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CHAPTER 1

INTRODUCTION TO EXPLORATION GEOCHEMISTRY IN PERMAFROST TERRAINS

I THESIS OBJECTIVES

Geochemical investigations of metal dispersion in soil, water and sediment were conducted over and adjacent to volcanogenic massive sulphide deposits at Bathurst Norsemines in the District of Mackenzie, N.W.T. The area lies within the zone of continuous permafrost. Particular attention has been given to:

1) Defining spatial distributions of trace elements in soil, sediment and water and their relationship to mineralized zones.
2) Assessing the significance of glacial-periglacial phenomena upon dispersion patterns and ion mobility.
3) Determining the most appropriate sampling medium and method in terms of exploration.
4) Defining the mode of metal occurrence within the various sample media.
5) Identification and characterization of geochemical anomalies using various partial extractions and statistical methods.

In the course of this study, more than 1400 soil, 200 water and 100 sediment samples were collected. Over 24,000 analytical determinations were conducted on these samples in an effort to achieve the above objectives.

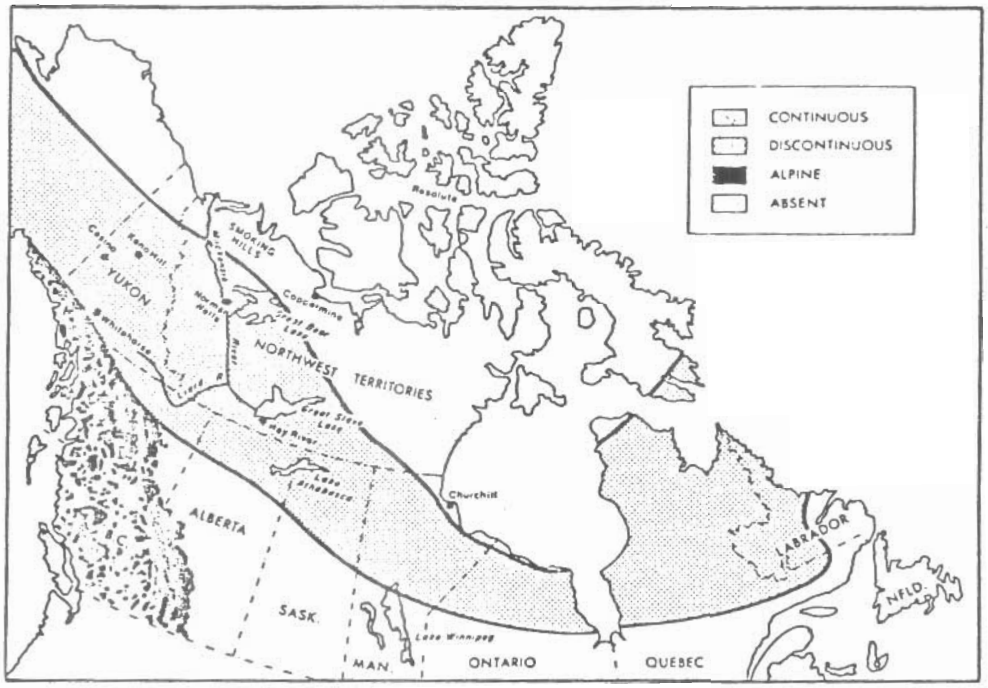

Figure 1. Distribution of permafrost in Canada.
Modified from Brown and Péwé (1973).

The active layer is the zone above permafrost which freezes and thaws annually. It is directly underlain by permafrost except in the discontinuous zone where it may be separated from permafrost by an intervening talik (Price, 1972; Fig. 2). It is relatively thin, 1.5 to 4.0 feet, in the far north but increases to about 12 feet near the southern boundary of discontinuous permafrost. In Canada, the active layer typically consists of an acidic, cold, wet, and rocky till. Soil profile development is minimal and Gleysolic and Regosolic soils dominate (Price, 1972; Brown 1970; Tarnocai, 1977). Furthermore, substantial frost action, especially cryoturbation, has mechanically differentiated the upper portions of the active layer into sorted and non-sorted features characteristic of patterned ground (e.g. circles, nets and stripes; Washburn, 1972). Almost all soil sampling in arctic Canada is done in the active layer, therefore, its effective use as a sampling medium necessitates an understanding of periglacial processes.

Although there are many types of periglacial phenomena (Washburn, 1956, 1972) the most relevant to exploration geochemistry are circles, sorted and non-sorted, and solifluction lobes. Circles are known by many names (e.g. mud boils, frost boils, frost scars, tundra craters, medallion patches, etc.). They are diapiric structures, 1.0 to 8.0 feet in diameter, which are thought to be produced by

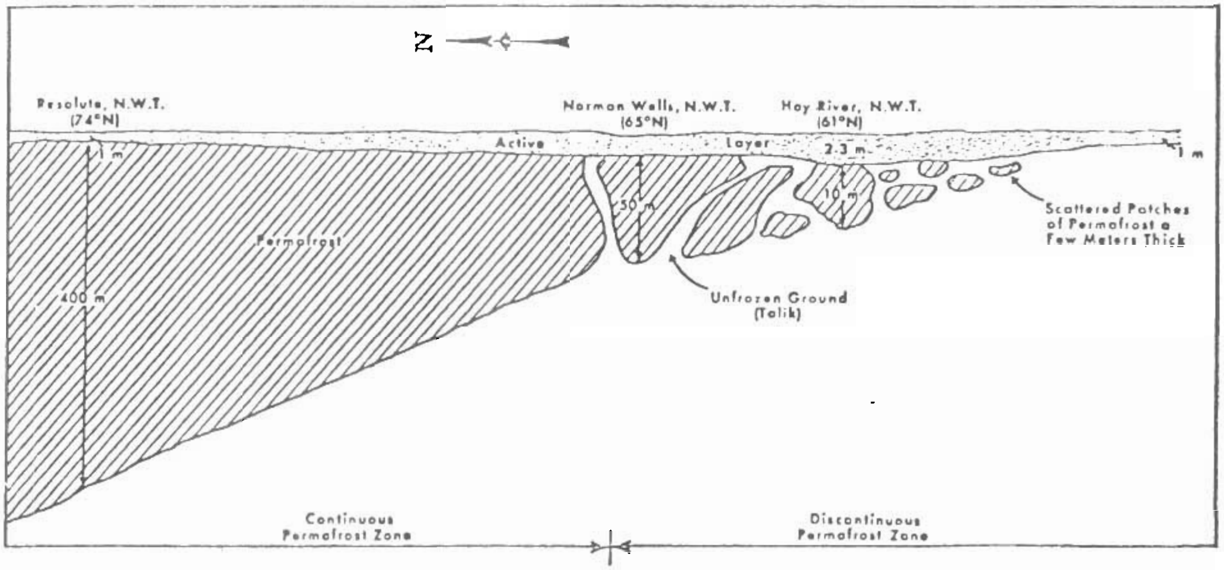

Figure 2. Idealized cross section of permafrost from the Arctic Islands to northern Alberta. Note that the active layer is deepest in the subarctic (e.g. Hay River, 61^{o}N) and decreases in depth north and south of this zone. Also note that the active layer can be separated from permafrost by an intervening talik (adapted from Price, 1972).

differential freeze-thaw (Corte, 1962) and/or pressures caused by hydrostatic or cryostatic conditions (Shilts, 1973a, Fig. 3). Generally, they are restricted to low angle slopes and, at Bathurst Norsemines, heaving and extrusion of silty material was observed to occur early in the summer when the active layer is most saturated with water (Plates 1 to 3). Following observations in the Mackenzie delta, by Mackay and MacKay (1976) it is suggested that hydrostatic rather than cryostatic processes are a more likely mechanism of frost boil generation (Fig. 4).

Solifluction or gelifluction is the slow (one to two inches per year), viscous, down-slope movement of waterlogged soil and other unsorted and saturated surficial material (Price, 1972; Highashi and Corte, 1971). Although soil creep and mass movement may be important components of solifluction (Fig. 5), the solifluction process is distinguished by higher soil moisture, differential soil movement, which often produces lobate structures, and a more restricted period of activity, generally in early summer when water is most available. Solifluction is best developed on slopes of 5 to 25 degrees where it generally manifests itself as large lobes, one hundred to several hundred feet in strike and two to four feet in height, which may coalesce forming a crenulated pattern. Solifluction can also occur on slopes of only two or three degrees, but is generally more subtle and re-

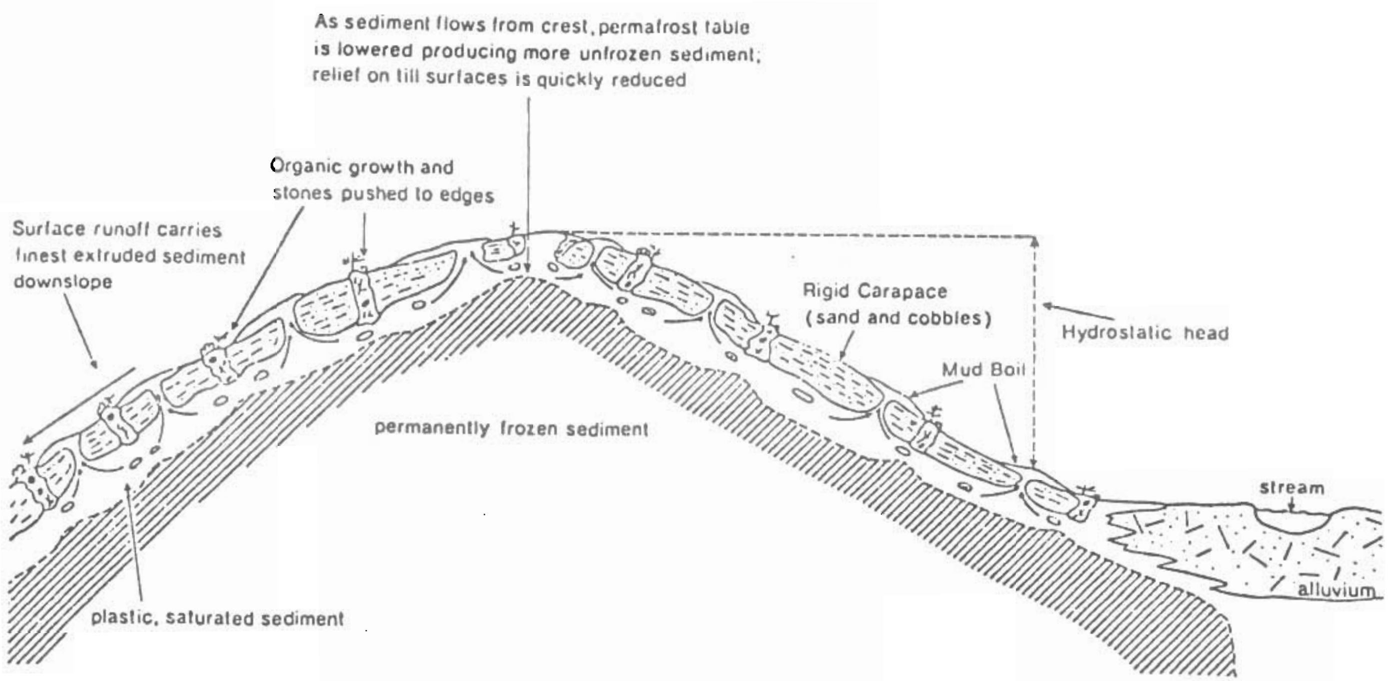

Figure 3. Idealized diagram depicting a possible mode of origin for circles (from Shilts, 1973a).

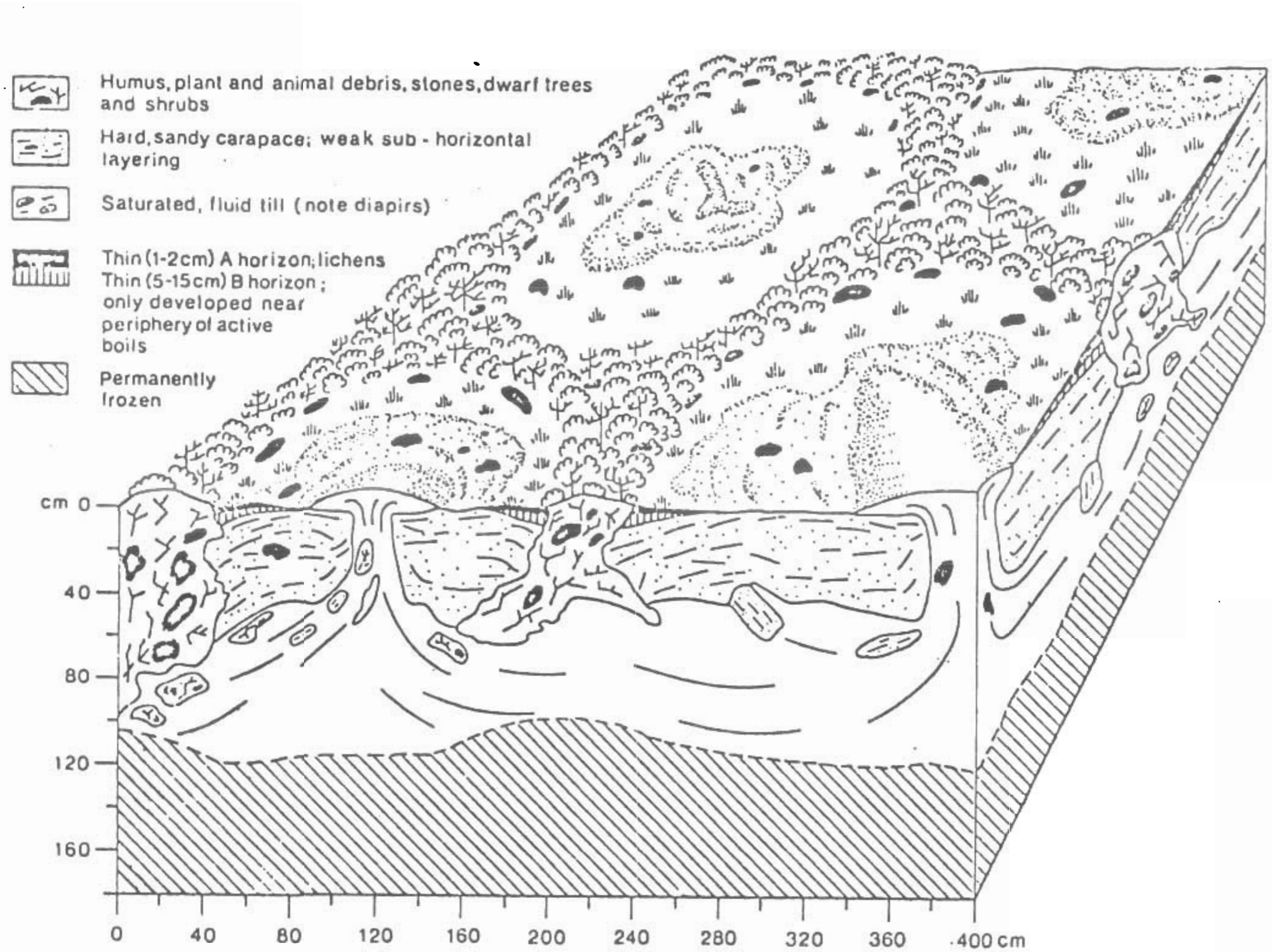

Figure 4. Block diagram of circles showing typical components and their spatial relationships (from Shilts, 1973a).

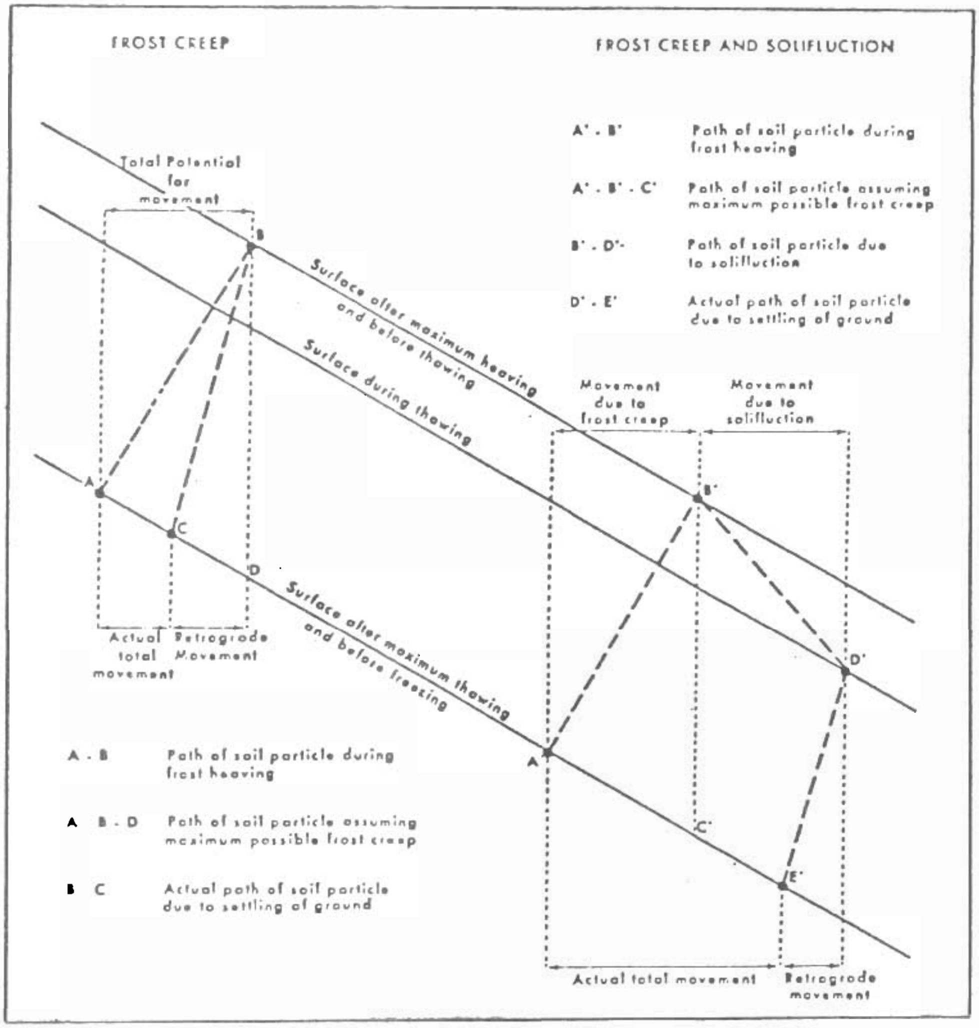

Figure 5. Relationship between frost creep, solifluction and retrograde movement (adapted from Price, 1972).

stricted. On slopes greater than 25 degrees water is quickly lost as runoff which carries away the finer soil. Because fine soil and high moisture contents facilitate solifluction development, the loss of both fines and water severely limits solifluction development on such slopes.

B. Climatic Influences

Since permafrost is a function of climatic conditions, systematic climatic changes over many years or hundreds of years will cause permafrost and active layer thicknesses to fluctuate (Gold and Lachenbruch, 1973; Bryson et al., 1965); however, such effects in terms of geochemical dispersion, have not been reported. It is suggested, therefore, that long term oscillations of the mean annual air temperature (M.A.A.T.) allow relatively unweathered permafrost material to be subjected periodically to intense chemical and physical weathering characteristic of the present active layer and, if cryoturbation is sufficient, incorporation of former permafrost material into the upper portion of the active layer may occur. Furthermore, an increase in the M.A.A.T. may result in longer periods of thaw and more intense chemical and biological activity; conversely, a decrease in the M.A.A.T. is thought to inhibit dispersion processes. Such long term climatic fluctuations are thought to be recorded in lake sediments as variations in sediment texture, trace element composition and organic matter content (cf. Karrow and Anderson 1975), which are subjects considered in Chapters 4 and 5, Sections V and II respectively.

C. Geochemical Dispersion in Permafrost Terrains

1. Ionic and hydromorphic dispersion

Although the same basic weathering and dispersion processes (biological, chemical and physical) operate in the permafrost regime, as in the temperate zone (Fig. 6), the severity of the climate and the presence of permafrost impose their own peculiar restrictions on geochemical dispersion. For example, until recently permafrost was considered to be almost impermeable. Consequently, groundwater movement, except in the shallow active layer, was thought to be virtually non-existent. However, as recent studies have shown (Anderson, 1967: Murmann, 1973) water and ion movement within permafrost can occur through diffusional processes (Fig. 7).

Ion diffusion rates in permafrost were preconceived to be similar to solid state diffusion rates. However, diffusion rates for frozen soils (-3^{o} to $-15^{o}C$) were found to range from 10^{-3}cm to 5 cm per day, which is only about a factor of 10 less than the same soils at $25^{o}C$ and substantially higher, by several orders of magnitude, than solid state diffusion rates (Anderson and Morgenstern, 1973). Furthermore, if the tortuosity of the migration path is considered, the rates are only slightly less than those in an aqueous solution.

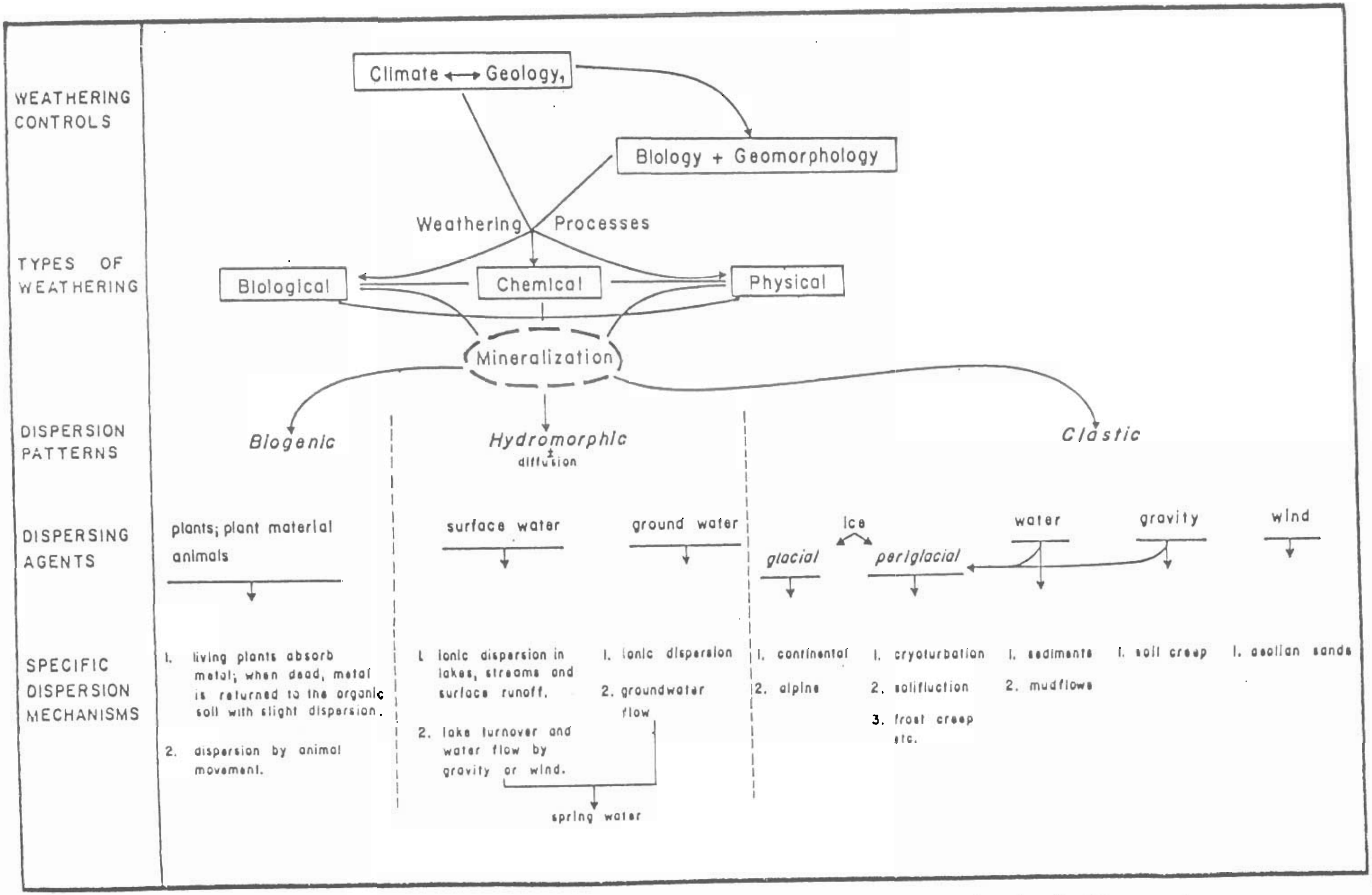

Figure 6. General relationship between weathering processes and geochemical dispersion.

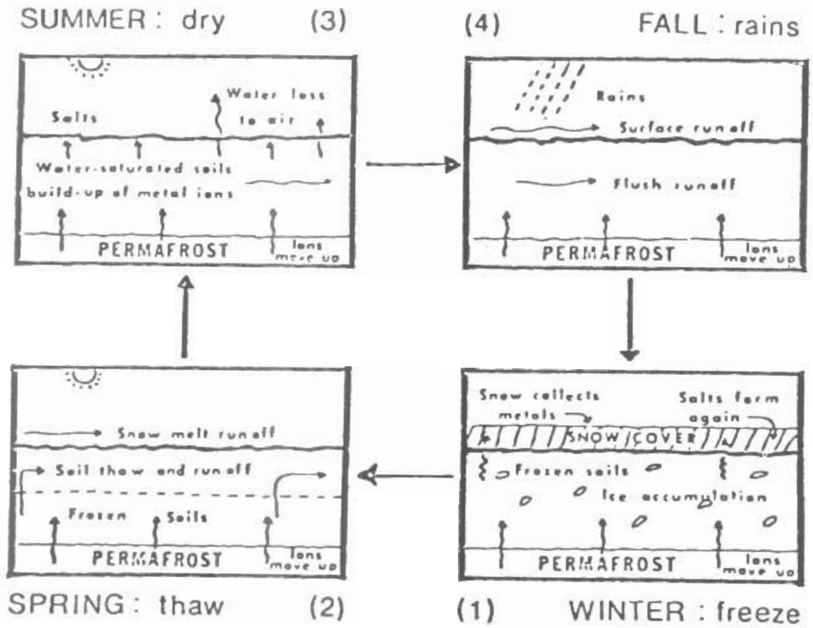

Figure 7. Metal ion migration in permafrost terrains: effects of seasonal changes. The basic process by which ions move from permafrost upwards is probably ionic diffusion in solution. There is sufficient moisture in permafrost to allow capillary-type migration to occur. In the winter metal ions move towards the soil surface in response to various gradients. Carbonate and sulphate crusts are formed and some metal moves into the overlying snow. This process continues until spring when there is melting and metal ions are flushed out in a pulse of early run-off, which may take several weeks. In summer surface runoff has ceased, but capillary action continues to supply metal-rich waters to the soil surface where the water evaporates leaving behind soluble metal complexes if there is little summer rain. In the fall, rain is more frequent resulting in a flush runoff which may be as intense as the spring pulse under certain conditions (from Jonasson and Allan, 1973).

Diffusion rates of this magnitude can only be accounted for by the existence of continuous, thin films of liquid water, 3 to 18 angstroms thick, surrounding the soil particles (Anderson and Hoekstra, 1965). Ugolini and Anderson (1972) and Tyutyunov (1960, 1961) have shown that these thin films of water are saline and probably allow important chemical reactions to occur. Consequently, permafrost may not be as much of a barrier to trace element movement nor as effective in limiting chemical weathering as once thought. Furthermore, many laboratory and a few field studies have shown that ions may move in response to various gradients and that weathering within permafrost does occur. However, the presence of massive ice (e.g ice lenses, layers and wedges), which can occupy as much as 80 percent of permafrost by volume, can drastically and unpredictably reduce ion movement (MacKay, pers. comm.). Field studies, assessing the relative importance of ionic diffusion within permafrost with respect to migration of elements from sulphide ore bodies have not been reported except in relatively inacessible Russian journals (e.g. Shvartsev and Lufkin, 1966).

Although permafrost generally is considered as a northward thickening relatively impermeable wedge, its distribution - because of the large numbers of lakes on the northern Canadian Shield - resembles a well perforated and dented sieve. This is because lakes greater than about six feet deep do not completely freeze in the winter and, since water is most dense at approximately 4°C, the deeper water bodies remain at or near this temperature year around. Consequently, well developed taliks, occur beneath larger lakes and rivers (Fig. 8). The presence of large numbers of taliks might result in interconnected networks of thawed ground allowing groundwaters to circulate and exchange or dispense metals and other ions into overlying sediments and waters as postulated by Allan (1971).

At Bathurst Norsemines the presence of very thick (>1600 feet) permafrost (Taylor and Judge, 1974) effectively prevents lake induced taliks from penetrating permafrost, except where lakes exceed 4500 feet in diameter. Furthermore, because the till is relatively thin, generally less than 50 feet on the northern Shield, bedrock permeability is the critical factor in terms of ion and deep groundwater movement. Unless the bedrock is permeable, i.e. faulted or fractured; the presence of taliks is irrelevant.

If ionic diffusion through permafrost is discounted as a major factor of metal dispersion, hydromorphic dispersion of metals within the overburden is restricted to the shallow active layer. Furthermore, it seems likely that this layer, which is usually water saturated and constantly reworked by cryoturbation, is a zone of comparatively intense chemical activity. Sulphide minerals entering the active layer from

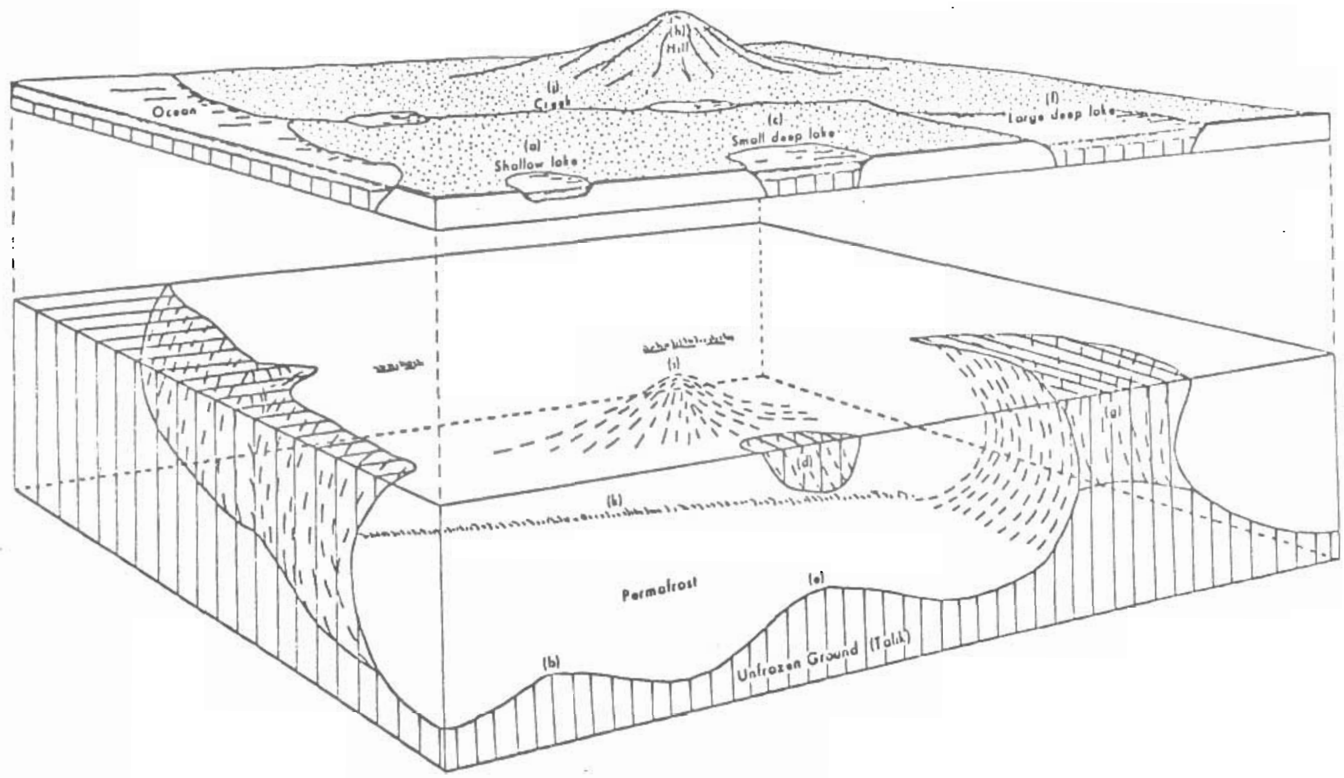

Figure 8. Schematic representation of the effect of water bodies on permafrost. Note the double convex shape of the lake induced talik (g). Also note that the bottom of permafrost closely follows surface topography (after Price, 1972).

outcrop or sub-outcrop would be expected to decompose allowing their soluble and mobile products to be transported into the network of streams and lakes which covers an average of 15 to 30 percent of the northern Canadian Shield. The possible role of glacial and periglacial processes in bringing trace elements and mineralized rock fragments into the upper portions of the active layer is considered in the next section.

2. Mechanical dispersion

i) Glacial

The whole of the northern Canadian Shield has been subjected to at least one episode of continental glaciation. It seems likely, therefore, that prior to onset of present periglacial conditions, characteristic clastic dispersion patterns developed as a result of glacial corrosion of mineralized bedrock. Normally this results in finger or fan-shaped geochemical or boulder indicator trains extending down ice several miles from the source These indicator trains have been widely used for prospecting in both Finno-Scandia and Canada. Shilts (1973a, b, c, 1974a, 1976) has described examples from the Kaminak region of the N.W.T. Consequently, glaciation is the single most important dispersive process in the permafrost environment of the Bear and Slave Structural Provinces. Without glaciation, whereby fresh rock is comminuted and widely dispersed, chemical activity and subsequent hydromorphic dispersion would not be as intense nor as widespread.

At Bathurst Inlet the ice-sheet scoured bedrock and left relatively thin till deposits, generally thought to be of local provenance, and moderate to abundant fresh bedrock exposures (Craig, 1960). Locally, the till has been reworked and/or largely removed resulting in esker, kame and outwash deposits with associated features (e.g. esker scour channels).

Eskers are common throughout glaciated regions, but are particularly noticeable in the continuous permafrost zone. Although they may appear continuous over many miles, most eskers are built in short overlapping segments from streams extending from tens or hundreds of feet to perhaps a few miles back from the ice margin (Howarth, 1971). Consequently, they drain relatively restricted areas and, unlike streams and rivers whose sediment has been derived from all of their upstream drainage basin, esker material can only have been derived from as far upstream as the head of the short segment associated with its formation and, therefore, is of very restricted provenance. This, combined with their low density (1 linear mile per 10^2 square miles around Bathurst Norsemines), makes them generally unsuitable geochemical sampling medium for exploration purposes, although they have been used in other areas (Shilts, 1973a; Cachau-Hereillat and LaSalle, 1971).

ii) Periglacial

In terms of exploration the two most important periglacial processes and features of the permafrost zones are circles and solifluction lobes. Circles, sorted and nonsorted, are ubiquitous in the continuous permafrost zone and are thought to bring to the surface, through cryoturbation, soil which is very similar in trace metal content to that at the base of the active layer (Pitul'ko, 1968; Allan and Hornbrook, 1970, 1971; Shilts, 1973a). Furthermore, because circles are often closely spaced, even impinging on one another to form nets, the churning motion ascribed to their development tends to homogenize the active layer and disrupt soil profile development. As a result, even though chemical activity and hydromorphic dispersion are substantial, there is little visual representation of these activities in terms of soil profile development. This contrasts with undisturbed tundra where eluviation and illuviation may make sampling depth a significant factor (Fig. 9). Additionally, circles are thought to contain a greater percentage of finer soil material relative to less disturbed tundra because of physical sorting by various frost processes (cf. Corte, 1962). When active, these frost processes result in circles being free of vegetation, thereby presenting an easily and readily available sample of mineral soil. Consequently, where possible, sampling of circles has generally been recommended.

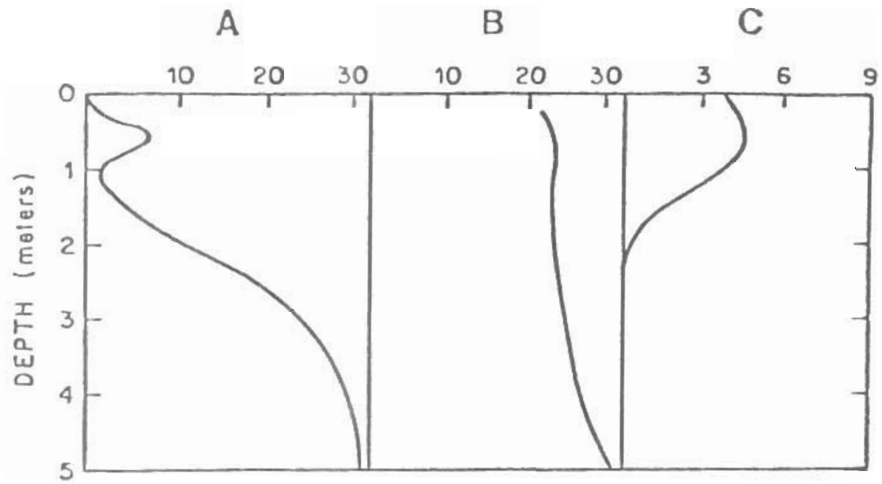

Figure 9. Profiles of geochemical dispersion in: A) undisturbed till, B) in circles, and C) solifluction lobe with considerable displacement. Scale of concentration is arbitrary. Modified from Pitul'ko (1968).