Geological Survey
of Canada

Current Research
2000-C3

Preliminary surficial geology studies and mineral exploration considerations in the Yellowknife area, Northwest Territories

D.E. Kerr and P. Wilson

2000

Natural Resources Canada　Ressources naturelles Canada

Canada

Catalogue No. M44-2000/C3E-IN
ISBN 0-660-18022-7

Available in Canada from the
Geological Survey of Canada Bookstore website at:
http://www.nrcan.gc.ca/gsc/bookstore (Toll-free: 1-888-252-4301)

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website http://dsp-psd.pwgsc.gc.ca. A list of these libraries can be consulted at this site or obtained by calling the toll-free number above.

Price subject to change without notice

Authors' addresses

D.E. Kerr *(dkerr@NRCan.gc.ca)*
Terrain Sciences Division
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

P. Wilson *(pwilson@NRCan.gc.ca)*
Wilson Geo-Consulting
#414-200 Back Road
Courtenay, British Columbia V9N 3W6

Preliminary surficial geology studies and mineral exploration considerations in the Yellowknife area, Northwest Territories

D.E. Kerr and P. Wilson
Terrain Sciences Division, Ottawa

Kerr, D.E. and Wilson, P., 2000: Preliminary surficial geology studies and mineral exploration considerations in the Yellowknife area, Northwest Territories; Geological Survey of Canada, Current Research 2000-C3, 8 p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Abstract: Surficial geology mapping and soil sampling in the Yellowknife area provide regional baseline data for geochemical exploration techniques and integrated environmental assessment planning. Till veneers are the most widespread surficial sediment, and have been modified by meltwater and glaciolacustrine processes, resulting in variable textures. Glaciolacustrine sediments are common in depressions and between bedrock ridges below 280 m a.s.l. Textural similarities between glaciolacustrine sediments and till hinder the recognition of these sediments as distinct map units. Consequently, geochemical signatures should be interpreted with caution. Eskers and glaciofluvial outwash can serve as potential aggregate resources. Dominant glacial flow directions correspond to the last southwestward ice movement. Minor variations indicate local late-glacial flow ranging from west-northwestward to south-southwestward. Glacial dispersal patterns of pebbles in till are not immediately apparent because of bedrock constraints. However, distributions strongly reflect predominant southwestward flow, predominance of metasedimentary clasts in till, and maximum transport distances of 150 km.

Résumé : La cartographie des dépôts meubles et l'échantillonnage des sols dans la région de Yellowknife fournissent des données de base régionales pour la prospection géochimique et la planification intégrée des évaluations environnementales. Les placages de till sont les sédiments superficiels les plus répandus et ont été remaniés par les eaux de fonte et les processus glaciolacustres, qui ont donné lieu à des textures variées. Les sédiments glaciolacustres sont communs dans les dépressions et entre les crêtes de socle rocheux à une altitude inférieure à 280 m au-dessus du niveau de la mer. Les caractéristiques texturales des sédiments glaciolacustres et du till se ressemblent, ce qui nuit à la différenciation de ces matériaux. Par conséquent, l'interprétation des signatures géochimiques exige une certaine prudence. Les eskers et les dépôts d'épandage fluvioglaciaires peuvent constituer des ressources en agrégats. Les principales directions d'écoulement des glaces sont le produit du dernier mouvement des glaces vers le sud-ouest. Des variations mineures indiquent un écoulement tardiglaciaire local allant de l'ouest-nord-ouest au sud-sud-ouest. Les configurations de dispersion des cailloux par les glaces ne sont pas évidentes à cause des limites imposées par le socle rocheux. Toutefois, cette dispersion reflète un écoulement principalement vers le sud-ouest, la prédominance des clastes métasédimentaires dans le till et un transport sur des distances maximales de 150 km.

INTRODUCTION

Declining ore reserves of producing gold mines and reduced exploration in the mining industry have resulted in the need for a long-term strategy for sustainable mining in the Yellowknife area. In response, the GSC, DIAND, GNWT, and private industry developed the Yellowknife EXTECH program: a multidisciplinary, integrated geoscientific study aimed at augmenting the geoscience database to support exploration and development. Terrain Sciences Division initiated regional surficial geology mapping through this program to provide baseline data of surficial materials, ice-flow history, and soil geochemistry. Reconnaissance surficial geology mapping was undertaken during July 1999 in the Yellowknife area: NTS 85 J/7, 8, 9, 10, 11, 16; 85 I/ 4, 5, 12, 13; 85 O/1; and 85 P/4 (Fig. 1). An environmental geoscience component was incorporated into the 1999 investigation within a 50 km radius of Yellowknife in order to provide more regional data to mining-related contaminant studies being carried out in the City of Yellowknife.

METHODS

In order to provide regional coverage in this orientation study, the area was surveyed by road access, fixed wing and helicopter-assisted traversing, and interpretation of 1:60 000 scale airphotos. From a total of 70 stations, samples were collected in order to assess sampling and analytical strategies. Samples collected include fifty-eight 2 kg soil samples for trace element and grain size analyses and 60 litter fall and humus samples of 25–100 g for trace element geochemistry determinations. Approximately 50 pebbles (2–6 cm in diameter) were collected from 47 sites for provenance and glacial transport investigations. In addition, twelve 10 kg soil samples were collected to document the range and background concentrations of kimberlite indicator minerals. An additional 25 samples of 20 kg have been submitted for kimberlite indicator mineral analysis as part of a detailed dispersal train study in the Drybones Bay area, southeast of Yellowknife. Glacial striae were measured at 66 locations and rock type and vegetation noted at each station. Soil samples were collected from hand-dug pits at depths of 0.1–0.6 m. Although till is the preferred sample medium, a range of sediment types were encountered and sampled, including glaciolacustrine clayey silt, sandy glacial diamictons (till), and sandy glaciofluvial outwash. Humus and litter fall were collected over or adjacent to the mineral-soil sampling site but due to recent forest fires in certain areas, organic soils were charred or nonexistent.

REGIONAL SETTING

The Yellowknife area lies in the southwestern Slave structural province, District of Mackenzie. Elevations range from 157 m (Great Slave Lake) and rise gradually to 350–400 m north of Thistlethwaite Lake. Much of the terrain southwest and southeast of Yellowknife is generally of low relief and less than 200 m a.s.l. Local terrain consists mainly of bare rocky outcrops with glacial and glaciolacustrine sediments in topographic lows between outcrops (Fig. 2a). Relief is

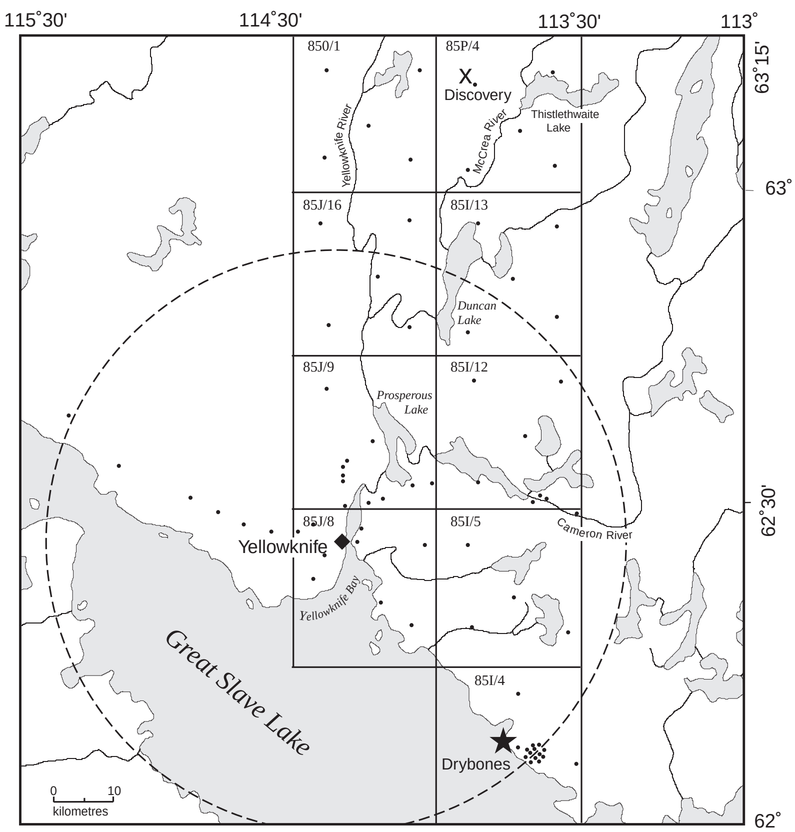

Figure 1.

Location of the study area and station locations (black dots); "X" represents Discovery mine while the star indicates the Drybones Bay kimberlite. A 50 km biogeochemical sampling radius from Yellowknife is also shown.

- ***a)*** *Extensive granitic outcrops east of Yellowknife, with glaciolacustrine sediments (covered by spruce) occurring in depressions associated with joints and fractures.*
- ***b)*** *Washed till veneer forming sandy gravel lag over bedrock, northwest of Duncan Lake. Note evidence of recent forest fire.*
- ***c)*** *Poorly sorted glaciofluvial deposits, northeast of Yellowknife. Note high concentration of rounded boulders on surface resulting from winnowing of fines by wave action.*
- ***d)*** *Large peat bog underlain by glaciolacustrine sediments, northwest of Yellowknife.*
- ***e)*** *Bedrock surface showing evidence of striae at 230° (upper section of photograph) crosscut by younger striae at 212° (lower section of photograph), north of Yellowknife.*
- ***f)*** *Glacially fluted granitic outcrops recording ice flow towards the southwest (right to left), east of Prosperous Lake.*

Figure 2. *Glacial features in the Yellowknife area.*

variable, commonly between less than 10 m and 30 m in areas of outcrop, although escarpments and steep rock ridges more than 50 m may be encountered in the central and northern regions of the study area.

The Yellowknife River is the principal drainage system, and its basin occupies much of the area under investigation; its southern outlet flows into Yellowknife Bay, Great Slave Lake. The northeastern region falls within the McCrea River drainage basin via Duncan Lake, whereas the east-central region is part of the Cameron River–Prelude Lake drainage system. The natural drainage around Yellowknife has been influenced by the bedrock structure, and numerous small elongated lakes have formed where weaker rocks have been preferentially glacially scoured along fault lines and joints. Most streams and rivers are shallow, and few have cut into bedrock or surficial sediments. The study area lies south of treeline, and supports open to dense forests of black spruce, jack pine, larch, trembling aspen, and paper birch mixed with marshes, fens, and peat bogs in low-lying areas. Yellowknife lies within the zone of discontinuous permafrost, where permafrost is localized or absent (Wolfe, 1998).

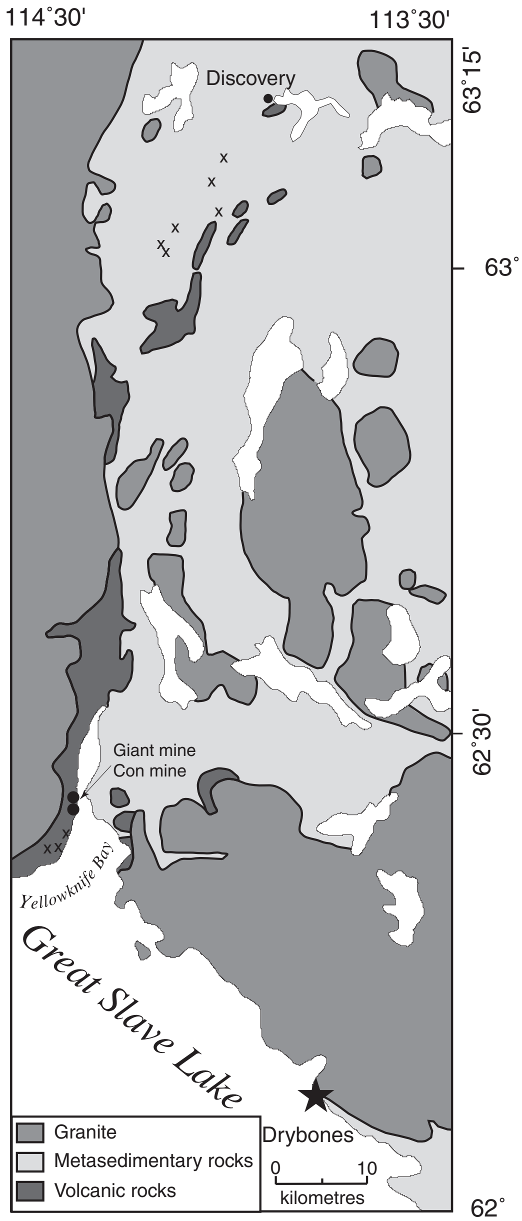

Figure 3. *Generalized bedrock geology and selected mineral deposits; small "x" represent mineral occurrences while the star indicates the Drybones Bay kimberlite; modified from Jolliffe (1942), Henderson (1985), and Stubley (1997).*

BEDROCK GEOLOGY

The bedrock in the Yellowknife area constitutes part of the southern Slave structural province of the Canadian Shield, and outcrops throughout all of the study area. Archean metavolcanic and metasedimentary rocks of the Yellowknife Supergroup are intruded by younger granitoid rocks (Fig. 3). The Yellowknife Supergroup contains greywacke, slate, schist, and phyllite in the east-central and northern map areas, and mafic to felsic volcanic rocks, including basalt, andesite, and pillowed flows of the north-trending Yellowknife greenstone belt (Jolliffe, 1942; Henderson, 1985) in the central regions. These have been intruded by widespread granitoid rocks consisting of granite, granodiorite, and tonalite to the west and southeast, as well as isolated intrusive bodies in the metasedimentary rocks to the north and east (Stubley, 1997). The region is crosscut by a variety of early Proterozoic diabase and gabbro dykes which trend northeast. Several major fault lines divide the volcanic rocks from the younger granitoid rocks, including the Kam Lake Fault and the West Bay Fault that run through Yellowknife.

A number of important mineral deposits occur within the Yellowknife area, notably two producing gold mines (Con and Giant), four past producers (Discovery mine), and numerous gold showings associated with the volcanic rocks. More recently, a kimberlite pipe has been reported in the Drybones Bay area, 40 km southeast of Yellowknife, as well as several to the north of the study area, in the Upper Carp Lake region (Armstrong, 1998).

SURFICIAL SEDIMENTS

Till

Although glacial sediments are common in the central and northern Slave structural province, the Yellowknife region is characterized by abundant bedrock outcrops which may cover up to 75% or more of a given area. Of the surficial sediments present, till is the most prevalent in the map area. It consists of a loosely compact, stony, matrix-supported diamicton, with the matrix ranging from coarse to fine sand with minor amounts of silt. Clasts of various lithologies range in size from small pebbles to large boulders, and are subangular to subrounded. Till is composed of up to 60% clasts, but most exposures have between 20% and 40%.

The till within the study area is generally less than 2 m thick, and forms a discontinuous veneer covering large areas containing small to large bedrock outcrops. Locally it is restricted to topographic depressions of variable depth between outcrops. In many instances, till is characterized by high concentrations of subrounded cobbles and boulders at the surface (Fig. 2b). At these locations, much of the fine-grained sediments in the matrix were removed by meltwater and wave action, resulting in lag deposits with variable textural characteristics. These deposits range in texture from coarse-grained and sand-rich diamictons, to massive, sandy gravel deposits to boulder gravels formed as beaches perched along the flanks of outcrops. Till is more extensive in the northern map area; in the central and southern regions, it has undergone greater postdepositional erosion and modification.

Glaciofluvial sediments

Glaciofluvial sediments are relatively uncommon, and consist of fine sand to cobbles in the form of eskers, kames, and subaqueous outwash (Fig. 2c). Eskers have a linear to slightly sinuous form, and generally trend parallel to the glacial flow direction defined by striae — southwest (Fig. 4). Their crests are rounded to flat-topped. Cobble and boulder lags may be associated with the top and sides of eskers. Eskers range from small ridges or mounds a few tens of metres in length, to larger systems up to 2 km long and 10–15 m high. Many eskers and kames are commonly flanked by meltwater corridors of boulder lags and washed and scoured bedrock zones several tens of metres wide. Meltwater channels carved in bedrock may also be found linking esker segments together, forming part of the subglacial drainage network. Subaqueous outwash plains deposited in proglacial lakes are rare but the large sand and gravel complex on which the Yellowknife airport is built, and the gravel pits to the east of the airport, may represent one such deposit which was subsequently reworked by wave action. Glaciofluvial deposits are potential resources for large volumes of granular materials, and can serve as airstrips to facilitate development, as was done in Yellowknife.

Glaciolacustrine sediments

A number of erosional and depositional features are derived from glacial Lake McConnell which formed in the Great Slave Lake, Great Bear Lake, and Athabasca Lake basins during deglaciation. Depositional features consist of poorly to moderately sorted coarse to fine sand, silt, and clay deposits estimated to be up to 20 m thick, with variable amounts of pebbles, cobbles, and boulders, occurring preferentially in topographic lows. Some of these sediments are laminated but do not appear to be varved, as also noted by Lemmen (1990) for comparable deposits south of Great Slave Lake. Stratigraphically, these sediments may overlie till, outwash, and bedrock. Finer grained sediments associated with deeper water environments may be overlain by sand and gravel representing fluvial or littoral deposits of a regressive sequence. Perched terraces and spits resulting from wave-reworking of eskers and kames, and wave-washed bouldery till surfaces occur up to 100 m (275–280 m a.s.l.) above present lake level, and as far as 70 km or more inland. Washed till surfaces are likely sources for poorly defined boulder beaches which may occur in close proximity to erosional features at the base of steeper slopes.

Organic sediments

Organic sediments consist of peat formed by the accumulation of fibrous, woody, and mossy vegetative matter up to 1 m thick or more in bogs and other wetlands in low-lying areas (Fig. 2d). Dense sedges, shrub cover, and open forests of stunted black spruce may overlie these sediments. They are present in topographic depressions and poorly defined water

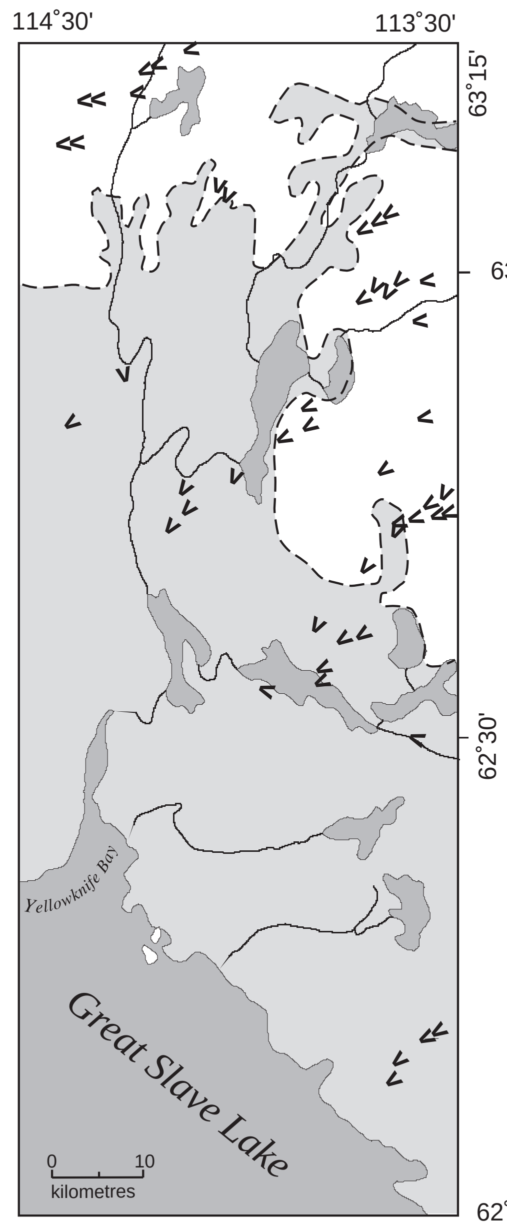

__Figure 4.__ Glacial drainage system as defined by eskers; estimated upper limit of glacial Lake McConnell (based on maximum elevation of 280 m) and its extent are shown (shaded area).

courses with imperfect drainage. In areas once submerged by glacial Lake McConnell, organic deposits may overlie fine-grained glaciolacustrine sediments. Frozen ground has been encountered at depths of 60 cm below the surface in late July.

ICE– FLOW PATTERNS

Figure 5 is a summary diagram of ice flow based on airphoto interpretation and striae measurements at 66 sites, as well as on regional observations made by Jolliffe (1942), Henderson (1985), Kerr (1990), and Boyce (1998) in the Yellowknife area. Ice-flow indicators throughout the study area are generally consistent with a dominant southwest flow across the region, with minor striae variations of less than 10°. In the northeastern and central-eastern areas, there are indications of a slightly west-southwest flow which gradually shifts to the more prevalent direction. Yellowknife Bay is characterized by a few examples of crosscutting relationships of striae, possibly due to the greater influence of topographic control over ice flow in this rugged area (Fig. 2e). In isolated localities, there is evidence of a south-southwest flow crosscutting a southwest flow. Faceted outcrops with angles up to 90° of each other were also observed at some locations within the City of Yellowknife, though no corresponding striae were noted. Large-scale ice-flow indicators such as crag-and-tail and fluted outcrops (roches moutonées) typically reflect the dominant southwest flow across the study area (Fig. 2f).

GLACIAL HISTORY

The last glacial episode to affect the study area was the Late Wisconsin glaciation, which reached its maximum extent about 18 000 years ago. During this period, the Laurentide Ice Sheet advanced to the southwest and eventually retreated towards the northeast. The Yellowknife region was ice covered to about 11 000 BP and became ice free by about 10 000 BP (Dyke and Prest, 1987). Ice-flow indicators relate to ice movement towards the southwest, as evidenced by striae in conjunction with the subparallel orientation of eskers. These are interpreted as representing the last phase of ice flow which occurred prior to and during deglaciation. Minor variations in local ice flow are likely the result of topographically controlled bedrock highs and lows as the ice sheet thinned and receded. Glacial Lake McConnell, a large ice-marginal lake, formed along the western margin of the retreating ice, and occupied the combined basins of Great Bear, Great Slave, and Athabasca lakes, up to an elevation of 280 m. Because this glacial lake was in contact with the ice front (Craig, 1965), the Yellowknife area was likely submerged by 80 m of water as the area was deglaciated. The large sand and gravel complex stretching eastward from the airport was deposited as a major subaqueous outwash system, formed on the lake floor in contact with the ice front. Westerly paleocurrent directions measured within this deposit (Aspler, 1978) are consistent with this interpretation. Given the regional context for deglaciation, it is unlikely that the airport complex represents braided stream deposits relating to a subareal environment following deglaciation and before the transgression of glacial Lake McConnell (Aspler, 1978). Great Slave Lake reached its present level of 157 m a.s.l. by about 8500 BP (Vanderburgh and Smith, 1988). Above the limit of inundation by glacial Lake McConnell, there is evidence of widespread washing of till and bedrock by meltwater which likely occurred during the easterly retreat of the ice front from the study area.

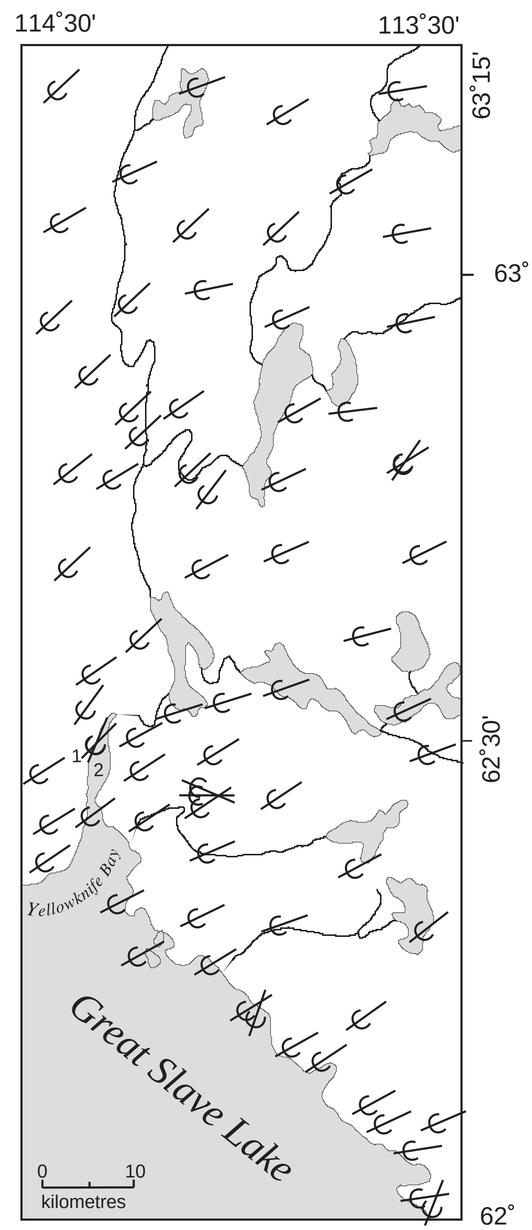

Figure 5. *Summary ice-flow diagram for the Yellowknife area; “1”= oldest, “2” = youngest.*

PEBBLE LITHOLOGY PROVENANCE STUDIES

To illustrate patterns of glacial dispersal and to estimate transport distances as an aid to mineral exploration, granitoid rocks were chosen as an indicator lithology over other bedrock types because of a clearly defined source area, and the ease at which granitoid clasts can be distinguished from metasedimentary and metavolcanic rocks. In the study area, the various bedrock lithologies form complex geological structures where lithological contacts are convoluted and irregular. These conditions are not conducive to regional provenance studies or well defined dispersal trains. Figure 6 shows the percentage (by count) and distribution of granitoid pebbles in till over the area. They occur at all of the 47 sample sites, with one exception.

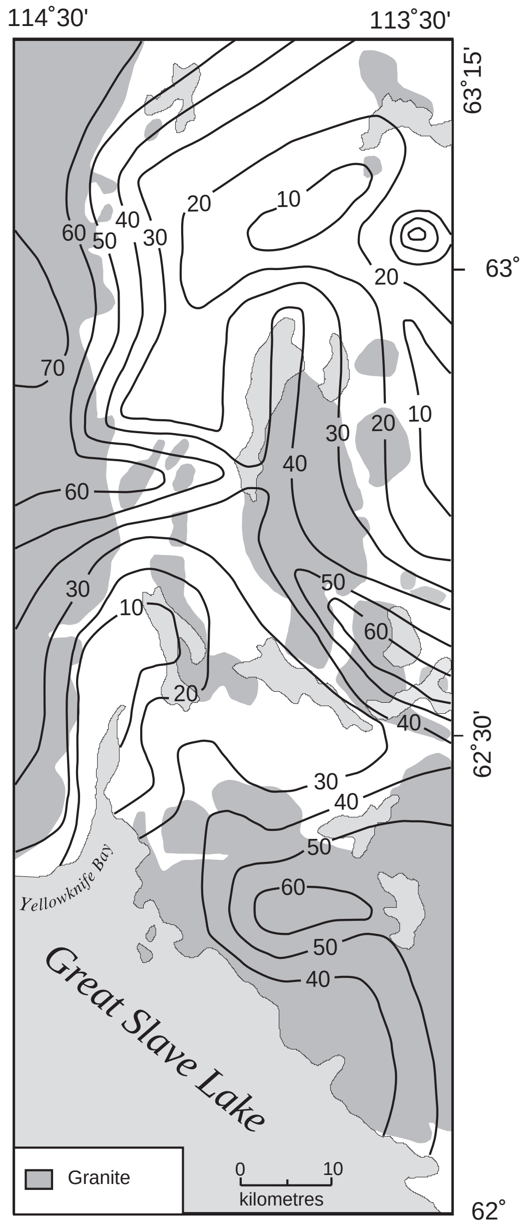

Figure 6. Clast lithology map showing contoured percentages of Archean granitoid pebbles in till. Granitoid bedrock represented by shaded area.

The highest concentrations of granitoid clasts (up to 72%) occur in three regions underlain by the largest granitoid bodies, the west-central, central, and the southeastern areas. Maximum granitic pebble contents of 69% and 64% decrease to 30% with increasing distance of transport over 7 km or more in the down-ice direction, even in areas where till cover is thin and granitoid outcrops are exposed for hundreds of square kilometres. Granitoid clast concentrations of up to 40% occur as much as 25 km down-ice (southwest) of their source, whereas some sample sites underlain by granite contain up to 70% metasedimentary clasts, indicating transport distances of 25 km or more. The dilution of granitoid clasts by metasedimentary and volcanic clasts likely resulted from the greater ease at which metasedimentary and volcanic rocks were glacially eroded in the up-ice direction, contributing to their abundance and dominance in certain areas underlain by granitoid bedrock. The observed clast distribution (Fig. 6) is likely the result of the last, dominant southwestward ice flow. The lowest concentrations of granitoid clasts in till (0 to <10%) are found overlying volcanic and metasedimentary rock, between Yellowknife and Prosperous Lake, and south of the Discovery mine. Changes in pebble composition can thus be observed along the path of ice flow, indicating that there is an overlap in pebble lithologies between adjacent bedrock types. The presence of granitoid clasts in the northeast quadrant can be attributed to granitic sources located up-ice, outside the map area. A typical or average glacial transport distance is difficult to ascertain because of the presence of far-travelled clasts. Some distinctive Proterozoic sedimentary erratics originate 125–150 km or more to the east and southeast. Because ice flow was generally from the northeast, it is likely that these erratics were ice-rafted during the early phases of glacial Lake McConnell.

ACKNOWLEDGMENTS

The authors would like to thank Indian and Northern Affairs Canada (INAC) for logistical support, as well as Great Slave Helicopters; Mr. David Smith for till samples and data from the Drybones Bay area; and the City of Yellowknife for access to certain sample sites. The authors would also like to thank R. Knight for drafting assistance, and P. Henderson for critical review.

REFERENCES

Armstrong, J.P.
1998: NWT kimberlite occurrence database; EGS 1998-113, NWT Geology Division, Indian and Northern Affairs Canada, Yellowknife.

Aspler, L.B.
1978: Surficial geology, permafrost and related engineering problems, Yellowknife area, part of 85J/8; EGS 1978-08, NWT Geology Division, Indian and Northern Affairs Canada, Yellowknife, text and one map, 16 p., scale 1: 6000.

Boyce, S.
1998: Overburden sampling report, Drybones 2 Mineral Claim; Unpublished NWT Geology Division assessment report, text and 3 maps, 7 p., scale 1: 50 000.

Craig, B.G.
1965: Glacial Lake McConnell, and the surficial geology of parts of Slave River and Redstone River map-areas, District of Mackenzie; Geological Survey of Canada, Bulletin 122, 33 p.

Dyke, A.S. and Prest, V.K.
1987: Paleogeography of northern North America 11 000 - 8 400 years ago; Geological Survey of Canada, Map 1703A, 3 sheets, scale 1:12 500 000.

Henderson, J.B.
1985: Geology, Yellowknife - Hearne Lake, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1601A, scale 1: 250 000.

Jolliffe, A.W.
1942: Yellowknife Bay, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 709A, scale 1: 63 360.

Kerr, D.E.
1990: Surficial geology of the Yellowknife River basin, parts of NTS 85 I, J, O, P and 86A; EGS 1990-03, NWT Geology Division, Indian and Northern Affairs Canada, Yellowknife, scale 1: 250 000.

Lemmen, D.S.
1990: Surficial materials associated with glacial Lake McConnell, southern District of Mackenzie; *in* Current Research, Part D; Geological Survey of Canada, Paper 90-1D, p. 79–83.

Stubley, M.P.
1997: Geological compilation of the Carp Lakes area, NTS 85P and southeastern 85O; EGS 1997-07, NWT Geology Division, Indian and Northern Affairs Canada, Yellowknife, scale 1: 250 000.

Vanderburgh, S. and Smith, D.G.
1988: Slave River delta: geomorphology, sedimentology and Holocene reconstruction; Canadian Journal of Earth Sciences, v. 25, p. 1990–2004.

Wolfe, S.A.
1998: Living with frozen ground. A field guide to permafrost in Yellowknife, Northwest Territories; Geological Survey of Canada, Miscellaneous Report 64, 71 p.

Geological Survey of Canada Project 990032DK