Solifluction processes are usually observed on slopes of 5 to 25 degrees as large lobate structures, the noses of which are outlined by abundant grasses, large shrubs and bushes. Where present, solifluction is generally thought of as a hindrance in geochemical data interpretation, particularly at the detailed stage, because in many instances it differentially displaces and fragmentizes soil anomalies (Levinson, 1974). It may displace soil, particularly surficial soil, considerable distances down slope (up to 600 feet: Pitul'ko, 1968) and consequently, anomalous soil commonly overlies non-anomalous soil and barren bedrock (Fig. 9c). Therefore, metal trends with depth should be considered where solifluction or other forms of down-slope movement are thought to be present. Conversely, because solifluction displaces geochemical anomalies, it may be thought of as a dispersal mechanism and therefore a possible aid, instead of a hindrance, by enlarging geochemical anomalies. However, although common in the periglacial environment, at Bathurst Norsemines solifluction is noticeable in only a few restricted areas where slopes are in excess of 10 degrees. Consequently, solifluction does not appear to significantly disrupt or aid the development of soil geochemical anomalies in this area. Likewise, at Yava Lake, 40 miles southeast of Bathurst Norsemines, Cameron (1977a) found solifluction processes to be of minor importance with soil displacement generally less than 30 feet.

3. History of geochemical exploration within the zone of continuous permafrost

Few papers have been published on the application of geochemical methods within the zone of continuous permafrost. Although many mining companies have made geochemical surveys, the information derived from these projects is largely held in confidential company reports. Only since 1970 have published reports in the West become available (Allan and Hornbrook, 1970). Until that time, the only available literature was by Russian scientists (Ivanov, 1966; Kozhara 1964; Pitul'ko, 1968). Canadian literature since Allan and Hornbrook's 1970 paper totals less than 20 articles covering a wide variety of sampling programs and techniques utilized in the N.W.T.

Most literature has been concerned primarily with the feasibility of geochemical methods and with providing a data base for future programs. Although intense physical weathering has been documented and widely accepted for some time (Price, 1972; Tricart, 1970) chemical weathering and ionic mobility, were thought until recently, to be severely limited. However, Kozhara (1964) assessed the relative importance of chemical weathering by comparing ion runoff between rivers flowing within areas underlain by permafrost and those within a more temperate climate. The resulting values from rivers within the permafrost zone were fully commensurate with known figures for the Volga and Dnepr rivers in temperate central Russia.

Shilts (1973a, 1974b) and Cameron (1977a, b) also believe chemical weathering to be intense. From his observations in the Northwest Territories, Shilts concluded that within the active layer labile minerals (e.g. sulphides and carbonates) are completely destroyed and weathering products such as iron and manganese oxides, along with clays, are moved via cryoturbation towards the soil surface. These weathering products are subsequently deposited along drainage paths via snow-melt runoff or heavy rains.

The realization that chemical weathering is intensive and that movement of ions via drainage paths does occur has led to successful application of hydrogeochemical methods in arctic Canada (Cameron and Ballantyne, 1975; Allan, 1974b) and in the U.S.S.R., where hydrogeochemistry is used extensively in exploration programs (Shvartsev, 1971).

Allan (1971), in a pioneering study of lake waters and sediments, found a density of one sediment sample per 10 square miles sufficient over a 1500 square mile region in the Coppermine River area, N.W.T., to delineate areas of copper mineralization associated with faulted basaltic flows. However, the possibility exists that the patterns Allan obtained may reflect mechanical rather than chemical dispersion processes because near-shore sediments, where the water depth was generally less than five feet, were collected. Nevertheless, most of Allan's sediments were composed of silt and were not located near any obvious inflowing or outflowing streams. Consequently, the geochemical patterns are thought to reflect a significant degree of chemical weathering and hydromorphic dispersion. Further evidence of this is provided by a strong positive correlation between the copper content of anomalous lake waters and sediments.

Cameron et al. (1974b), in an extensive investigation in the eastern Slave Province, also found near-shore lake sediments at a density of one sample per 10 square miles effective in delineating areas containing massive sulphide occurrences. However, Cameron in follow-up studies in 1975 and 1976 (Cameron, 1977a, b), found center-lake sediments a better sampling medium than near-shore sediments. A companion study by Cameron and Ballantyne (1975) of the same region utilizing lake waters showed this medium to also be useful in detecting massive sulphide occurrences. Results from these studies showing the relationship of Zn in lake waters, near-shore and center-lake sediments as a function of pH and distance from the Agricola Lake massive sulphide prospect are shown in Figure 10. Boyle et al. (1971) also found lake-water sampling for the mobile elements Cu, Zn and Ni, an effective regional reconnaissance method in the Kaminak Lake region, N.W.T.

Hydrogeochemistry has been critized as an exploration tool because of: 1) temporal variation in water chemistry, 2) dissolved metal concentrations are often near the detection limit of most analytical methods, and 3) samples are bulky and pre-analytical treatment including filtering, acidifying and concentration of trace metals is often required (Hoffman, pers. comm.; Cameron and Ballantyne, 1975). However, many of these drawbacks appear to be insignificant when hydrogeochemical methods are used for locating volcanogenic massive sulphides within the continuous permafrost zone. In particular, temporal variations in lake-water chemistry and pre-analytical treatment such as filtering and acidifying appear to have little effect on the overall results as emphasized by Cameron and Ballantyne (1975) and Cameron (1977b). The overall homogeniety of trace element levels in lake waters, compared to the marked variation that can occur within sediments in a lake, suggests that lake waters may be a very useful medium for regional reconnaissance surveys.

With respect to other reconnaissance sampling media, Shilts (1973a, 1974a) has advocated the use of the clay-size

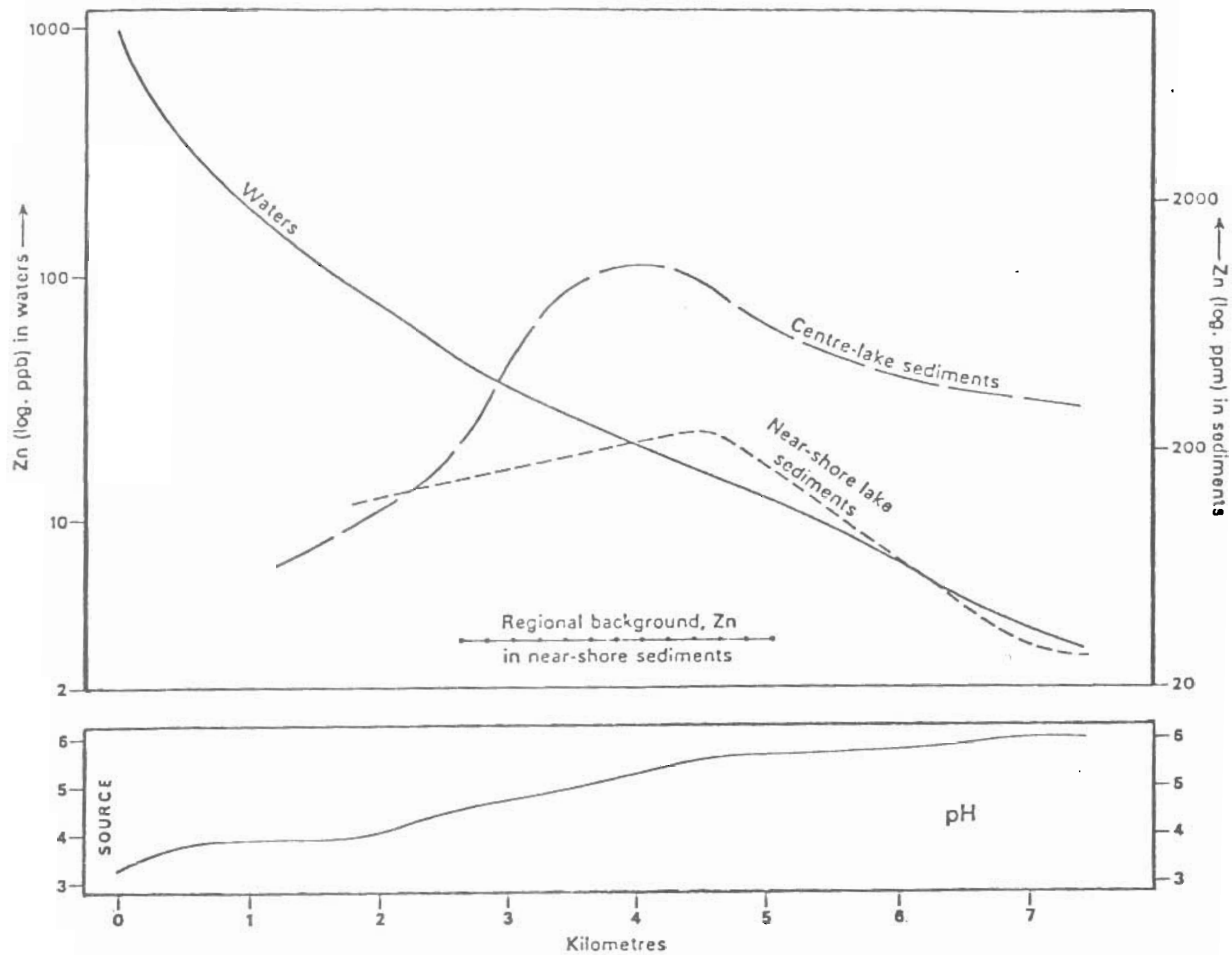

Figure 10. Dispersion of zinc in lake sediments and waters from the Agricola Lake massive sulphide prospect (from Cameron and Ballantyne, 1975).

fraction (< 2μ) in soil reconnaissance surveys. This recommendation was based on the need to reduce erratic results caused by variable quantities of fine sand and silt in the minus 80-mesh fraction. Use of the relatively homogeneous clay-size fraction takes advantage of the ability of clays and associated colloids to scavenge trace metals. However, separation of the minus 2μ fraction is tremendously time consuming and expensive and, therefore, unsuited for rapid processing of large numbers of geochemical samples. Although Shilts found eskers to be a better sampling medium than till (circles), because of the ease of sampling, consistency of sampling and higher contrast, it was concluded that because eskers have limited and erratic distribution they may only be suitable for broad reconnaissance. However, to be effective even for broad reconnaissance they would have to be sampled at very short intervals because of their segmented character.

Allan (1973) also compared till and esker sampling, along with stream sediments, over the Ragland deposit, Ungava, Quebec and found them all to be useful media, although esker sampling was the least satisfactory in outlining the Ni-Cu ore bodies. Till sampling, at relatively high densities (intervals of 200 ft.) in anomalous areas outlined by stream sediment or esker surveys, defined areas of interest more precisely. Similar results were obtained at Coppermine River, N.W.T. where it was found that Cu mineralization could be defined best regionally by lake water, semi-regionally by stream sediments and in detail by till (circle) sampling on a 200 x 100 foot grid (Allan, 1971).

Cameron and Durham (1975) and Cameron (1977a) also found circle sampling very effective in outlining the Agricola Lake Cu-Pb-Zn prospect, 40 miles southeast of Bathurst Norsemines. Although geochemical patterns are 'smeared' down ice for more than 1000 feet, Pb anomalies (unlike Cu and, in particular, Zn) are well developed with values over 5000 ppm contrasting sharply with non-anomalous levels of 15 to 30 ppm.

Allan and Hornbrook's (1970, 1971) findings concerning the importance of circle sampling, on a detailed scale, follow those of Pitul'ko (1969), in that, if samples are taken at the same depth from circles and from undisturbed till, the former will usually exhibit higher geochemical contrast due to the effects of cryoturbation.

One important aspect of exploration geochemistry which appears to have been neglected almost totally in studies of geochemical dispersion within the zone of continuous permafrost is the use of partial extractions to identify and characterize geochemical anomalies. In view of the probable importance of hydromorphic dispersion this is particularly surprising. Consequently, in this thesis several extraction procedures have been investigated in order to provide information on both dispersion processes, and as a means of improving anomaly contrast.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

I LOCATION AND ACCESS

The Bathurst Norsemines property is in the District of Mackenzie, N.W.T. (Fig. 11), at approximately 65°55' north latitude and 108°25' west longitude (NTS coordinates 76/F-16). No trails or roads lead to the area and access is by aircraft from Yellowknife, the main supply center 300 air miles to the southwest. Break up of the ice occurs in mid to late June and makes access to the property difficult at this time.

Field studies were centered on Camp Lake, over the A or Main Zone, and at Anne-Cleaver Lakes along the "mineral horizon" within a large block of claims held by Bathurst Norsemines. However, discussion will be confined largely to geochemical dispersion at Camp Lake (Main Zone). Data for Anne-Cleaver Lakes are included, however, in Appendix B.

II CLIMATE, TOPOGRAPHY AND DRAINAGE

Due to its remoteness, climatic data are lacking; however, a weather station is maintained at Contwoyto Lake, approximately 100 miles to the southwest. Table 1 summarizes climatic data from this station (Penny, pers. comm. Vancouver Climatology Office) and supplementary sources. This area,

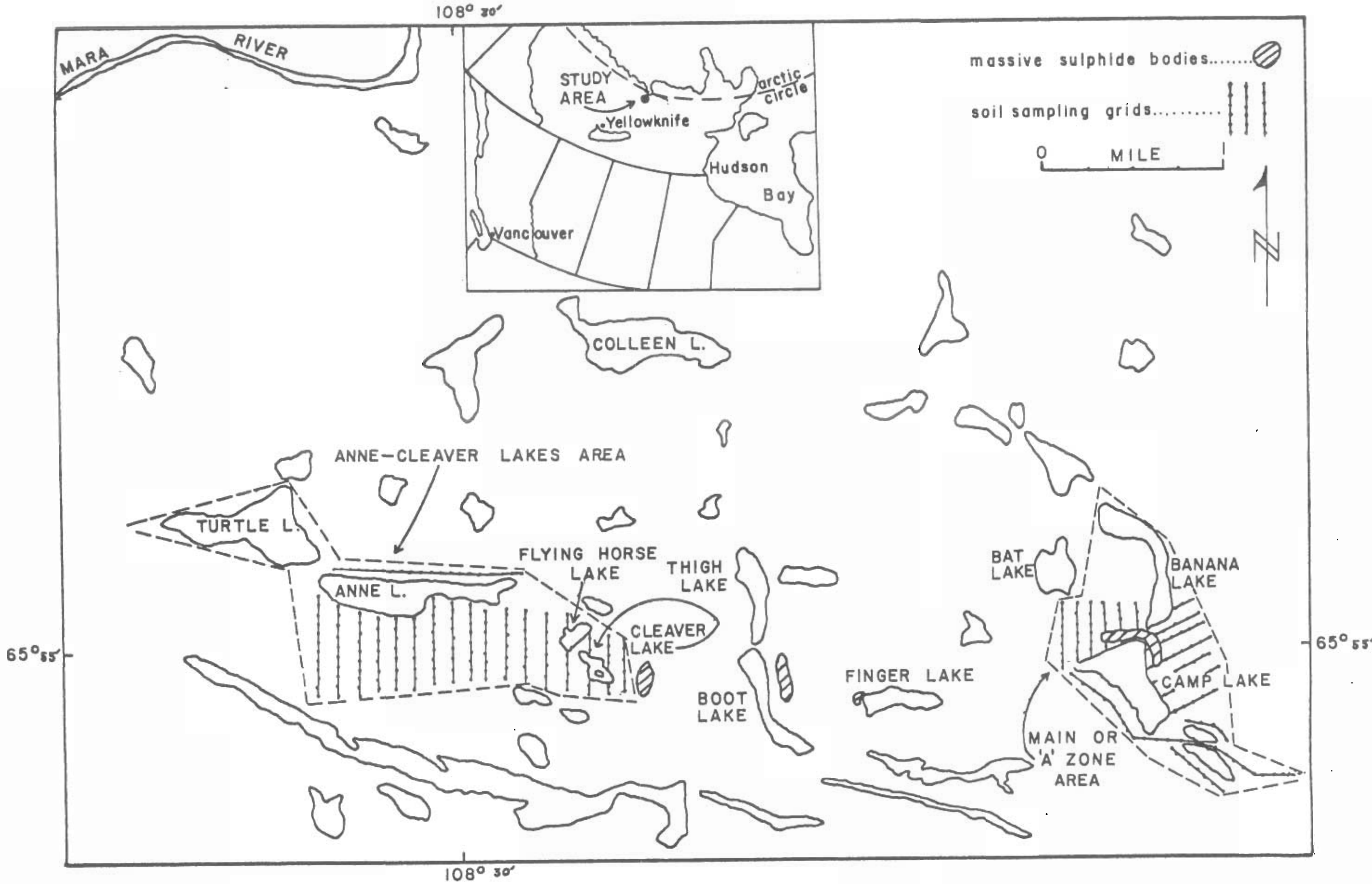

Figure 11. Location of study areas and massive sulphide bodies.

Table 1. Climatic data[1] from Bathurst Norsemines and Contwoyto Lake, 100 miles to the southwest.

	Metric	English
Mean annual air temperature (M.A.A.T.)	-12.5°C	10.3°F
Mean annual ground temperature	- 7.1°C	19.0°F
January mean air temperature	-31.0°C	-23.9°F
July mean air temperature	9.0°C	48.2°F
Total mean annual precipitation	27.6 cm	10.8 in.
a) rain	14.5 cm	5.7 in.
b) snow	131.0 cm	51.2 in.
Average number of days of precipitation per year	130	130
Active layer thickness (estimate)	1.5 m	4.9 ft.
Permafrost thickness[2]	500.0 m	1640.0 ft.

1: Based on observations made between the years 1959 to 1970. Data supplied by Penny, Vancouver Climatology Office, Canada.

2: Data from Bathurst Norsemines property, courtesy of the Department of Energy, Mines and Resources, Ottawa, Canada.

because of low precipitation (10 to 11 inches per year), may be considered to be an arctic desert with very thick permafrost (>1600 feet).

Despite low precipitation, the combination of low temperature over much of the year with subdued topographic relief (50 to 200 feet) has resulted in water being retained in numerous lakes, ponds and swamps which comprise some 30 percent of the surface area (Plate 5). The remaining surface consists of gently rolling boulder strewn hills and flat, relatively boulder-free, lowlands ranging from 1300 to 1500 feet elevation. Well developed streams are rare because of the subdued topography and most of the lakes and ponds have no visible outflows or inflows. However, possible drainage paths may be inferred from a comparison of lake elevations (Fig. 12, cf. Cameron and Ballantyne, 1975).

III GENERAL GLACIAL HISTORY AND SURFICIAL GEOLOGY

A. Bathurst Inlet

Evidence of Pleistocene glaciation is well documented (Craig, 1960; Blake, 1963; Tremblay, 1971). Numerous erratics, eskers, kames, outwash deposits, drumlins and bedrock striae occur throughout the region. However it is unclear whether there were multiple glaciations (Blake, 1963; Tremblay, 1971) or a single glacial event (Craig 1960)

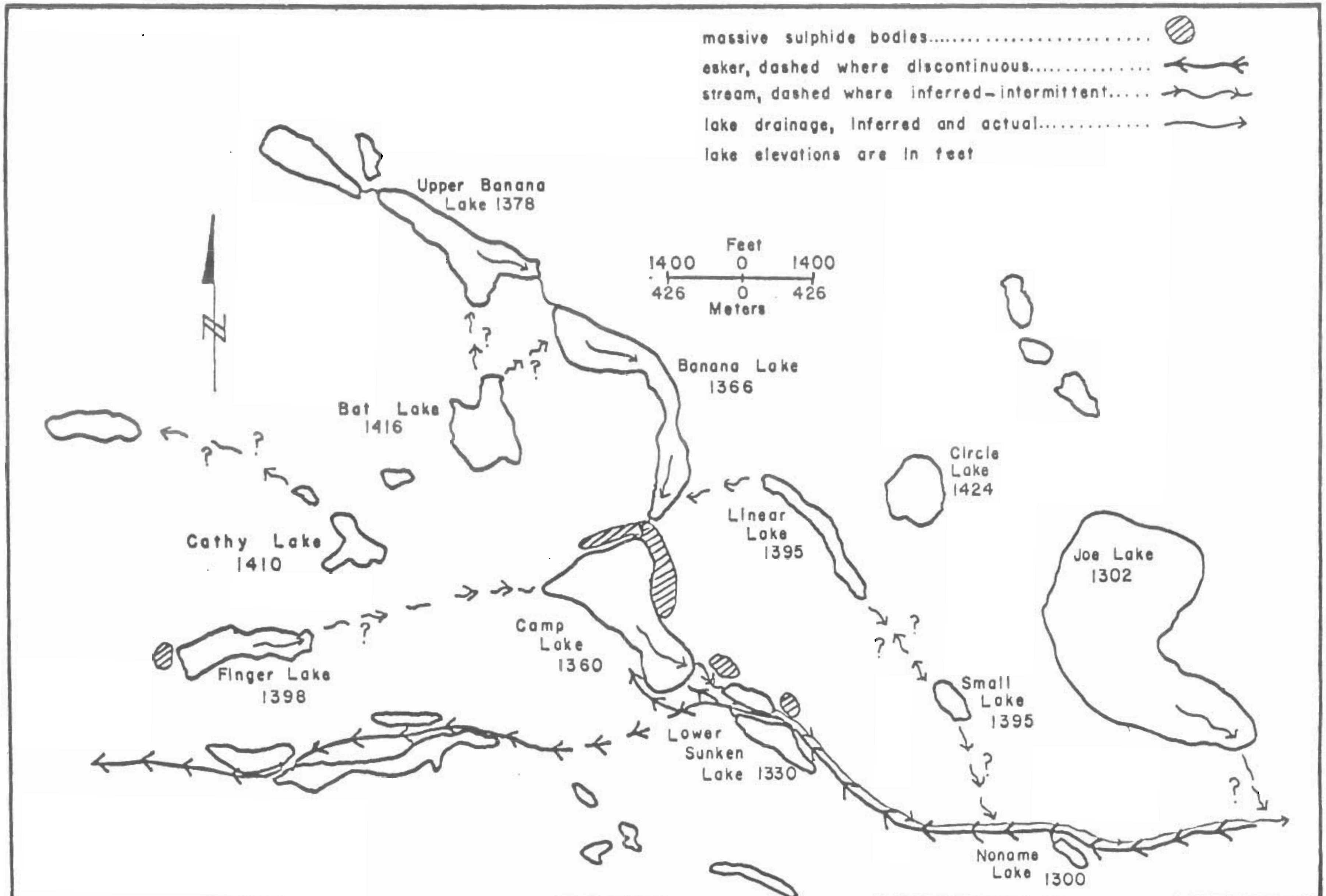

Figure 12. Inferred drainage paths based on airphoto interpretations, field observations and a comparison of lake elevations (cf. Cameron and Ballantyne, 1975).

at Bathurst Inlet. Nevertheless, Craig and Blake (op. cit.) have both established that ice movements in the region were bimodal (Fig. 13). This discontinuity in the flow pattern is believed by Blake to have resulted from a funneling effect, and consequently more rapid flow, through the Bathurst Trench relative to the less active or stagnant ice of the plateau (Tremblay, op. cit.). This resulted in northwesterly ice movement within the Trench and west-southwesterly movement west of the Trench. Consequently, because the study area lies along the Trench-plateau margin, an area of glacial flow transition, measurement of striae within the study area show a bimodal distribution (Fig. 14) consistent with the principal regional trends established by both Blake and Craig (op. cit.).

As the ice retreated eastward from the Bathurst region, glacial sediments were deposited. Till cover is generally thin, 6 to 25 feet, except in bedrock valleys. Most of the till is probably a lodgement or basal till deposit with only minor amounts of ablation till (Scott, 1976). The till is generally compact, bouldery and difficult to penetrate with hand tools. Boulders and cobbles, which comprise approximately 20 to 40 percent of the till, are subangular to subrounded, with the exception of erratics, which are generally rounded to well rounded.

Eskers, prominent features of the region, occur at 8

Figure 13. Measurements of generalized glacial flow directions in the Bathurst Inlet region (from Blake, 1963).

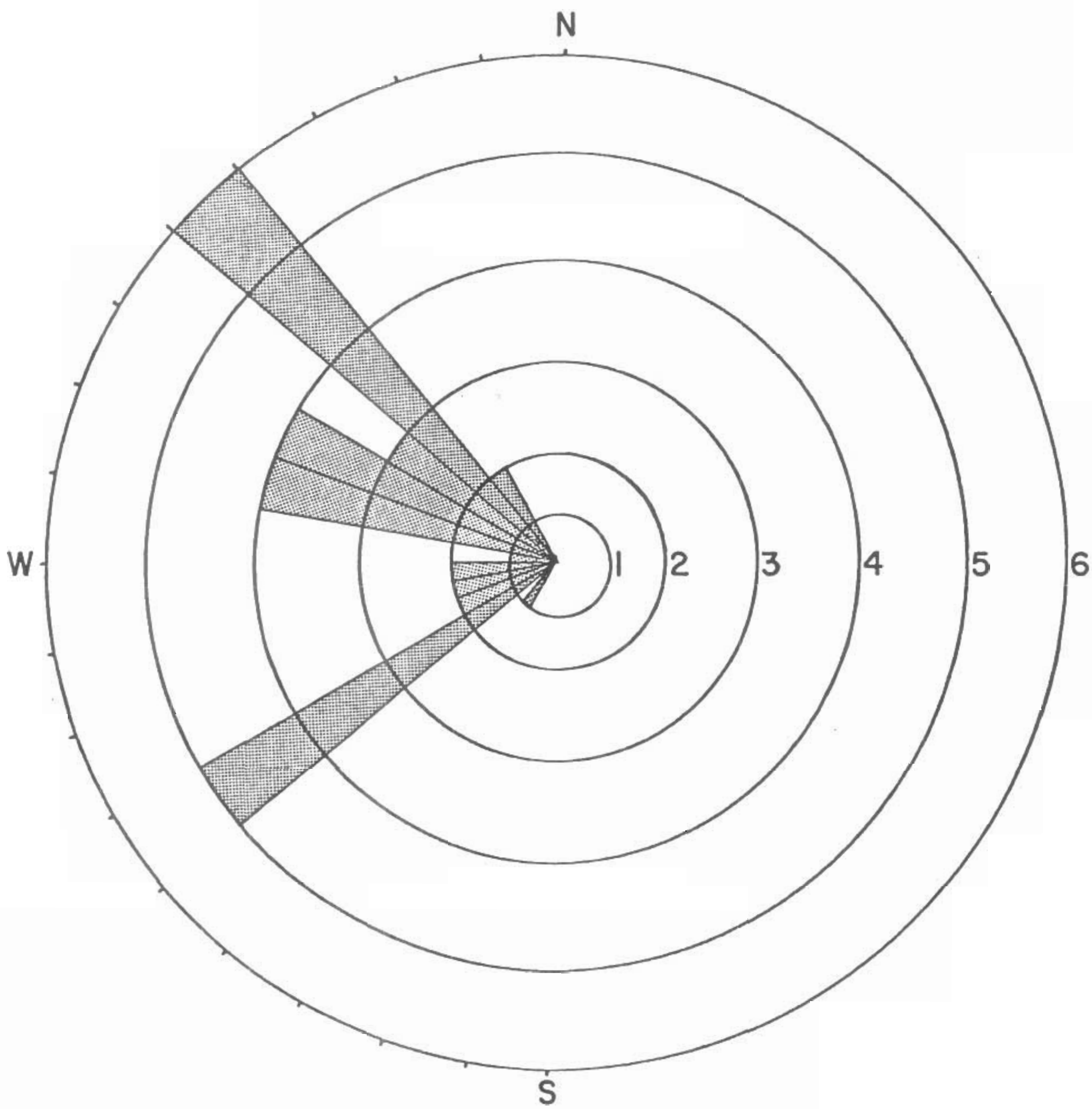

Figure 14. Distribution of 32 measurements of glacial direction movements at Bathurst Norsemines.

to 15 mile intervals and generally parallel the glacial flow direction. They are fairly continuous over several miles and in some cases extend in excess of 25 miles in an unbroken chain. Kames, deltas, outwash deposits and scoured bedrock surfaces are associated with eskers and/or present day drainage paths. Drumlins are also common features of the Bathurst region, while end moraines are not recognized. Since the development of end moraines is most likely during pauses or slight readvances in the overall course of ice recession, their absence is attributed to a relatively uniform and rapid retreat of the ice mass.

Two other common features of the area are the presence of well exposed bedrock and blockfields (felsenmeer). Also noted is the occurrence of boulder fields and/or trains which can be distinguished from blockfields by a lesser degree of angularity and a more direct relationship with glacial quarrying, i.e. boulder fields are largely glacially derived whereas blockfields are largely the result of in situ frost weathering of the underlying bed-rock. In general blockfields occur on relatively flat ground and are well defined even though they may be irregular in plan.

Blockfields consist of angular to subangular blocks 1.5 to 7.0 feet in diameter with virtually no matrix of finer soil or rock. Blockfields may cover large areas or be relatively restricted to a few thousand square feet. Since blockfields generally arise from in situ weathering by frost riving and heaving of the underlying bedrock, a well jointed or fractured bedrock surface where water may accumulate and freeze is most conducive to their development. Alternatively, because some blockfields contain erratics and/or rounded boulders, they are thought by some (Bird, 1967) to have resulted from the washing out of fines from a boulder-rich till. However, at Bathurst Norsemines the blockfields, based on lithology, geochemical patterns and lack of nearby glaicofluvial deposits, are believed to have resulted from in situ frost heaving and, to a lesser extent, glacial quarrying from very nearby bedrock projections.

B. Glacial Geology of Camp Lake

Several units of glacial sediments have been defined with till, esker, esker delta, kames and outwash deposits most easily identified. However, for convenience, glaciofluvial deposits (e.g. esker, kames, etc.) have been combined (Fig. 15). Glaciofluvial deposits occupy much of the area around the southeast corner of Camp Lake. Although the esker complex continues for many miles east and west of Camp Lake, it is particularly well developed over a one mile length southeast of Camp Lake (Plate 16). Based on the orientation of the esker delta, the internal structure of the esker sediments (observed in pits and trenches), aerial photographs, and the general glacial history of the area, sediment transport within the esker is judged to have been dominantly westward. Associated with these undifferentiated glaciofluvial deposits, particularly southwest of Camp Lake, is an area, 2000 to 6000 feet wide, of scoured bedrock produced by glacial meltwaters during ice recession (Plates 15 and 16).

Two well defined areas of boulder accumulations were mapped north of Camp Lake (Fig. 15). The one closest to the lake is cigar shaped, oriented east-west and lies between the two (?) glacial flow directions (Fig. 14). It contains numerous sulphide-bearing boulders, which are similar to and down ice from mineralized outcrops west of the Banana-Camp stream (B-C stream). A strong Pb anomaly (Fig. 40) associated with this boulder accumulation can also be traced to mineralized outcrops west of B-C stream. Consequently, this boulder accumulation is likely to have been largely glacially derived (via glacial corrosion) from these outcrops and/or nearby sub-outcrops and is therefore termed a boulder field or train.

The other boulder accumulation lies several hundred feet to the north, is more irregular and contains only a very few sulphide-bearing boulders (between site numbers

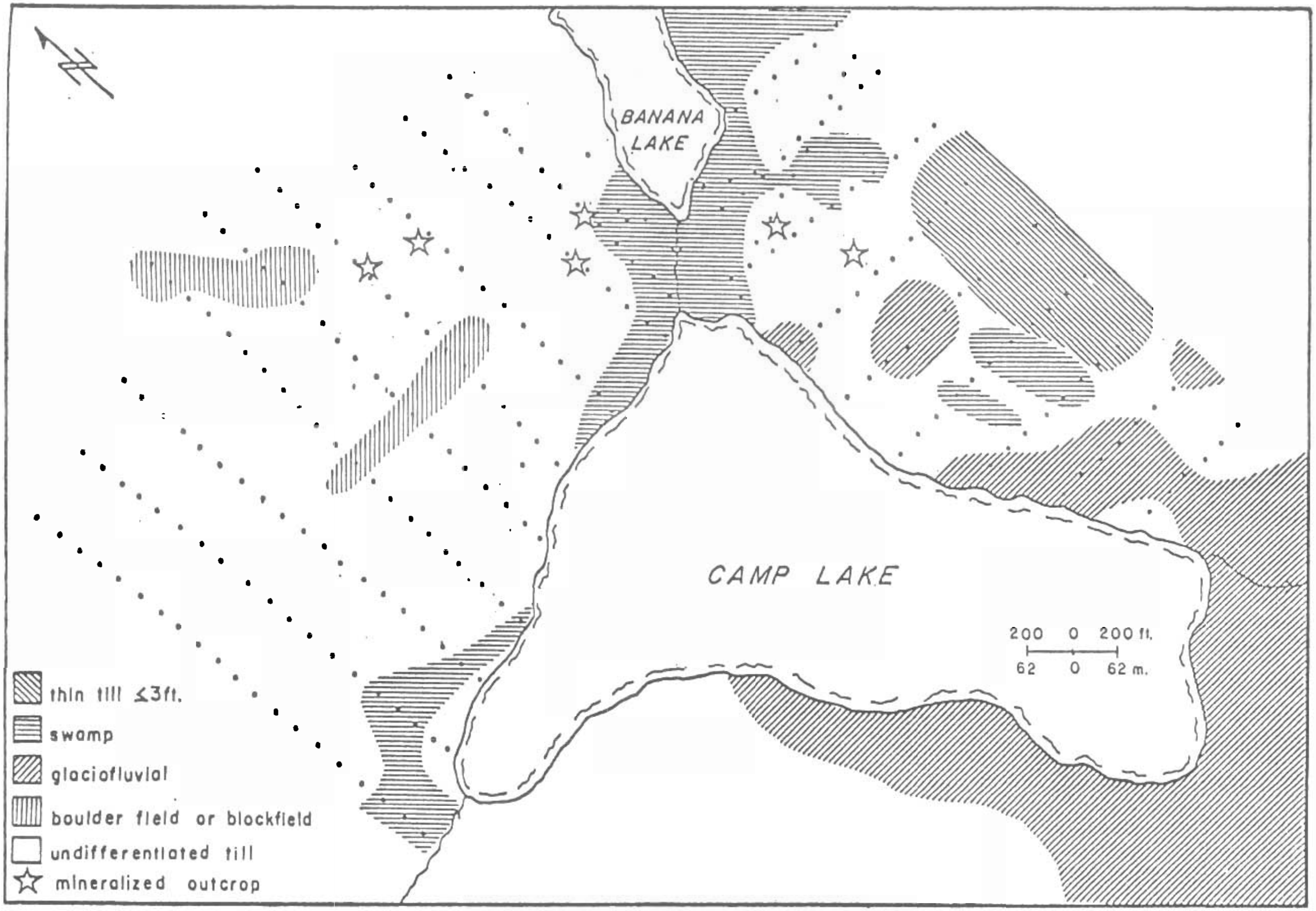

Figure 15. Generalized surficial geology and environment map.

60 and 76, see Fig. 19). Although it parallels a glacial flow direction (WNW), and is down ice from mineralized outcrops, this boulder accumulation probably originated in large part by frost heave because most of the boulders are angular and appear to be of local origin. Furthermore, geochemical patterns crosscut this boulder accumulation suggesting that, for the most part, it has not been derived from mineralized bedrock located up ice but has instead been derived from the underlying non-mineralized rock. Consequently this boulder accumulation is considered to be a blockfield.

Sulphide-bearing boulders were also noted near soil sampling site numbers 13, 14, 17, 19 and 64. Associated with these boulders are strong, well developed Pb anomalies (Fig. 40) which can be traced to mineralized outcrops near B-C stream. Based on geochemical patterns, it is suggested that these sulphide-bearing boulders were all derived from the vicinity of mineralized outcrops adjacent to B-C stream.

On the basis of field observations and diamond drill holes the till at Camp Lake is boulder and cobble rich and averages 10 to 20 feet thick. There may be some correlation between till thickness and the percentage of boulders. Thinner till is generally more boulder rich because of the ease with which frost heaving of blocks from underlying bedrock can occur; thicker till (10 to 15 feet) reduces