and cost commonly facing exploration programs.

The geochemical properties of unweathered till can be interpreted in terms of physical glacial transport, according to models of mechanical dispersal.

9. Sand-sized minerals can provide the most effective means of tracing glacial dispersal, and they can be a direct indication of the mineralization sought. From the study of the Red Wine Complex, heavy minerals can be far-travelled, presenting a larger effective target for exploration, and can be traced within till at extremely low concentrations.

10. Easily weathered minerals, such as sulphides, are not suited for tracing dispersal trains within near-surface zone because they are 'lost' from the soil due to weathering. Weathering effects extend at least 1 m below surface, and likely deeper.

11. Quantitative analysis of pebbles (wt. %) can provide an effective means of tracing glacial dispersal trains, although it is limited either by numbers of clasts available for counting, or by the small size of the fragments and corresponding difficulty in determining indicator properties, or both.

Lithologic mapping (boulder tracing) can be most readily applied in areas where vegetation is sparse and large numbers of clasts are exposed, washed clean at the surface. In areas of forest cover and soil formation, sufficient numbers of clasts are not as easily found and are commonly coated by secondary compounds of iron and manganese making identification of rock type difficult.

12. Till geochemistry appears best suited for exploration at the most detailed scales of investigation (hundreds of metres to a few kilometres).

Clay-sized material generally contains the greatest levels of trace elements (Cu, Pb, Zn, Ni, Cr, U), in comparison with coarser fractions. As such, it can provide a more sensitive basis for defining glacial dispersal trains by geochemical methods because of greater contrasts between background and anomalous samples. Near bedrock sources, where compositional contrasts between till containing indicator debris and background are greatest, the geochemical expression of the source is likely to be recognizable within all fractions. Thus, at detailed scales more typical of mineral exploration, analyses of coarser fractions may be suitable for geochemically defining glacial dispersal trains.

13. Regional geochemical surveys of till can provide a basis for distinguishing differences among and within lithological units, and as such can allow focus of the exploration effort. Distinction between the effects of glacial transport and underlying bedrock on geochemical patterns is most easily made within the context of till lithology, and the provenance of glacial debris.

It is unlikely that specific sources of mineralization are represented within regional geochemical surveys by elevated trace element levels, given the low density of samples and likely small size of mineralized sources. Nevertheless, geochemical analyses can serve to indicate bedrock variation that may not represented by geological maps. In areas such as Labrador where scale of bedrock mapping varies, geochemical maps provide an additional level of information for exploration decisions. Examples include the apparent geochemical 'enrichment' of bedrock within the southern Labrador Trough along the Grenville Front, and compositional differences among satellitic plutons of the Flowers River Igneous Suite.

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APPENDIX 1

Definition of terms

Terms commonly used in this report are defined here to clarify the text:

Ablation: Refers to processes by which ice is lost from a glacier, including melting, calving, and evaporation.

Agpaitic: Rocks crystallized in the presence of excess alkali elements (Na, K); applied to rocks derived from the Red Wine Complex near Letitia Lake, central Labrador, that appear as distinctive green and blue-green gneisses (Curtis and Currie, 1981).

Anomalous: Concentrations of an indicator rock, mineral, or element that are notably greater than those represented by normal background variation in samples. The term is qualitatively defined and is not used with reference to statistical analyses of geochemical data.

Background: Concentrations of an indicator rock, mineral, or element that are characteristic of either bedrock or till within a region over areas measured in hundreds of square kilometres. The term is qualitatively defined and is not used with reference to statistical analyses of geochemical data.

Basement: Igneous and metamorphic rock of Archean and Proterozoic ages forming the Canadian Shield. They have been subject to varying degrees of metamorphism and structural change during the orogenic events associated with the geological provinces of the Shield.

Clay: Clay-sized debris (<0.002 mm) including, in varying proportions, primary rock-forming minerals; secondary clay minerals; secondary oxides and hydroxides of aluminum, iron, and manganese; and organic debris and compounds.

Crystalline: A general term used to describe rock derived from the basement complex.

Dispersal train [head, tail: negative, positive]: The compositional record of glacial erosion and transport during one or more glacial events, defined by the distributions of indicator erratics and geochemical, mineralogical, and lithological analyses. Within trains, concentrations of indicator debris are greatest at or near the bedrock source ('head'), and decrease exponentially with distance down-ice ('tail') (Shilts, 1976). 'Positive' dispersal trains are characterized by greater concentrations of the 'indicator' than occurs within underlying bedrock, and 'negative' trains contain lesser concentrations.

Down-ice: In the direction of ice flow.

Drift: A general term applied to sediments transported by and deposited from ice, and including sediments partially modified by glacial meltwater beneath ice. The sediments are non-sorted to poorly sorted, and massive to poorly-stratified. The term is used interchangeably with till in this report.

Event (of ice flow): A large-scale event within the ice sheet associated with striae and streamlined landforms that define a regionally coherent pattern (thousand to more several thousand square kilometres) and with significant glacial transport (ten to more than one hundred kilometres).

Hummocky moraine: Irregular mounds and hummocks a few metres to more than ten metres in height. In central Labrador they are commonly incised by meltwater channels, and can be associated with ice contact glaciofluvial deposits.

Ice divide: A zone from which ice flow is directed outward in opposing directions.

Ice stream: A zone characterized by an ice flow velocity greater than in adjacent terrain. An ice stream can define an elongate zone within the ice sheet and may be characterized by meltwater at its base.

Indicator (source, erratic): A known bedrock source, or debris, that has distinctive geochemical, mineralogical, or lithological properties, and that can be used to establish provenance and net glacial transport directions.

Labradorean Sector: That part of the Laurentide Ice Sheet covering Labrador and Quebec and having a pattern of flow independent of other parts of the Ice Sheet (e.g. Prest et al., 1968; Prest, 1984).

Latest ice flow: The last or youngest direction of ice flow. Throughout most of Labrador the record is prominently defined by glacially streamlined landforms and by striae on the most exposed bedrock surfaces. In some areas, for example near Schefferville, it is recorded by faint, cross-cutting striae, from which a late glacial event of limited duration is inferred.

Pebbles: Rock fragments 4 to 5.6 mm in maximum dimension. The size range is more limited than commonly used.

REE: Rare-earth elements (e.g. La, Ce)

Ribbed moraine: A nested series of short, sinuous ridges, the crests of which are roughly transverse to ice flow. Ridges are typically a few metres to a few tens of metres in height, and can be up to several kilometres in length.

Scale: A qualitative term used to describe geological variation of regional (ten to more than a hundred kilometres), local (kilometre to several tens of kilometres) and detailed (fractions of kilometres) extent. Mineral exploration is commonly carried out at detailed scales.

Soil: The near-surface expression of alteration by physical and chemical processes associated with weathering during postglacial time. Soil profiles are developed in essentially unweathered glacial sediments. The term is used without regard to the geological origins of the sediments, although profiles described in this report are developed in till.

Stratified drift: Poorly sorted glacial deposits characterized by internal stratification indicative of deposition from water. The term is applied here to sediments interpreted to have been deposited either beneath the ice sheet by meltout (meltout till) or in contact with ice, and that have undergone limited transport and sorting by meltwater.

Striae: Fine to coarse scratches on bedrock made by the movement of debris held within glacier ice. Striae are aligned in the direction of ice flow (e.g. Prest, 1983).

Supracrustal: Sedimentary and volcanic rock sequences that overlie igneous and metamorphic basement rock of the Shield. In Labrador, supracrustal sequences are little metamorphosed in comparison with the basement complex, particularly in the west.

Till: A glacial sediment transported and deposited from glacier ice without significant compositional modification by meltwater. It is typically poorly sorted and lacking obvious stratification. The term is used interchangeably with 'drift' in this report.

Up-ice: Against the direction of ice flow.

Weathering: Physical and chemical modification of glacial sediments that has occurred during postglacial time and has resulted in vertical variations in till composition (soil profile). Glacial sediments are interpreted to have been unweathered beneath the ice sheet, although they can contain debris weathered during preglacial periods, either Pleistocene (interglacial), Tertiary (e.g. Schefferville area, Labrador Trough), or Proterozoic (e.g. sedimentary rocks of Seal Lake Group).

APPENDIX 2

Regional variations in drift geochemistry
(see also Fig. A2-1 to A2-19, in pocket)

The following is a descriptive summary of salient geochemical features at the regional scale, emphasizing the relationship between bedrock (Fig. 2; Fig. A2-1) and till geochemistry (Fig. A2-2 to A2-19). Geochemical analyses are illustrated by a dot scaled to size according to trace element concentration (Lazerdot; Wyatt Geoscience, Ottawa). Scale and class interval were chosen to illustrate gross geochemical differences within till derived from the major bedrock units and to avoid emphasis of 'anomalous' results. The dot symbols are centred on the sample collection site and are layered so that larger dots do not obscure smaller ones. The manner of presentation fairly illustrates sample distribution, and isolated 'anomalous' samples do not affect the geochemical presentation of adjacent 'background' samples as they would on a 'smoothed' contour map. The maps are the basis for geochemical presentations of western Labrador, Letitia Lake and Flowers River regions in the text. Geochemical analyses, results, and summary maps are contained within a series of earlier publications (Klassen et al., 1986; Thompson et al., 1986a, b, c, 1988; Klassen and Thompson, 1990).

Superior Province

Till overlying the Ashuanipi Complex presents regional geochemical variations that relate both to glacial transport and to variations in underlying bedrock lithology. Generally, the till has low levels of lead (<30 ppm), uranium (<4 ppm), and manganese (200 to 600 ppm), and elevated levels of nickel (75 to 200 ppm) and chromium (120 to 300 ppm), particularly in the area of granitoid and paragneiss bedrock north of McPhadyen River (Percival and Girard, 1988). In areas of pyroxenite west of Schefferville, till contains anomalous levels of nickel (175 to 300 ppm), chromium (300 to 500 ppm), and gold (10 to 45 ppb), as well as scattered samples enriched in copper (150 to 250 ppm). Gold and gold-platinum anomalies occur in the Complex (McConnell and Newman, 1988; Thomas and Butler, 1987; Percival and Girard, 1988). Arsenic anomalies (10 to 20 ppm) in till along the eastern margin of the Ashuanipi Complex, west of Schefferville, are interpreted to reflect westward glacial transport of debris from the Labrador Trough, which has high concentrations of arsenic.

Across the northern Ashuanipi Complex, northwest of Schefferville, the distribution of supracrustal debris derived from the Labrador Trough (Fig. 22a) is closely matched by increased concentrations of zinc, iron, manganese, and uranium, and by decreased concentrations of nickel and chromium, in comparison with areas elsewhere in the Complex (see also Fig. 22b-f).

Nain Province

Till overlying gneissic terrain has low levels of lead (<30 ppm), iron (2 to 5 wt.%) and manganese (250 to 1000 ppm), and, east of the Moran Lake Group, has slightly elevated levels of copper (150 to 250 ppm). Till overlying the western margin of the Island Harbour Granite is enriched in nickel, possibly as the result of eastward glacial transport of supracrustal debris onto the margin of the intrusive. The till is red and contains sedimentary rock having a western provenance.

Churchill Province

Within the basement complex of the Churchill Province till has varied, but generally low, metal levels, and is geochemically similar to till overlying gneissic terrain of the Grenville Province. Too few samples are available to distinguish geochemically till derived from intrusive and gneissic bedrock of the Churchill Province. Till is notably enriched in zinc (300 to >1000 ppm) one to two kilometres north of the contact with the Moran Lake Group of the Central Mineral Belt. Although till there contains glacially transported shale erratics, trace element concentrations in till overlying the only mapped source of shale located up-ice, within the Moran Lake Group, are lower, suggesting that the geochemical patterns may reflect the geochemistry of underlying gneissic bedrock.

East of the Labrador Trough, till is enriched in nickel (75 to 175 ppm) and chromium (120 to 200 ppm). Although till geochemistry could relate to underlying gneissic bedrock, it is more likely the product of eastward glacial transport of mafic debris from the Trough. Such an interpretation is consistent with the eastward glacial transport of supracrustal debris (Fig. 19a), and occurrence of green till in the area, reflecting concentrations of finely ground chlorite characteristic of mafic terrain. Regional till geochemistry appears to record glacial transport up to 50 km east from the Trough, although sample density is low and the eastward extent of dispersal is poorly known.

Till overlying the anorthosite has uniformly low trace element levels; in many cases near the detection limit of the analytical method. Nickel is slightly enriched across the central portion of the Complex, and copper and zinc are enriched at a few sites scattered along the eastern margin.

Till in the central and western parts of the Trough is enriched in iron (5 to 9 wt.%) and manganese (400 to 3000 ppm), particularly in areas of iron-formation in the Schefferville region, and depleted in copper. Levels of zinc and uranium are greater to the north than to the south. In the Howells River valley west of Schefferville, till is anomalous for those elements and for lead. Geochemical anomalies occur in lake sediment and water samples in the areas of Howells River (McConnell, 1984, Anomaly 4, p. 54). Till also has elevated levels of cadmium and of arsenic (10 to >20 ppm) and samples containing 5 to 15 ppb gold are widespread. A few samples scattered throughout the northern portion of the Trough contained detectable levels of platinum (5 to 10 ppb) and palladium (2 to 4 ppb).

Till overlying mafic igneous bedrock of the eastern Trough is enriched in copper (150 to 500 ppm), nickel (>175 ppm), chromium (>200 ppm), iron (>6 wt.%), and gold (5 to 15 ppb), and contains scattered samples with concentrations of platinum (5 to 10 ppb) and palladium (2 to 8 ppb). It contains low levels of lead and uranium. Intrusive and extrusive mafic rocks are not easily distinguished at the scale reported here, although extrusive series generally predominate along the eastern margin of the Trough and till there contains greater concentrations of copper, nickel, and chromium than till overlying intrusive series to the west. Arsenic concentrations are greater in areas underlain by extrusive rocks. Geochemical patterns indicate compositional variations within the zone of mafic igneous rock.

Grenville Province

Till overlying the Trans-Labrador Batholith is not geochemically uniform and is relatively enriched in some elements (Cu, Pb, Zn, U) over the eastern part. East of Smallwood Reservoir, till characterized by elevated levels of uranium (8 to 15 ppm) defines an elongate zone that overlies most of the eastern Trans-Labrador Batholith, and includes the Letitia Lake and Aillik groups. Extensive areas along the northern margin of the Trans-Labrador Batholith are also enriched in lead (40 to 80 ppm). In comparison with till overlying gneissic terrain to the south, till overlying the Batholith contains less copper, although within the Benedict Mountains there is a zone of elevated levels of both copper and uranium.

South of Smallwood Reservoir, overlying the Trans-Labrador Batholith, till has lower metal levels than over the Batholith to the east, although samples in the Churchill Falls area are concentrated along roads and may not be representative of the region. Compared with samples collected along the road northeast of Churchill Falls, till along the Trans-Labrador Highway west of the town is notably enriched in copper (>250 ppm) and lead (40 to 80 ppm), and slightly enriched in zinc (100 to 200 ppm) and uranium (4 to 8 ppm). The geochemically enriched samples are located near, and down-ice (southeast) from the southern margin of the Trans-Labrador Batholith.

Till overlying Grenville gneisses has generally low metal levels (<30 ppm Pb; <200 ppm Zn), although isolated, samples enriched in other elements are scattered throughout. North of Lake Melville, for example, till contains elevated levels of copper (150 to 300 ppm) in an area underlain by sulphide-bearing gneisses west of Double Mer-White Hills (Gower and Erdmer, 1984). East of Churchill Falls, till is relatively enriched in iron (4 to 9 wt.%) and copper (150 to 500 ppm), and the metal levels could relate to southeastward glacial transport of debris from the Labrador Trough.

Generally, levels of copper, lead, zinc, and nickel in till overlying metamorphosed parts of the Labrador Trough within the Grenville Province are greater than in till overlying the southern portion of the Trough within the Churchill Province. Near the Grenville Metamorphic Front, however, till is enriched in copper (150 to 500 ppm), lead (40 to 200 ppm), zinc (150 to 500 ppm), nickel (175 to 300 ppm), chromium (300 to 500 ppm), uranium (8 to 15 ppm), and molybdenum (10 to 20 ppm), and that area is easily distinguished on the regional geochemical maps.

With regard to mineral exploration, one should note that three samples contained gold concentrations between 15 to 40 ppb, and that other nearby samples contained detectable levels (5 to 10 ppb). Bedrock is extensively drift-covered and is not well known. It includes carbonaceous shales and felsic volcanic rocks of the Menihek and McKay River formations (Rivers, 1985) and their metamorphic equivalents which could be potential sources of the metal levels. The extent of the geochemical pattern indicates a bedrock source that is of significant extent and susceptibility to glacial erosion.

Central Mineral Belt

Regionally, till overlying the Central Mineral Belt is geochemically distinctive, having trace element concentrations that are generally greater than within metamorphic terrain to the north and south. The Central Mineral Belt, however, is not geochemically uniform and lithological components can be recognized either by anomalous or enhanced levels of copper and zinc, and of uranium and lead. Some bedrock units are distinctive for several elements. Samples containing detectable levels of gold (5 to >15 ppb) are scattered throughout the Central Mineral Belt, and the greatest concentrations of platinum occur in areas of volcanic bedrock of the Seal Lake, Moran Lake, and Bruce River groups.

Geochemically, till overlying the Seal Lake Group is similar to that overlying other supracrustal sequences of the Central Mineral Belt, although levels of lead (<30 ppm) and zinc (<200 ppm) tend to be lower. There is little geochemical distinction between till overlying areas of sedimentary rock to the north and of volcanic rock to the south, although scattered samples slightly enriched in copper and nickel were more common in areas of volcanic bedrock.

Till overlying the Bruce River Group has elevated levels of lead (30 to 40 ppm), and nickel (75 to 300 ppm); scattered samples contain elevated levels of zinc (>300 ppm) and uranium (8 to 12 ppm). To the north, till overlying volcanic rock of the Sylvia Lake Formation is significantly enriched in nickel (120 to 300 ppm) and chromium (120 to 500 ppm) near the contact with sedimentary rock of the Haggart Lake Formation. Elevated levels of lead occur along the southern margin of the Bruce River Group.

Within areas of the Moran Lake Group, till is generally enriched in nickel (100 to 200 ppm), and manganese (500 to 1000 ppm), compared with elsewhere in the Central Mineral Belt. Within the Moran Lake Group, copper (150 to 250 ppm) concentrations are greater to the northeast, in the area underlain by basalt (Joe Pond Formation), and zinc (200 to 500 ppm) to the west in the area underlain by black shale (Warren Creek Formation).

Till overlying the Aillik Group has elevated to anomalous levels of lead (40 to 80 ppm) and uranium (8 to 40 ppm), and scattered anomalous concentrations of either copper or molybdenum, or both. Zinc is generally enriched (200 to 500 ppm) in the area east and south of Makkovik on the Labrador coast, and higher levels of nickel (75 to >300 ppm), chromium (200 to 900 ppm), and gold (10 to 25 ppb) were found near the western extent of the Aillik Group.

Peralkaline centres

Till derived from three peralkaline centres ('Strange' lake, Flowers River, and Letitia Lake) has low levels of copper, nickel, and chromium, elevated levels of uranium and lead, and scattered elevated levels of zinc. The centres are also known to be enriched in zirconium, yttrium, niobium, beryllium, and rare-earth elements (REE) (Miller, 1988), and those geochemical characteristics are reflected within till derived from them. The centres appear to have been susceptible to glacial erosion and geochemically defined glacial dispersal trains originating from them are clearly evident at the regional scale.

Samples in the 'Strange' lake region are sparse and unevenly distributed. Most were taken from a regional dispersal train originating at the Strange Lake Complex (Batterson, 1989b; Batterson et al., 1985, McConnell and Batterson, 1987). Within the dispersal train, till is characterized by elevated concentrations of lead (80 to 200 ppm) and uranium (8 to 15 ppm), and, toward its eastern (down-ice) extremity, copper. The source of copper does not appear to lie within the peralkaline complex as the till enriched in copper lies within the train, originating down-ice of the peralkaline source. The train is also enriched in yttrium (80 to 200 ppm), niobium (100 to 300 ppm), zirconium (1200 to 1800 ppm), cerium (100 to 300 ppm), and beryllium (8 to >20 ppm), all of which are known to be enriched within the complex (Miller, 1988).

Till overlying intrusive and extrusive rocks of the Flowers River Igneous Suite is enriched in lead (40 to 80 ppm), and depleted in copper (<80 ppm), nickel (<25 ppm), chromium (<40 ppm), and manganese (<400 ppm). It is moderately enriched in zinc (100 to 300 ppm) and uranium (10 to 20 ppm), particularly over the northwestern part of the complex and over adjacent granitic terrain. Scattered samples containing detectable concentrations of gold (10 to 40 ppb) are associated with volcanic bedrock in the southeastern part of the complex, where the greatest levels occur. Till is also enriched in yttrium (60 to 80 ppm), niobium (30 to 60 ppm), zirconium (100 to 200 ppm), and thorium (15 to 25 ppm). The greatest levels of lead, yttrium, and niobium occur to the east. The regional variations in till geochemistry indicate compositional variations within the intrusive complex, among the satellite plutons surrounding the central volcanic complex. Thus till geochemistry can serve as a guide for future exploration of the peralkaline complex. One fragment of cassiterite of unknown origin has been found in till overlying the complex (Klassen et al., 1986).

Over the southwestern margin (up-ice) of the Flowers River Igneous Suite, till geochemistry reflects a crystalline provenance and glacial transport, masking the compositional expression of underlying bedrock.

Till derived from the peralkaline complex near Letitia Lake, including the Red Wine Alkaline Complex, Arc Lake Intrusive Series, and Letitia Lake Group, is geochemically distinct, characterized by elevated levels of lead (40 to 500 ppm), zinc (200 to 1500 ppm), uranium (5 to 25 ppm), manganese (400 to 3000 ppm), yttrium (>80 ppm), niobium (>30 ppm), zirconium (>600 ppm), cerium (>300 ppm), and beryllium (4 to 8 ppm). The till is depleted in copper (<50 ppm) and nickel (<25 ppm). The greatest concentrations of zinc (1000 to 1600 ppm), uranium (15 to 25 ppm), yttrium (100 to 250 ppm), niobium (60 to 70 ppm), cerium (500 to 600 ppm), thorium (20 to 25 ppm), and beryllium (12 ppm) are in till derived from the large area of agpaitic rocks within the central part of the complex.

APPENDIX 3

Soil profiles

LEGEND

Eastern profiles

■ *Clay*

□ *Silt and clay*

\+ *2 to 4 mm*

◇ *Heavy mineral(s.g. >3.3)*

Western profiles

■ *Clay*

□ *Silt*

\+ *Sand*

◇ *< 2 mm*

Note: 1) *Key to soil horizon given by Figure 25 in report.*

2) *Within B horizon, shading characterizes relative variationin oxidation colours.*

3) *Arabic numerals indicate different samples of horizon.*

4) *Roman numerals indicate stratigraphic subdivisions of Quaternary sediment. The uppermost unit is not numbered.*

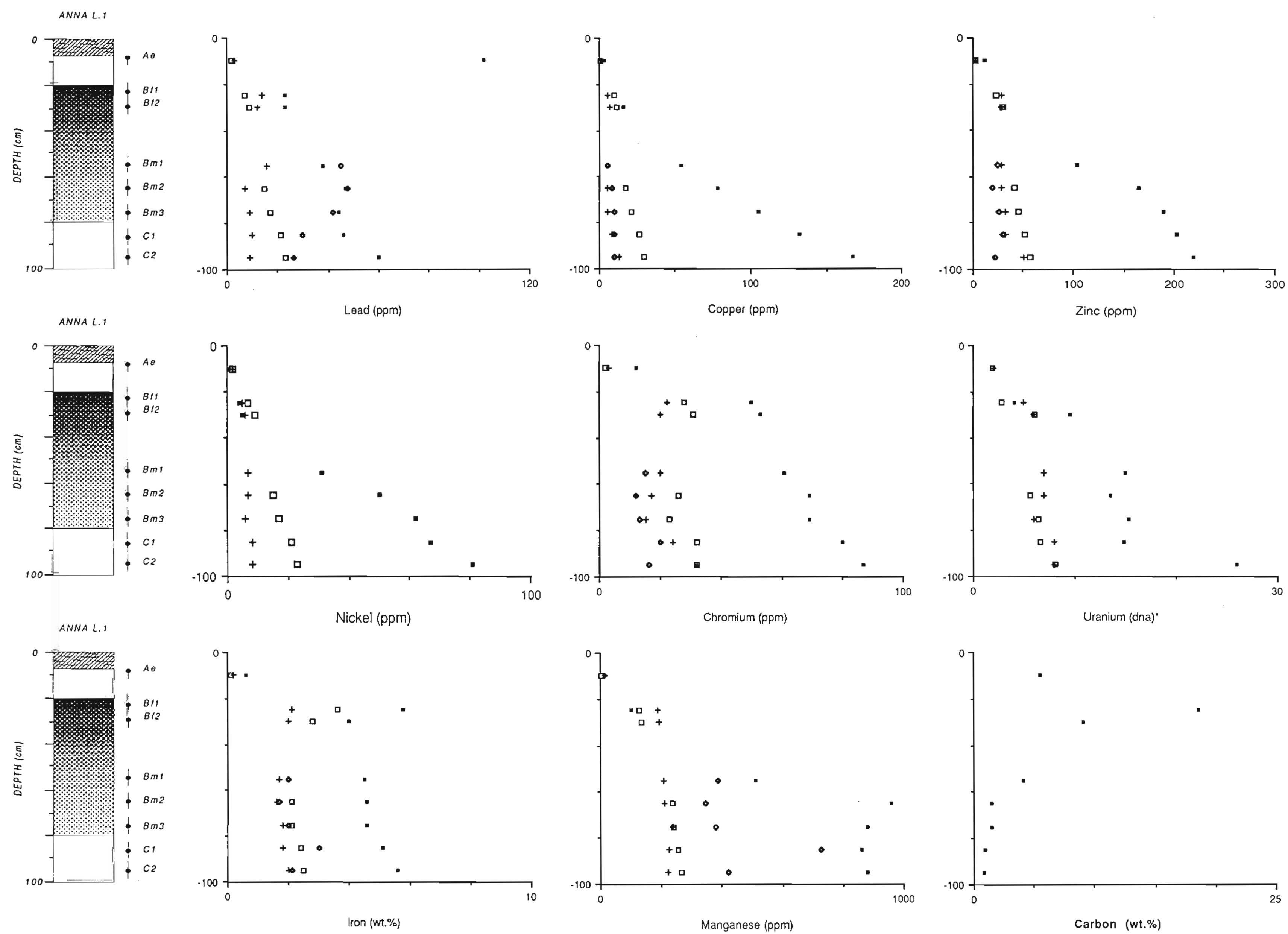

Figure A3-1. Anna lake 1 soil profile, eastern Labrador. *(dna-Delayed neutron activation analysis)

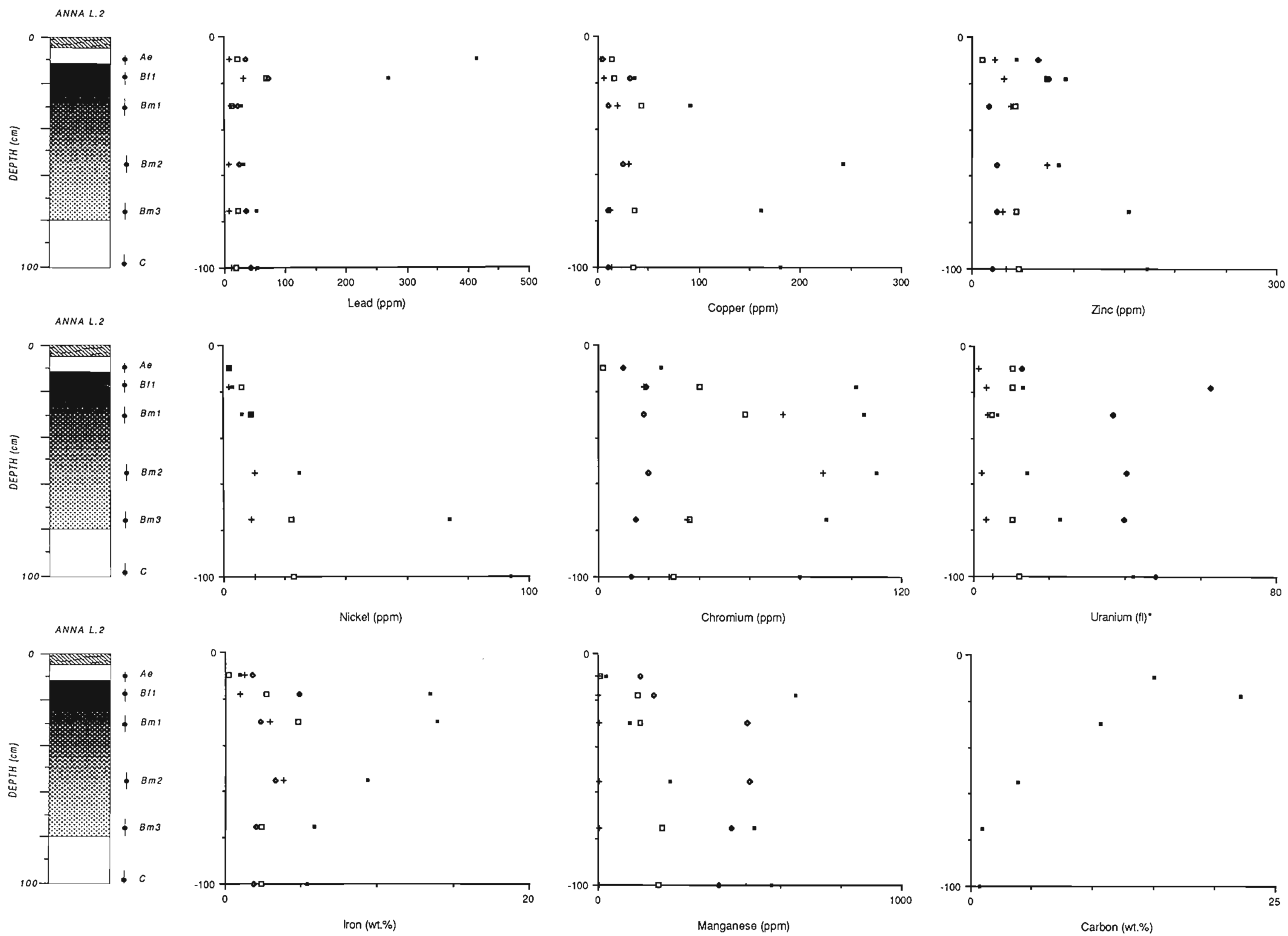

Figure A3-2. Anna lake 2 soil profile, eastern Labrador. *(fl-Fluorimetry)

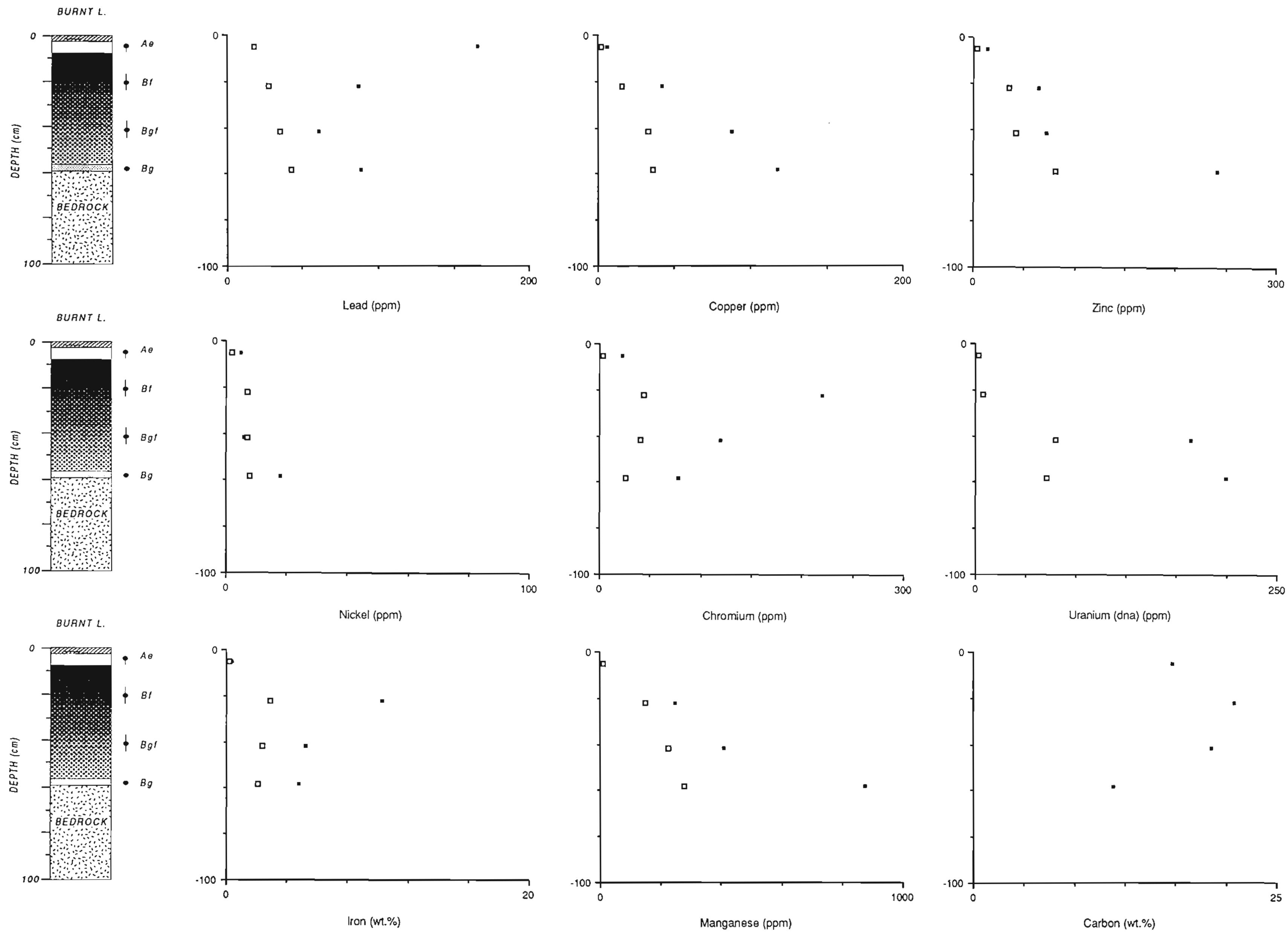

Figure A3-3. Burnt lake soil profile, eastern Labrador.

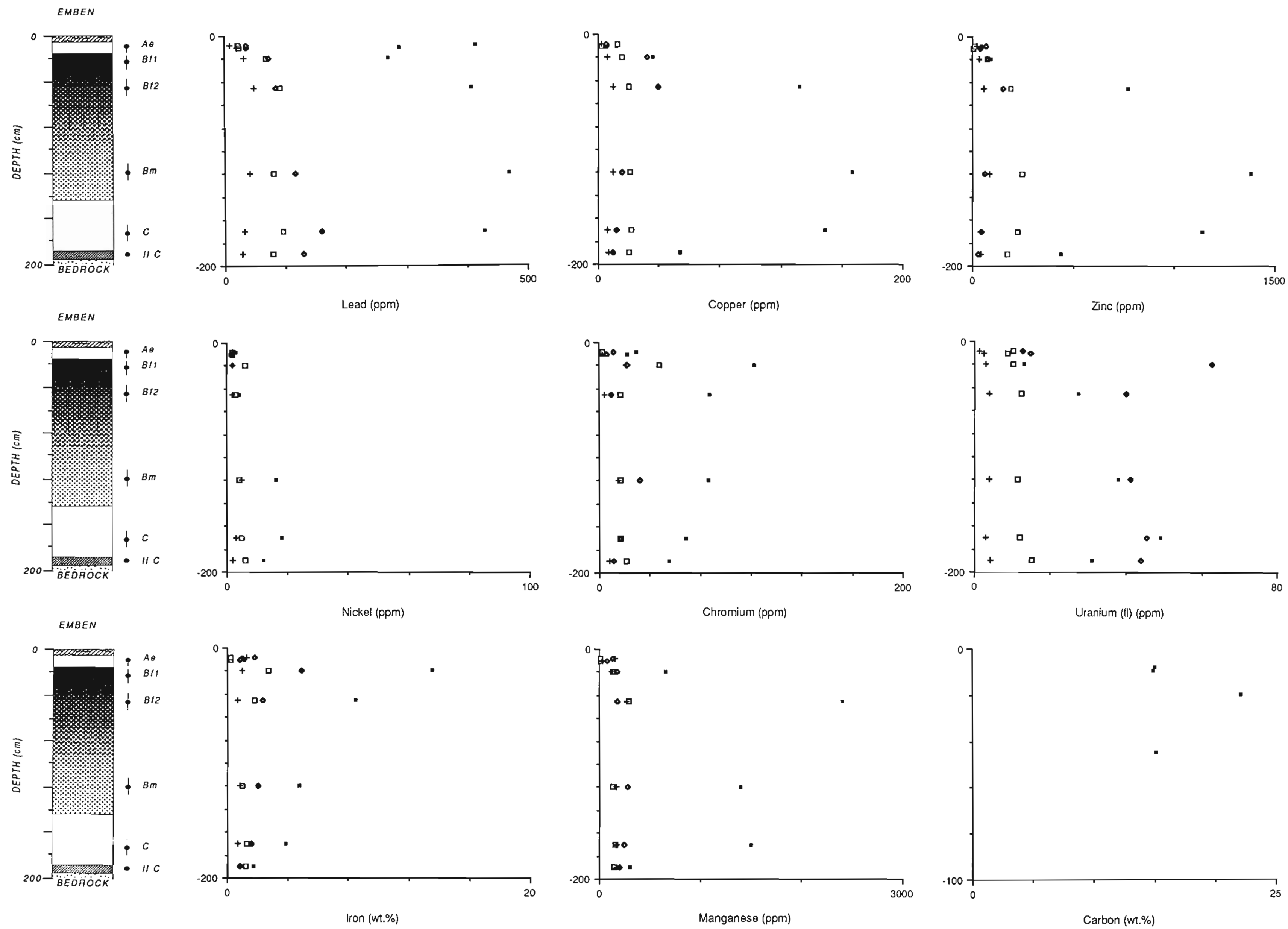

Figure A3-4. Emben soil profile, eastern Labrador.

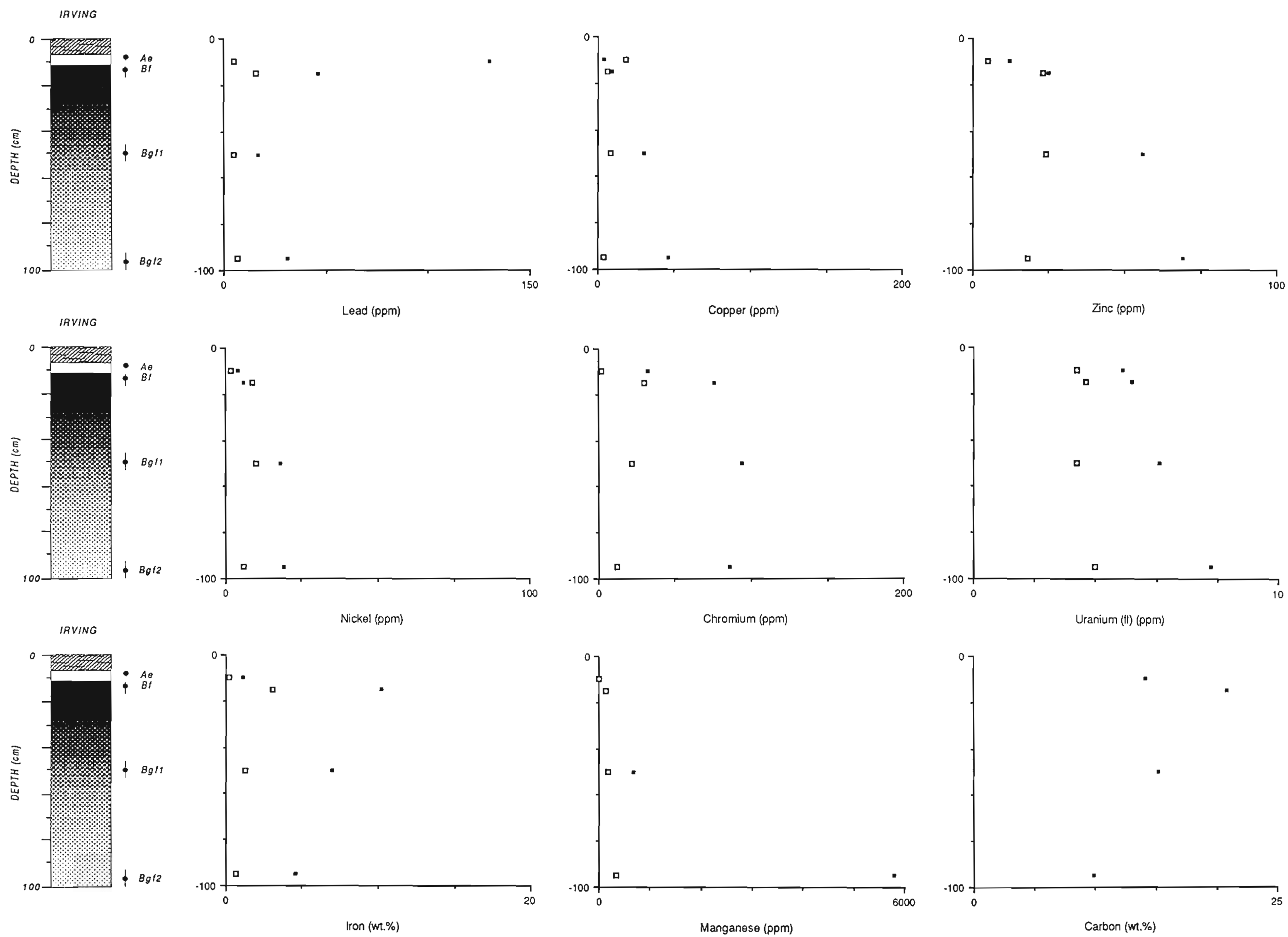

Figure A3-5. Irving soil profile, eastern Labrador.

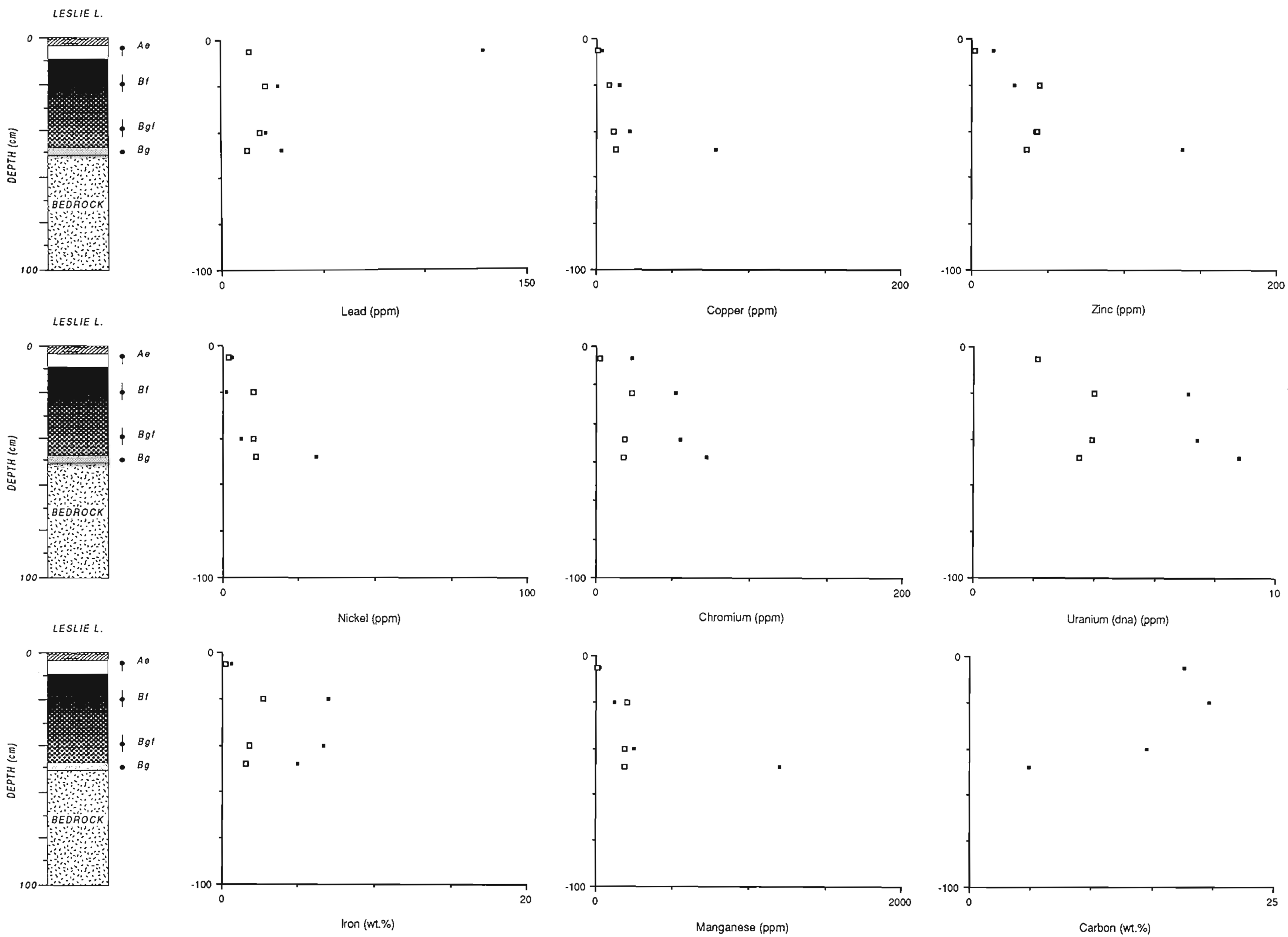

Figure A3-6. Leslie lake soil profile, eastern Labrador.

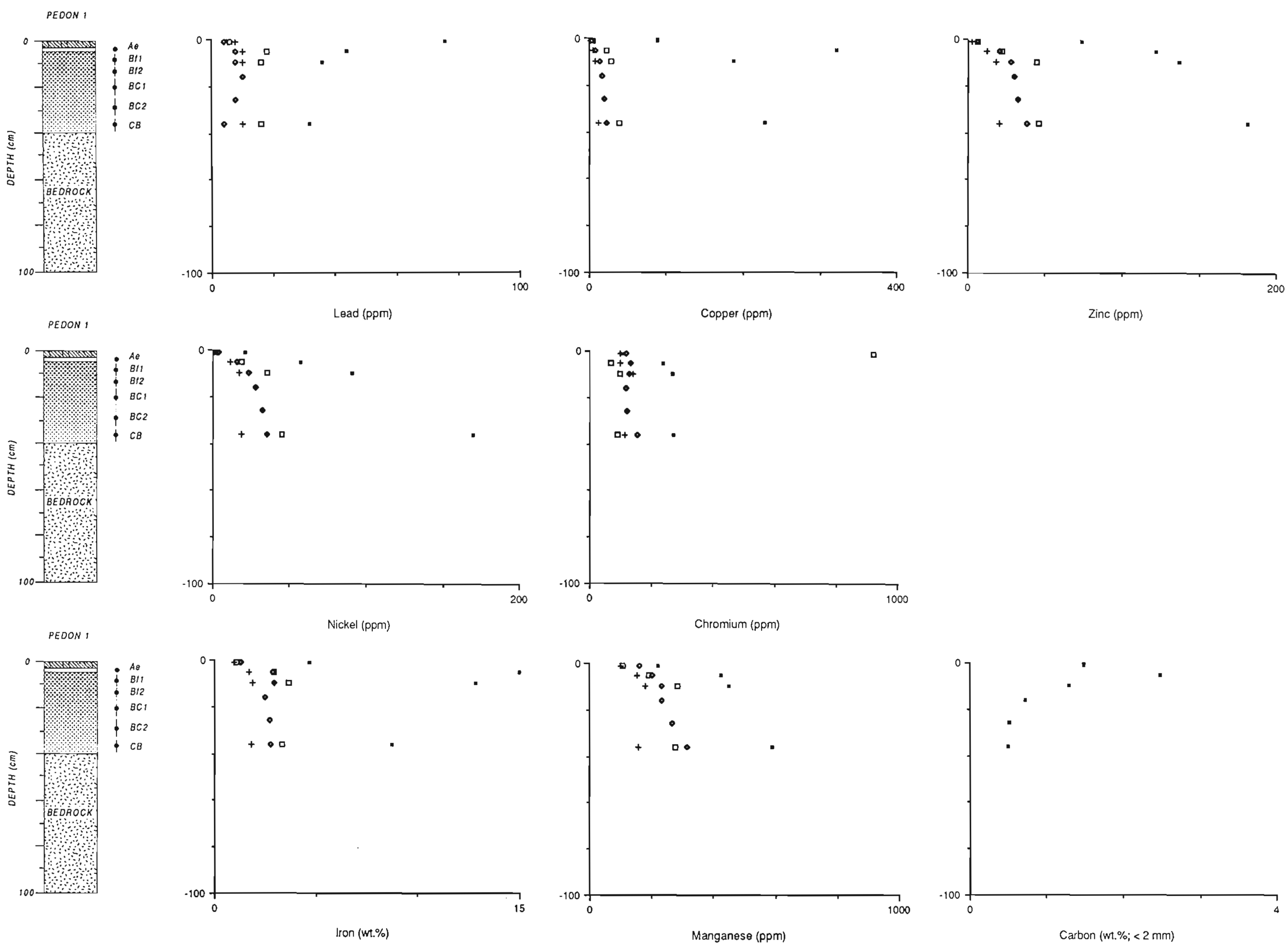

Figure A3-7. Pedon 1 soil profile, western Labrador.

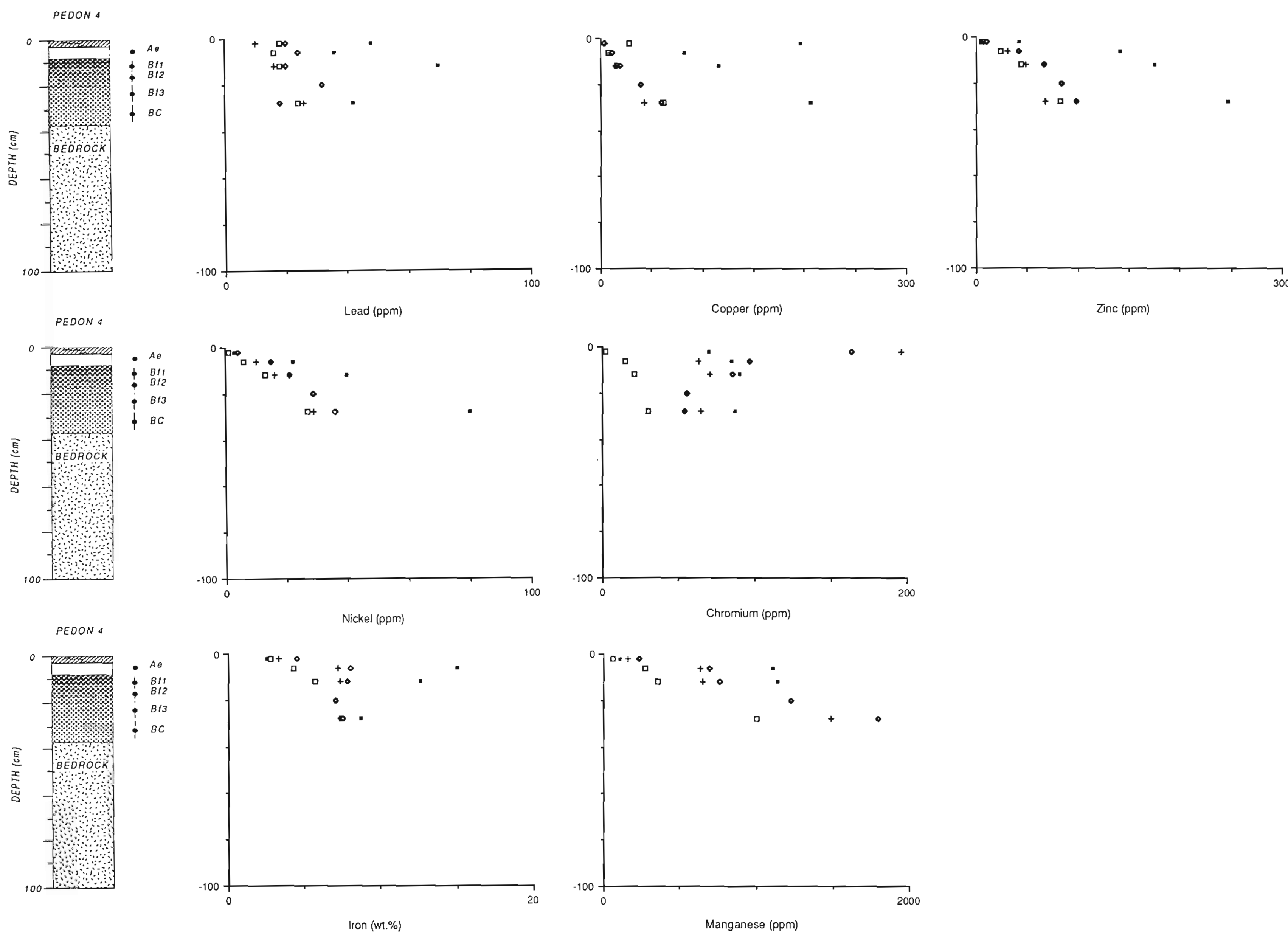

Figure A3-8. Pedon 4 soil profile, western Labrador.

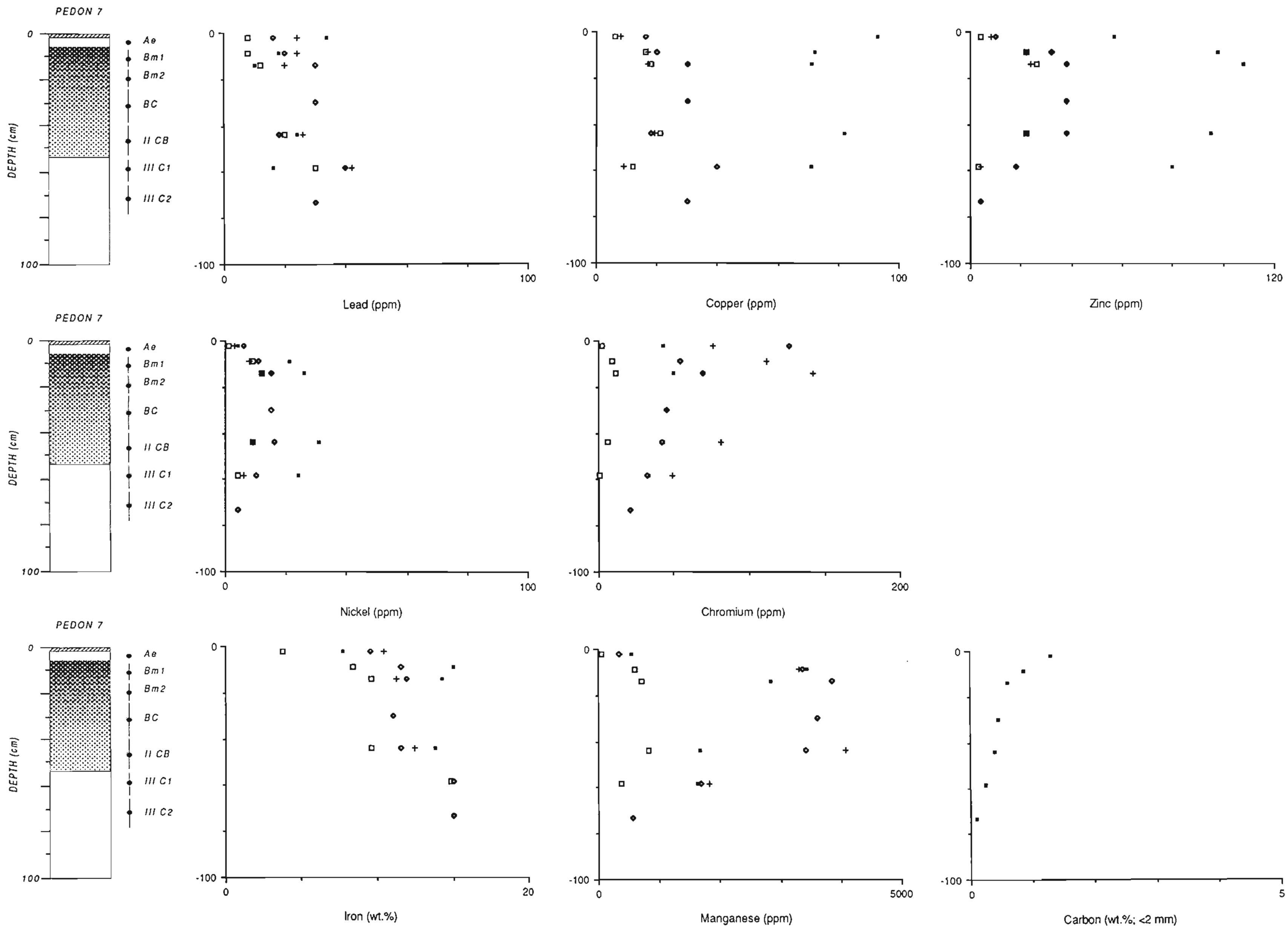

Figure A3-9. Pedon 7 soil profile, western Labrador.