Overview of Regional Geochemical and Geophysical Data for the South Mountain Batholith: Implications for Future Mineral Exploration

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Introduction

There has been sporadic and episodic mineral exploration for granite-hosted, polymetallic deposits in the South Mountain Batholith since the late 1800s (cf. MacDonald, 1994, and references therein). Early activities consisted of prospecting and boulder tracing which led to discovery of the New Ross Manganese Mines and numerous polymetallic occurrences, mostly near the village of New Ross, Lunenburg County (Fig. 1). Recent exploration, mostly since the mid-1970s, has combined basic prospecting with a variety of geochemical and geophysical surveys, most notably till geochemistry and airborne gamma-ray spectrometric (i. e. "radiometric") surveys. This activity led to discovery of the East Kemptville (Sn-Zn-Cu-Ag) and Millet Brook (U-Cu-Ag) deposits and numerous other mineral occurrences. Concurrent bedrock and surficial mapping of the batholith (the South Mountain Batholith project) during the 1984-1989 Canada - Nova Scotia Mineral Development Agreement produced extensive lithogeochemical and till geochemical databases.

This report summarizes the geochemical and geophysical data currently available for the South Mountain Batholith, reviews some of the methods used by explorationists, and makes recommendations for future mineral exploration.

General Geology and Physiography

The South Mountain Batholith is a massive, post-tectonic, composite peraluminous granitoid body that outcrops over approximately 7300 km^2 in southwestern Nova Scotia. For a full description of its composition and geological setting the reader is referred to MacDonald *et al.* (1992b). In summary, the batholith intrudes predominantly flyschoid metawacke and metapelite of the Cambro-Ordovician Meguma Group. Along its northwestern margin it intrudes a conformable succession of metavolcanic and metasedimentary roeks that range in age from Ordovician (White Rock Formation) to Devonian (Torbrook Formation). The batholith is overlain by coarse subaerial clastic sediments and marine carbonates of the Horton and Windsor groups of Early Carboniferous age.

The batholith ranges in composition from biotite granodiorite to muscovite±topaz leucogranite (Fig. 1). MacDonald *et al.* (1992b) grouped the granitic rocks into Stage 1 plutons, consisting mostly of biotite granodiorite and biotite monzogranite, and Stage 2 plutons, consisting mostly of muscovite-biotite monzogranite, coarse- and fine-grained leucomonzo-granite and leucogranite with minor biotite granodiorite and biotite monzogranite. Field evidence indicates that Stage 2 plutons invariably intrude Stage 1 plutons. In spite of this sequence of intrusion, geochronological data indicate that all of the granitic rocks of the batholith were intruded circa 370±5 Ma.

The South Mountain Batholith is located in the south-central portion of the Atlantic Uplands of Nova Scotia, as defined by Goldthwait (1923). Most of the batholith is blanketed by three regionally mappable till sheets (Finck and Stea, 1995) with provenances varying from local to distal. Physiography over much of the batholith is typified by low-lying or hummocky terrane with abundant lakes. Over most of the batholith sluggish, meandering streams with sparse sediment load dictate that the area is not favourable for stream sediment surveys. In contrast, the northern margin of the batholith along the Annapolis Valley is cut by incised streams that are well suited for stream sediment surveys.

Geochemical Data

Exploration geochemistry is based on the premise that ore deposits are enriched (or depleted) in one or more elements relative to host- or cover-rocks and that this enrichment can be detected in sample media near, and over, the deposit. There are four mineralization types in the batholith (MacDonald, 1994), each with a characteristic assemblage of ore, gangue and alteration minerals and their associated elements: (1) greisen - Sn, W, Mo, As, Cu, Pb, Zn, Bi, Au, Ag, B, F, P, Na and K; (2) vein - U, Cu, Mn, P, F and Ag; (3) breccia - Pb, Zn, Ba, Sn, W, Au and Ag; and (4) pegmatite - Mo, Sn, W, Cu, Nb, Ta, Be, B, F and Li. It is important to note that

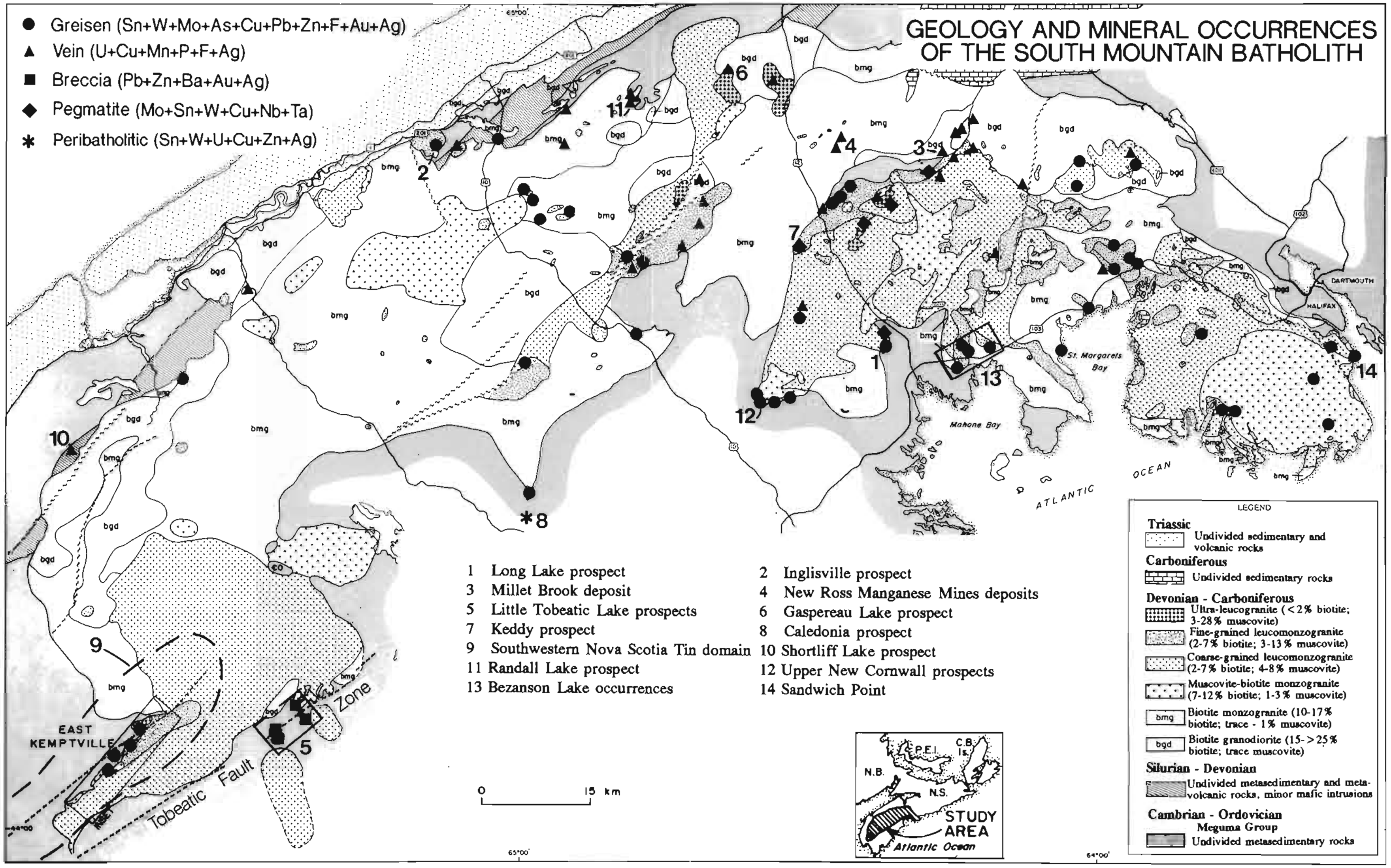

Figure 1. Geological map of the South Mountain Batholith showing distribution of the major rock types. The locations and types of mineral deposits are also indicated.

individual deposits may not be enriched in all of the elements associated with the particular style of mineralization. In addition to the detection of individual mineral deposits, geochemical data can also be used to delineate metallogenic domains (Chatterjee, 1983) and 'specialized' leucogranites, both having characteristic enrichments and/or depletions in granophile elements which are variably reflected in the surficial sampling media (MacDonald *et al.*, 1992a).

A variety of geochemical surveys have been conducted over the batholith since the 1950s (Rogers and Lombard, 1990). The following sections discuss some salient aspects of these surveys, with particular attention to exploration for granophile deposits.

Stream Sediment Surveys

The first regional geochemical project over the batholith was a stream sediment survey conducted by the Geological Survey of Canada (Boyle *et al.*, 1958). Samples collected during this survey were analyzed for Cu, Pb and Zn in the field using the organic re-agent dithizone. The limited suite of elements and the scarcity of samples from the interior of the batholith limited the applicability of this survey for granite-hosted mineral exploration.

Lake Sediment Surveys

In general, private-sector companies did not use lake sediment surveys for exploration over the batholith. The Nova Scotia Department of Mines and Energy conducted a centre-lake bottom survey over the entire Meguma Zone in 1977 and 1978 (Bingley and Richardson, 1978). Lake sediment data reflect the collective geochemical response of the bedrock and, perhaps more importantly, the till in a catchment basin. Thus, the composition of a single lake sediment sample may be representative of a large area. The chief advantage of lake sediment surveys, compared to other types of regional geochemical surveys, is that they are easy to conduct, particularly if helicopter support is available. Another advantage is the relatively uncomplicated sample preparation procedures, consisting essentially of drying and sieving the sediment (gyttja) prior to analysis. The elimination of complex and costly sample preparation procedures reduces the possibility of laboratory-introduced contamination; however, roads and habitations highlight the possibility of anthropogenic contamination of lake sediments. The chief drawback with lake sediment surveys is the lack of geological information that is available from the sample medium. For example it is not possible to establish the exact bedrock or till compositions within the catchment basin by examining collected samples.

Samples collected during the 1977 and 1978 surveys were first analyzed for a suite of 15 elements including Cu, Pb, Zn, Ag, Fe, Mn, As, Mo, U, Cd, Ba, F, Sr, Ca, Mg and Loss On Ignition (LOI) (Bingley and Richardson, 1978). With the exception of U, F and possibly Cu, Pb, Zn and Ba, most elements are not effective pathfinders for detecting granophile deposits. Accordingly, the entire sample set was re-analyzed for a suite of 16 elements including the 'granophile elements' Sn, W, Li, Rb, F and Nb (Rogers *et al.*, 1985). Figures 2 and 3 are plots of Sn and Cu concentrations for lake sediments over southwestern Nova Scotia. The boundaries of Stage 1 and Stage 2 plutons, and the metallogenic domains of Chatterjee (1983), have been plotted on these diagrams for comparison.

Examination of the centre-lake bottom data (Rogers *et al.*, 1985; Lombard, 1991) reveals large geochemical contrasts throughout the batholith, which are attributed to several geological features. For example, high tin concentrations were noted in several lakes proximal to granite-hosted tin occurrences throughout the batholith, as previously discussed by Rogers and Garrett (1987). High tin levels are also present along the southeastern batholith margin, an area previously noted to have significant potential for granophile mineralization (Finck *et al.*, 1988). In contrast, large portions of the batholith outside the polymetallic tin domains of Chatterjee (1983) have high tin concentrations in lakes. One such area is located in the central part of the batholith (Fig. 2) where anomalous tin levels (i.e. >90th percentile) span several Stage 1 and 2 plutons. The source for these high tin levels is presently unknown.

The highest copper concentrations are mostly in lakes that overlie metasedimentary rocks peripheral to the batholith. The highest copper concentrations in lakes over the batholith are mostly over a Stage 2 (i. e. fractionated) pluton in the central part of the batholith and near copper-bearing mineral occurrences. The distribution of Rb, Li, F and other 'granophile' elements is somewhat erratic; however, the highest concentrations are mostly in lakes over Stage 2 plutons, particularly in the central and southwestern regions.

Rogers *et al.* (1990) noted that multi-element lake sediment plots more accurately reflected the metallogenic domains defined by Chatterjee (1983) compared to single-element lake sediment plots. The distribution of multi-element anomalies involving the granophile elements F-Li-Nb-Rb±Sn is shown in Figure 4 and illustrates a good correlation with the domains of Chatterjee (1983). These observations support the use of lake sediment geochemistry for targeting regions of the batholith for detailed follow-up exploration. It should be noted that lake surveys are not suited to detailed exploration owing to the relatively large size of catchment basins.

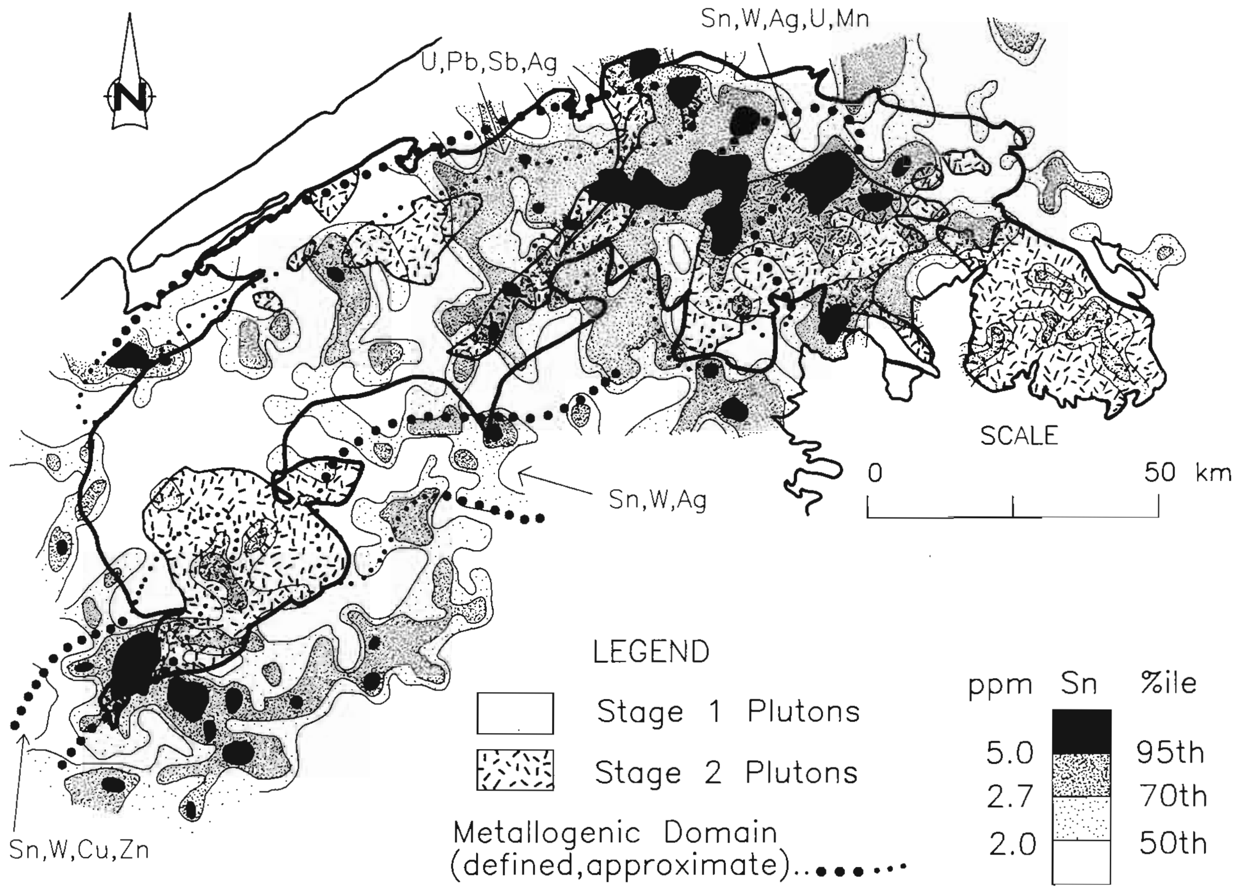

Figure 2. Contoured plot of tin concentration in lake sediments from southwestern Nova Scotia (modified after Lombard, 1991). Contour intervals were based on percentile values for the entire Meguma Zone data set and were arbitrarily selected at the 50th, 70th and 95th percentile levels. Metallogenic domains of Chatterjee (1983) and Stage 1 and 2 pluton boundaries from this study have been plotted for comparison.

Till Surveys

Till geochemical surveys were commonly used by private-sector companies during the exploration 'boom' of the 1970s and 1980s. Results of these surveys are detailed in numerous assessment reports in the DNR library. Several studies of till stratigraphy and till geochemistry over the entire batholith were also conducted by the Nova Scotia Department of Mines and Energy during this same time period. For the sake of brevity, the following section focuses only on results from the government surveys.

Most of the surface of the batholith is blanketed by glacial till which was formed by glacial erosion of local bedrock and, in some areas, previously deposited till sheets (Finck and Stea, 1995). Much of the batholith is overlain by a stony local till with >90% locally derived clasts that were dispersed 1-4 km (Finck *et al.*, 1990a, b). Other parts of the batholith are overlain by more distally derived tills, most notably the Lawrencetown Till (Stea and Fowler, 1981), which may have clasts that originated more than 20-50 km north of the Meguma Terrane (Stea and O'Reilly, 1982); however, these tills also contain varying percentages of locally derived (i. e. <1-2 km) clasts and matrix (Finck *et al.*, 1989). Therefore, the geochemical characteristics of the various till sheets that overlie the batholith vary in response to their respective provenances. Caution should be exercised when using till geochemistry in mineral exploration, as noted by Graves *et al.* (1988). The main advantage to till surveys is that, unlike lake sediment surveys, individual till samples contain clasts that provide information about bedrock from the till's source area. In general, till surveys do not have the problem of anthropogenic contamination, as previously noted for lake surveys. The chief disadvantage to heavy mineral till surveys is the increased sampling time and costly, complex sample preparation procedures that increase the possibility of contamination (MacDonald *et al.*, 1992a).

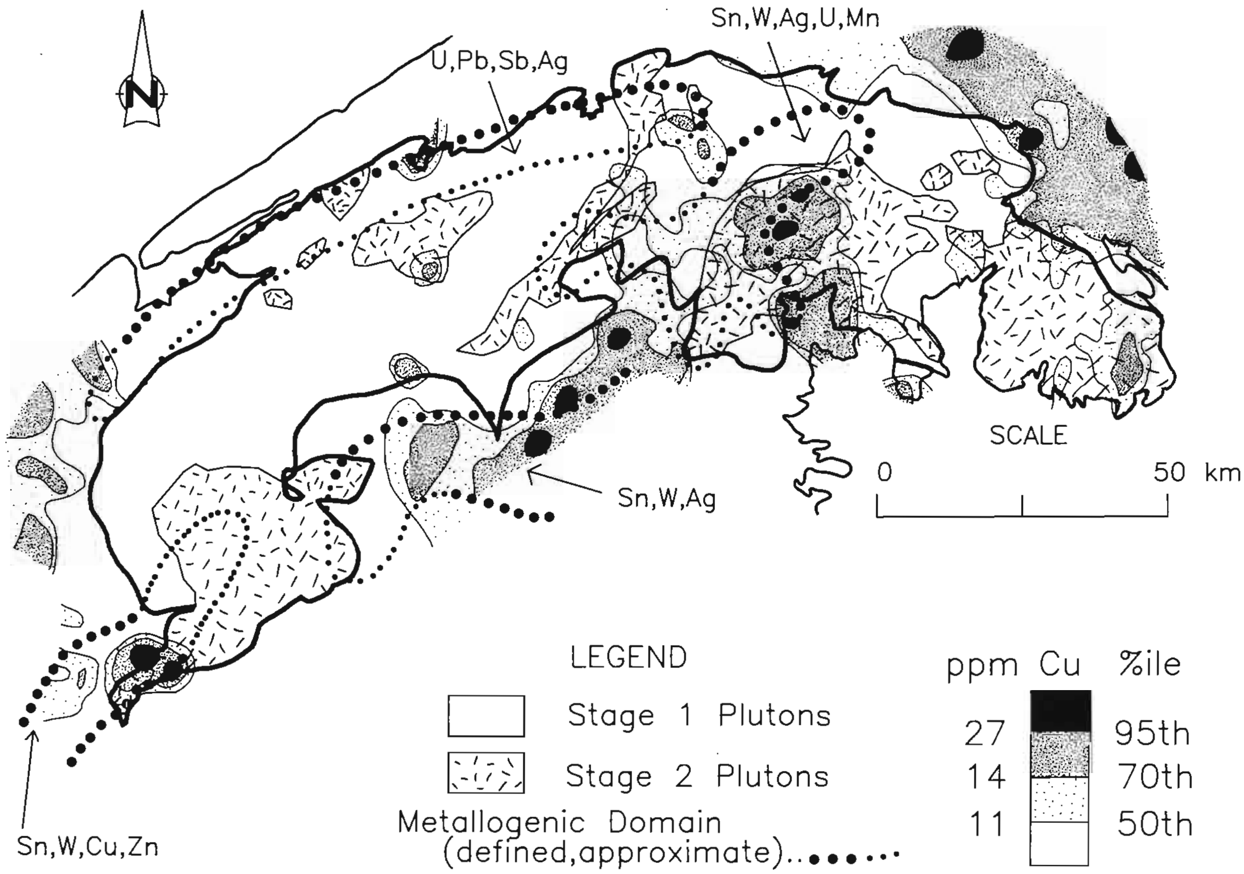

Figure 3. Contoured plot of copper concentration in lake sediments from southwestern Nova Scotia (modified after Lombard, 1991). Contour intervals were based on percentile values for the entire Meguma Zone data set and were arbitrarily selected at the 50th, 70th and 95th percentile levels. Metallogenic domains of Chatterjee (1983) and Stage 1 and 2 pluton boundaries from this study have been plotted for comparison.

Till surveys were first conducted over the batholith by Stea and Fowler (1981), Stea and Grant (1982), and Stea (1983). These workers analyzed till samples to determine concentrations of Cd, Ag, Cu, Pb, Zn, Ni, Co, Mg, As, U, Mo, Sn and W. Stea and O'Reilly (1982) noted significant chemical variation among the various till sheets. Furthermore, they noted that most Sn and W anomalies in the heavy mineral separates were located at the margins of the batholith. They also observed that most of the W anomalies were in the northern and eastern sections of the batholith, whereas most Sn anomalies were in the southern part of the batholith, which they regarded to reflect regional metallogenic zonation.

The entire South Mountain Batholith was surveyed for till geochemistry in the 1980s, with a sampling density of 1 sample per 4 km^2 (Finck *et al.*, 1990a, b). The survey was conducted in concert with bedrock geological mapping and was designed to help define geological contacts and act as an aid to mineral exploration. Approximately 2100 till samples were analyzed for a suite of 16 elements including Ni, Cr, Ba, Th, Sc, As, Rb, Sb, Ta, U and W by neutron activation (INAA) and Pb, Zn, Cu, Fe and Mn by atomic absorption (AAS). Analytical results are given in Boner *et al.* (1990). In addition, data for tin in heavy mineral concentrates from the same 2100 samples were given by Finck *et al.* (1990a, b). In spite of the presence of several till sheets over the batholith, as noted above, there is a very good correlation between bedrock type and the relative abundances of several 'granophile' elements. For example, the concentration of Ta in tills derived from Stage 2 plutons is markedly higher than for Stage 1 plutons (Fig. 5). Conversely, the distribution of U and Th, which reside mostly in the accessory minerals zircon and monazite, does not reflect the type of underlying bedrock but rather can be correlated to the degree of bedrock weathering (Finck, personal communication). The distribution of Cu, Pb, Zn and As generally does not reflect the distribution of Stage 1 and 2 plutons. These elements mostly reflect the presence of sulphide minerals, as noted for the Halifax Pluton (Graves *et al.*, 1988), but may also reflect the degree of weathering of bedrock (Finck, personal communication, 1993). High copper levels may also be

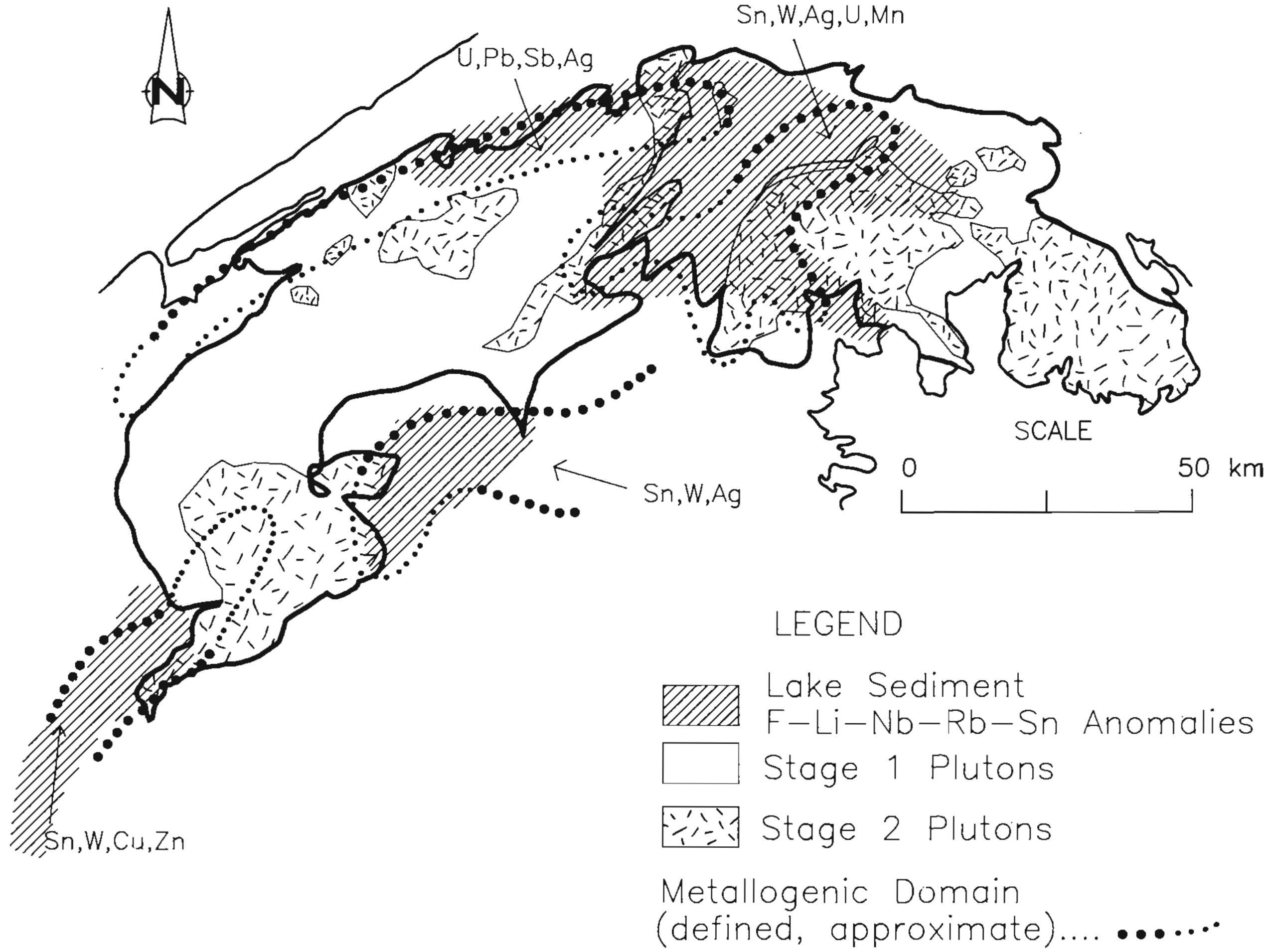

Figure 4. Plot of multi-element centre-lake bottom anomalies for the South Mountain Batholith. Only anomalies involving the granophile elements F-Li-Nb-Rb ± Sn are plotted. Metallogenic domains of Chatterjee (1983) have been plotted for comparison.

caused by distally derived Lawrencetown Till with high proportions of copper-enriched basalt (Finck, personal communication, 1997).

Perhaps one of the most striking features of till geochemistry over the batholith is the distribution of tin in heavy mineral concentrates (Finck *et al.*, 1990a, b). All areas with high concentrations of tin in till (i.e. >90th percentile for entire data set; Fig. 6) also host polymetallic deposits (e.g. East Kemptville, East Dalhousie, New Ross, Long Lake and Bezanson Lake areas; MacDonald, 1994).

The southwestern portion of the batholith, which hosts the East Kemptville tin deposit, has concentrations of tin in heavy mineral separates from tills that overshadow the remainder of the batholith. A detailed plot of the distribution of weighted tin concentrations (cf. Finck *et al*, 1990b for weighting method) from the southwestern portion of the Stage 2 Davis Lake Pluton is given in Figure 7. Weighted (w) tin levels are mostly >5 ppm_w with maximum of >80 ppm_w, compared to the rest of the batholith where the 98th percentile is 3.50 ppm_w and the maximum is 10.66 ppm_w. If the percentile levels were defined for the batholith using a subset of data from this region, none of the samples from the rest of the batholith would be considered anomalous. Distribution of these high tin concentrations defines the Southwestern Nova Scotia Tin Domain as first described by Chatterjee (1983) and further investigated by Kontak *et al.* (1990). The extremely high tin levels presumably reflect the presence of the East Kemptville tin deposit, situated on a prominent bedrock ridge that presumably underwent significant erosion and glacial dispersion. The relatively low tin levels elsewhere in the batholith may not necessarily reflect low potential but rather a lack of extensive glaciation of tin-bearing rock.

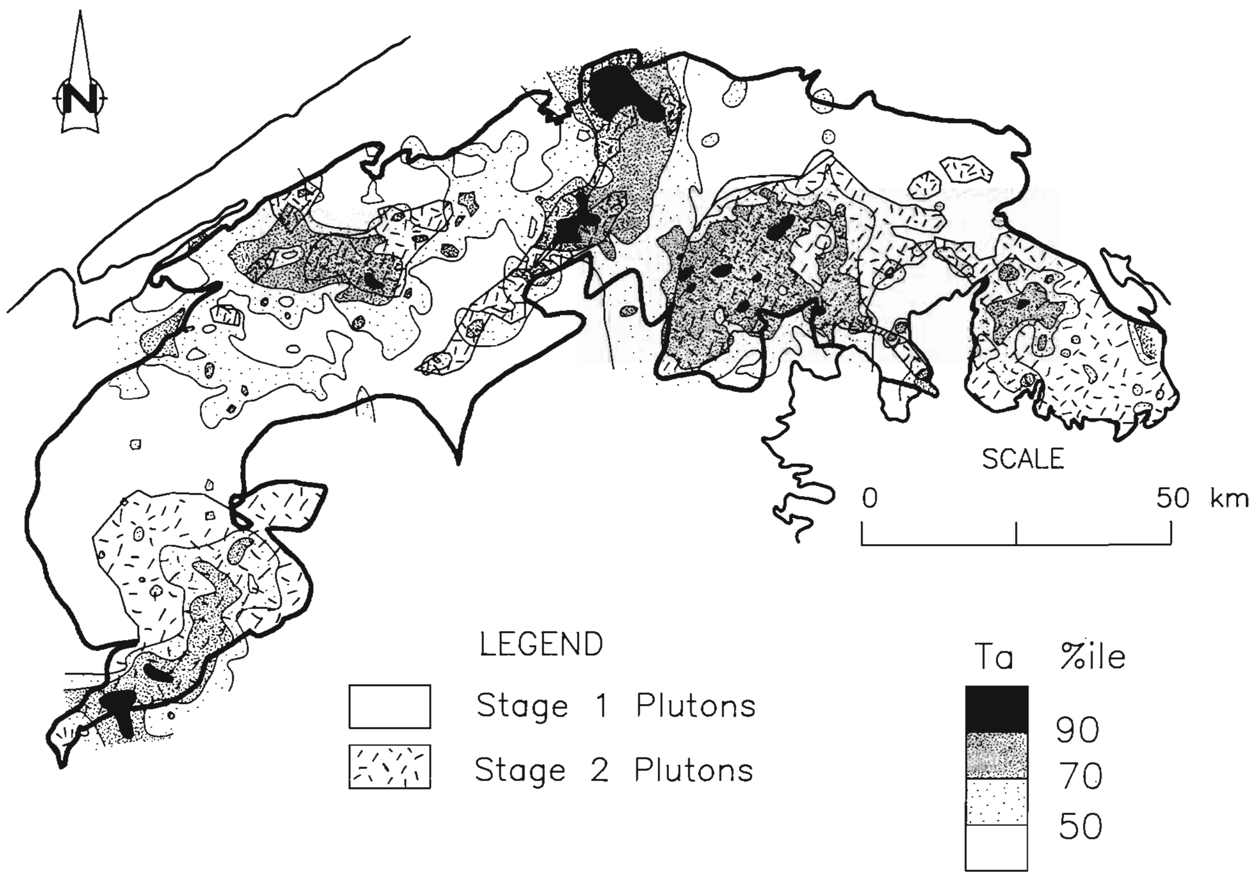

Figure 5. Plot of tantallum concentration in the -230 (-62.5 μm) mesh fraction of whole till for the South Mountain Batholith (data from Boner *et al.*, 1990). Contour intervals were calculated using the entire data set. Note the strong spatial association between high concentrations of tantallum in till and the distribution of Stage 2 plutons.

In general, till geochemical data, when interpreted with stratigraphic and provenance information, can be used to define discrete exploration targets. In addition, follow-up surveys using a close sample spacing (e.g. 25-100 m) can be used to define targets for trenching and diamond-drilling, as shown by the detailed work of MacDonald *et al.* (1992a). In spite of the presence of distally derived tills, the concentrations of Ta, Rb and possibly other granophile elements can be used to locate geochemically 'specialized' granites.

Biogeochemical Surveys

In general, exploration companies did not use biogeochemical surveys to explore in the batholith. In fact, the applicability of biogeochemical methods for granite-hosted mineral deposits in the Meguma Zone was only investigated in the 1980s and 1990s. The chief advantages of biogeochemical surveys are their ease of collection and straightforward sample preparation procedures that reduce the risk of contamination. The main drawbacks to biogeochemical surveys are the lack of geological information in the sample media and the possibility of anthropogenic contamination.

The first biogeochemical study in the batholith was done by Brooks *et al.* (1982) at the Millet Brook U-Cu-Ag vein-type deposit. They measured the uranium concentrations in red spruce and three species of hardwood trees over mineralized zones at the deposit. Results were then compared with uranium data for "B" horizon soils and scintillometer data over the same areas.

Brooks *et al.* (1982) noted 'anomalous' concentrations of uranium in red spruce that compared favourably with the scintillometer and bedrock geological information. Relatively poor analytical results were obtained for all investigated hardwood species. Brooks *et al.* (1982) concluded that biogeochemical techniques could be successfully applied in uranium exploration, based on the marked contrast between uranium concentrations over mineralized as opposed to unmineralized biotite granodiorite in their study.

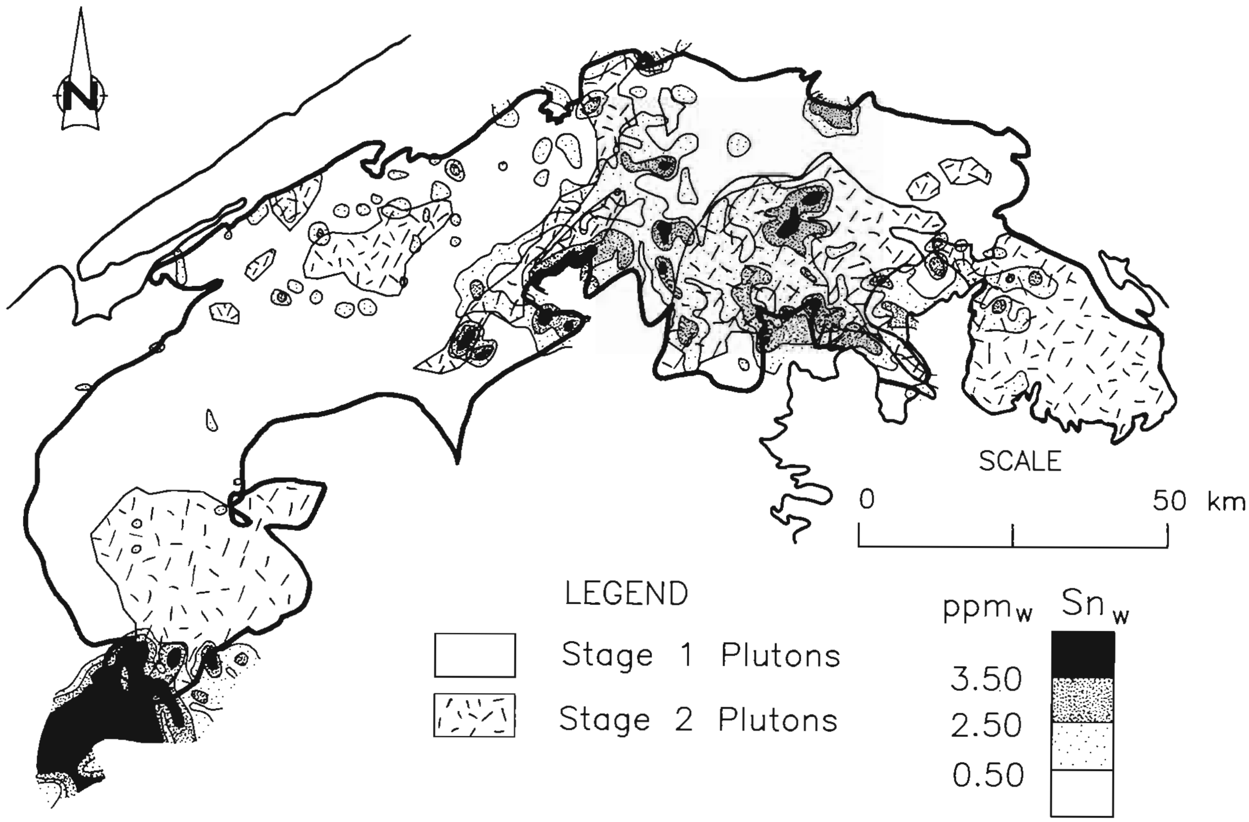

Figure 6. Plot of weighted tin concentrations in heavy mineral separates from the -60+230 (-250+62.5 μm) mesh fraction of till from the South Mountain Batholith (data and weighting method from Finck *et al.*, 1990a, 1990b). Contour intervals were calculated using the entire data set.

Dunn *et al.* (1989) conducted a regional biogeochemical survey in eastern Nova Scotia. Their data confirmed the presence of known gold deposits and indicated that biogeochemical techniques could be applied throughout the Meguma Zone. To follow up on these results, a regional biogeochemical survey was initiated over the southwestern part of the Meguma Zone (Dunn *et al.*, 1992). Data from this survey revealed extreme enrichment in many granophile elements (e.g. Sn, W, Ta, Cs, Rb, Li) in the region surrounding the East Kemptville deposit. This is depicted in the plots of Sn and Ta in red spruce bark (Figs. 8 and 9, respectively). Of particular interest is the discrepancy between the tin data for red spruce and the distribution of tin in heavy mineral separates from till (Fig. 6). The biogeochemical survey was conducted after several years of mineral production from the open-pit East Kemptville Sn mine and, therefore, may reflect a component of airborne contamination in the vicinity of the mine.

MacDonald *et al.* (1992a) analyzed balsam fir branches as part of a multi-media geochemical study of the Brazil Lake (Li, Be) pegmatites. They noted that branches (i.e. past 5-7 years growth) from balsam fir trees collected near pegmatite outcrops in the Brazil Lake area generally had much higher concentrations of Li±Cs±Ta±P±Sn±Nb±F than samples taken in other parts of the study area. They also noted different distribution patterns for Li, Be and Cs, which were tentatively attributed to primary zoning in the pegmatites.

These studies have shown that chemical analysis of plant tissues is an effective method for delineating areas of bedrock and overlying till that are enriched in granophile and chalcophile elements. In addition, these techniques have successfully confirmed the presence of known granite-hosted mineral deposits and metasediment-hosted rare-metal pegmatites in the southern Meguma Zone.

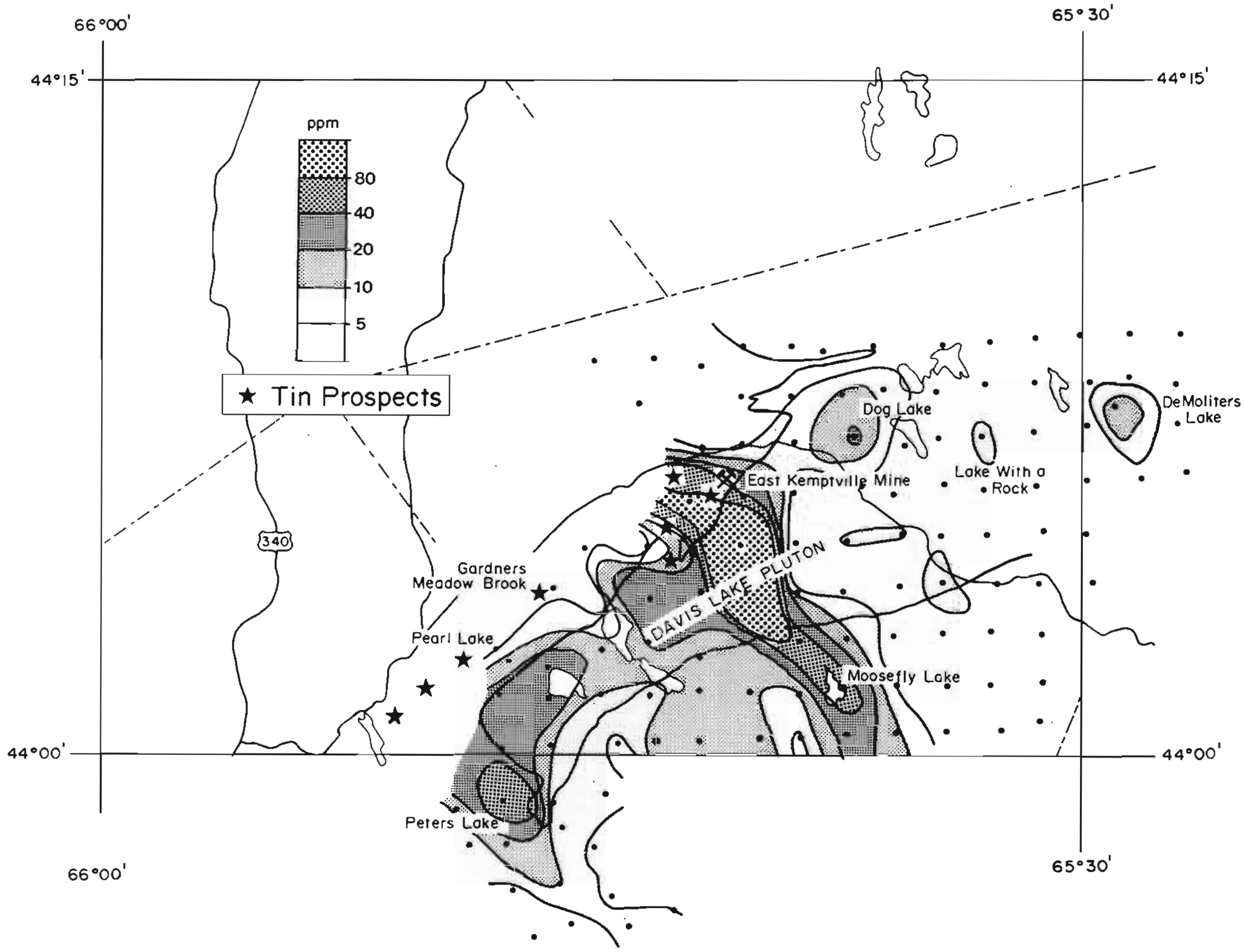

Figure 7. Plot of weighted tin concentrations in heavy mineral separates from the -60+230 (-250+62.5 μm) mesh fraction of till from the southwestern portion of the Davis Lake Pluton (data and weighting method from Finck *et al.*, 1990b). Contour intervals were chosen to best display the entire data range.

Lithogeochemical Data

The South Mountain Batholith project (1984-1989) produced a large lithogeochemical database (Ham *et al.*, 1989, 1990; MacDonald *et al.*, 1992b). Exploration companies routinely collected hand samples for geochemical analysis to measure the concentration of ore elements, or characteristic trace elements, that would suggest the presence of, or potential for, granite-hosted mineral deposits. However, to date there have been no systematic exploration lithogeochemical studies for the batholith.

MacDonald and Horne (1988), Horne *et al.* (1989), and MacDonald *et al.* (1992b) concluded that lithogeochemical data can be used to define normal and/or reverse compositional zoning in most Stage 1 and Stage 2 plutons. The core regions of normally zoned Stage 2 plutons commonly have the highest concentrations of granophile elements and, along with fine-grained muscovite ± topaz leucogranite, are the most 'specialized' rocks in the batholith. Specialized granites are considered to be the progenitors for granite-hosted mineral deposits in peraluminous granites (cf. Lehman, 1990, and references therein); subsequently, the location of these rocks is a crucial aspect of exploration.

The Davis Lake Pluton is characterized by systematic, normal lithogeochemical zoning (MacDonald *et al.*, 1992b). For example K/Rb ratios decrease from >200 along the northern and eastern margin to <50 in the southeastern lobe of the pluton. Detailed contour plots of F and Rb concentrations for the East Kemptville deposit and western Davis Lake Pluton are given in Figures 10 and 11, respectively. These data indicate normal zoning in the Davis Lake Pluton with the least evolved rocks

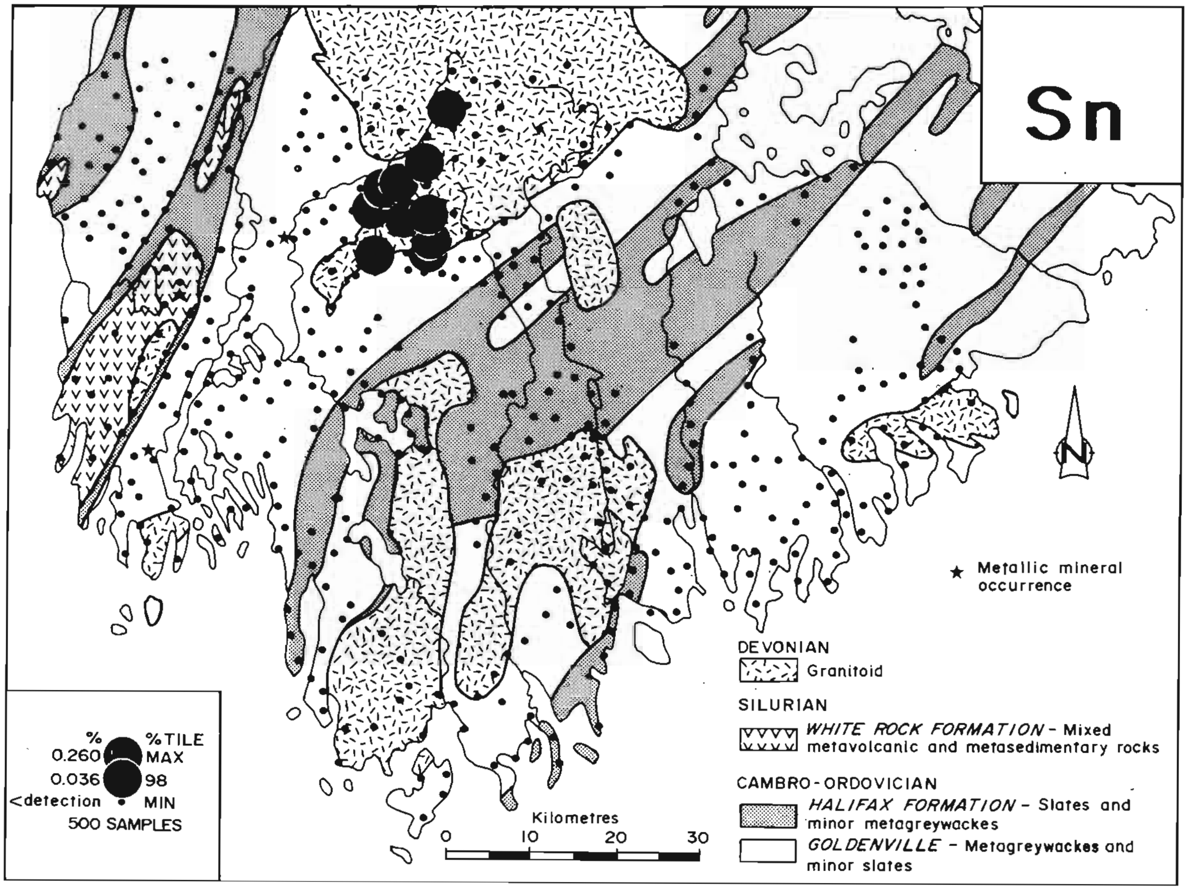

Figure 8. Proportional symbol plot showing the distribution of tin in red spruce bark from southwestern Nova Scotia (modified from Dunn et al., 1992). Simplified geology for this area has been plotted for reference.

along the eastern and northern margins having the lowest concentrations of F and Rb, and the most evolved rocks with the highest levels of F and Rb in the southern lobe. In fact the contours for F and Rb concentrations have a pronounced bulls-eye pattern centred on the East Kemptville leucogranite and the greisen-type Sn-Zn-Cu-Ag deposit. Lithogeochemical analysis of rocks of the Davis Lake Pluton accurately pin-points the East Kemptville deposit and thus should be considered a viable tool when designing future exploration programs, particularly for greisen-type deposits which are spatially associated with specialized granitoid bodies.

Humus Surveys

Organic humus (Or A_1 soil layer) has not been used extensively in exploration for granophile deposits in Nova Scotia. The only published reference for humus data is MacDonald *et al.* (1992a) for a multi-media geochemical study of the Brazil Lake pegmatites. They noted that concentrations of most elements, including Li, Be, Cs, F, Rb and Sn, varied significantly in the humus samples collected throughout their 600 m x 600 m sampling grid. They concluded that a large proportion of this variation in concentration correlated to the organic content of the samples, which ranged from 5-90%, and subsequently applied a correction factor to the raw analytical data based on the percentages of organic material.

A proportional symbol plot of Li concentration (corrected for organic content) in humus from the Brazil Lake survey is given in Figure 12a. Symbol size is proportional to concentration of Li, Be, Cs and Ta (see MacDonald *et al.*, 1992a for description of data presentation). The highest Li levels are in humus samples collected directly over the known spodumene-bearing pegmatites. The results for Be, Cs and Ta (Figs. 12b, c, d) are less definitive but also reflect the location of known pegmatite occurrences. High concentrations of these granophile elements elsewhere in the sample grid suggest that additional pegmatite dykes are also present. The most significant finding from this study, in terms of the implications for mineral exploration, is that anomaly to background contrast can be easily detected in samples of organic humus. It should be stressed that the results from a previous multi-media geochemical study over the Yava

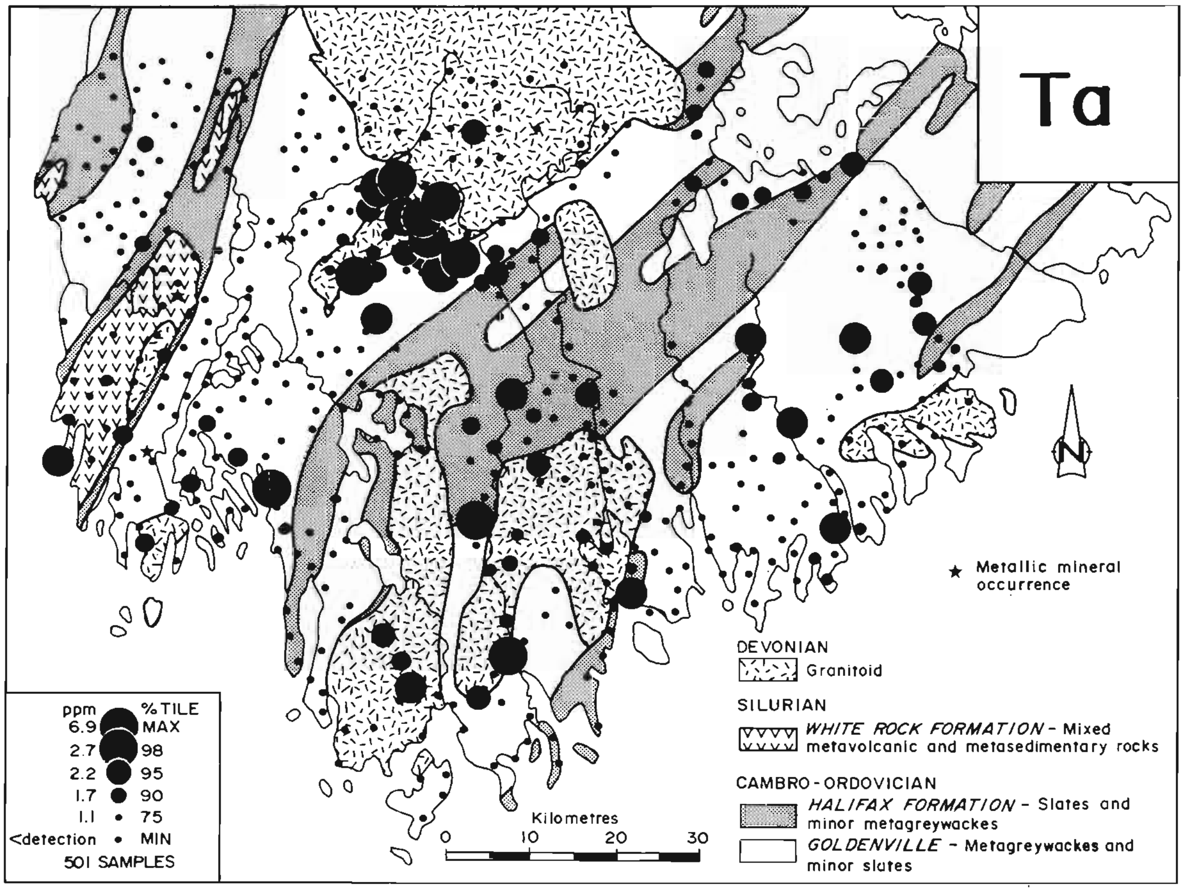

Figure 9. Proportiona symbol plot showing the distribution of tantallum in red spruce bark from southwestern Nova Scotia (modified from Dunn *et al.,* 1992). Simplified geology for this area has been plotted for reference.

lead deposit in eastern Cape Breton Island (MacDonald and Boner, 1993) revealed that the distribution of Pb, Zn and other heavy metals in humus is strongly influenced by hydromorphic processes. A good understanding of the geomorphology of the study area is therefore essential when conducting humus surveys.

Geophysical Data

Several geophysical techniques have been used by explorationists and government organizations to investigate the granitic rocks of the South Mountain Batholith and other plutons of the Meguma Zone. The most widely used regional geophysical surveys have employed airborne gamma-ray spectrometry, whereas ground scintillometer surveys were routinely used for property-scale evaluations. Other geophysical methods were also used with varying degrees of success. The following sections summarize some of the applications of geophysical methods in the batholith.

Airborne Gamma-ray Spectrometric Surveys

Airborne gamma-ray spectrometric (i.e. radiometric) surveys were flown over the entire province between 1976 and 1990 (Ford *et al.*, 1992). These surveys report spectrometric response as total count (TC) and as individual elemental components including equivalent uranium (eqU), equivalent thorium (eqTh) and equivalent potassium (eqK), and the various ratios of these individual components. The relationship between the results of these surveys and bedrock and surficial geology have been addressed in several studies including Chatterjee and Muecke (1982), Ford and Ballantyne (1983), Ford and O'Reilly (1985), O'Reilly *et al.* (1988), and Finck *et al.* (1988). Spectrometric surveys over the granitic rocks of the Meguma Zone were also used by private sector companies, mostly in the search for uranium.

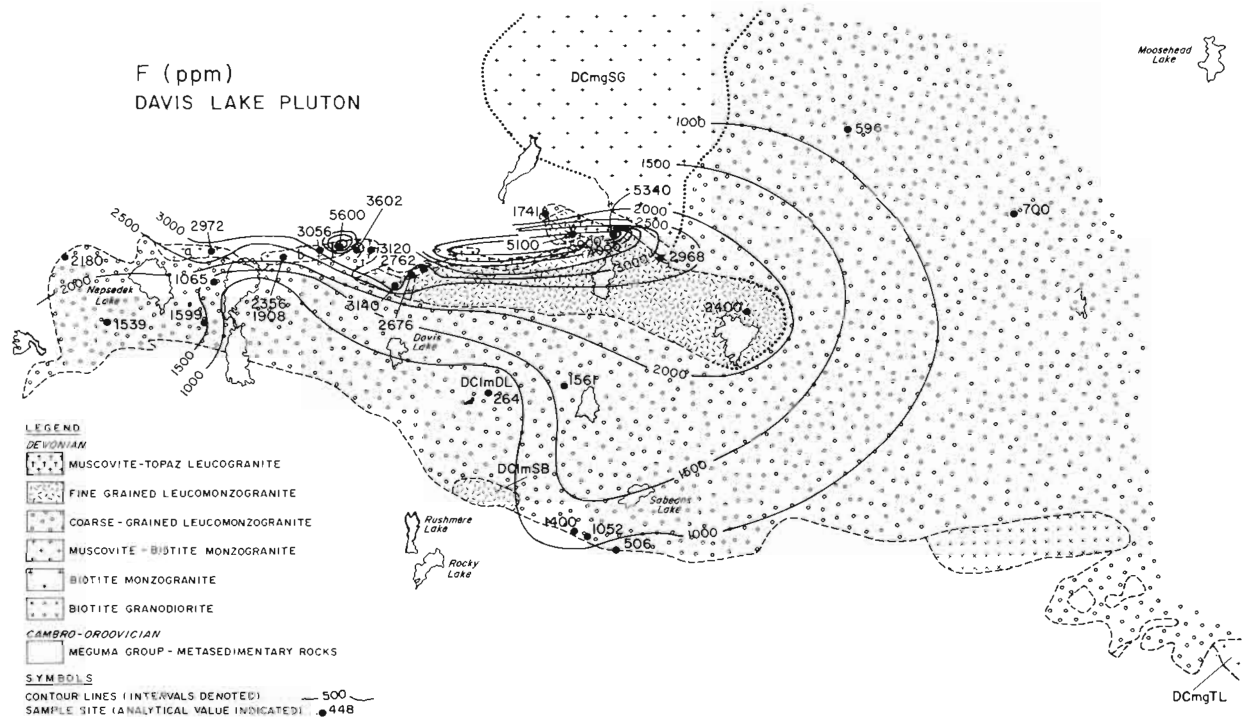

Figure 10. Distribution of fluorine in whole-rock samples from the Davis Lake Pluton (data from Ham *et al.*, 1990). Contouring was performed manually using contour intervals chosen to best display the entire data range.

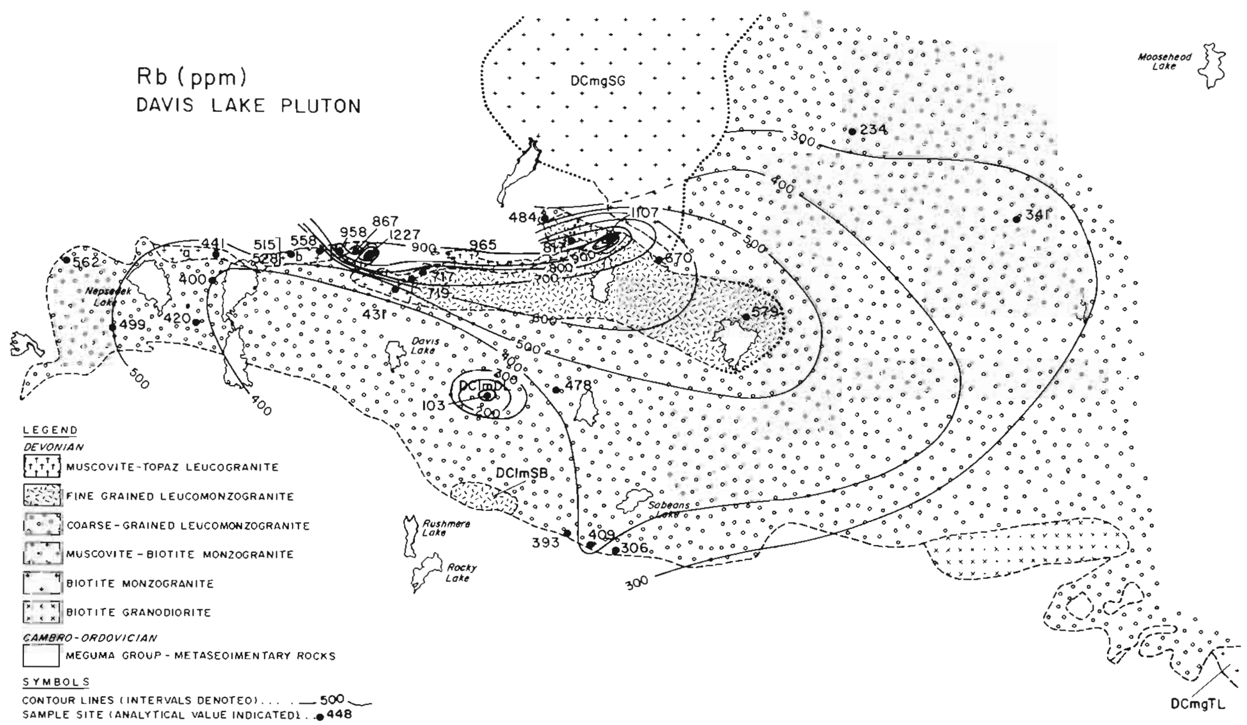

Figure 11. Distribution of rubidium in whole-rock samples from the Davis Lake Pluton (data from Ham *et al.*, 1990). Contouring was performed manually using contour intervals chosen to best display the entire data range.

It is generally agreed by the above authors that the penetration of radiometric surveys is approximately 1 m. Therefore, radiometric responses from the Geological Survey of Canada data can be explained by a combination of bedrock and surficial features. For example, most of the Stage 1 plutons, which are lithogeochemicaly enriched in U and K when compared to Stage 2 plutons, are clearly defined by several responses, including eqU, eqK and

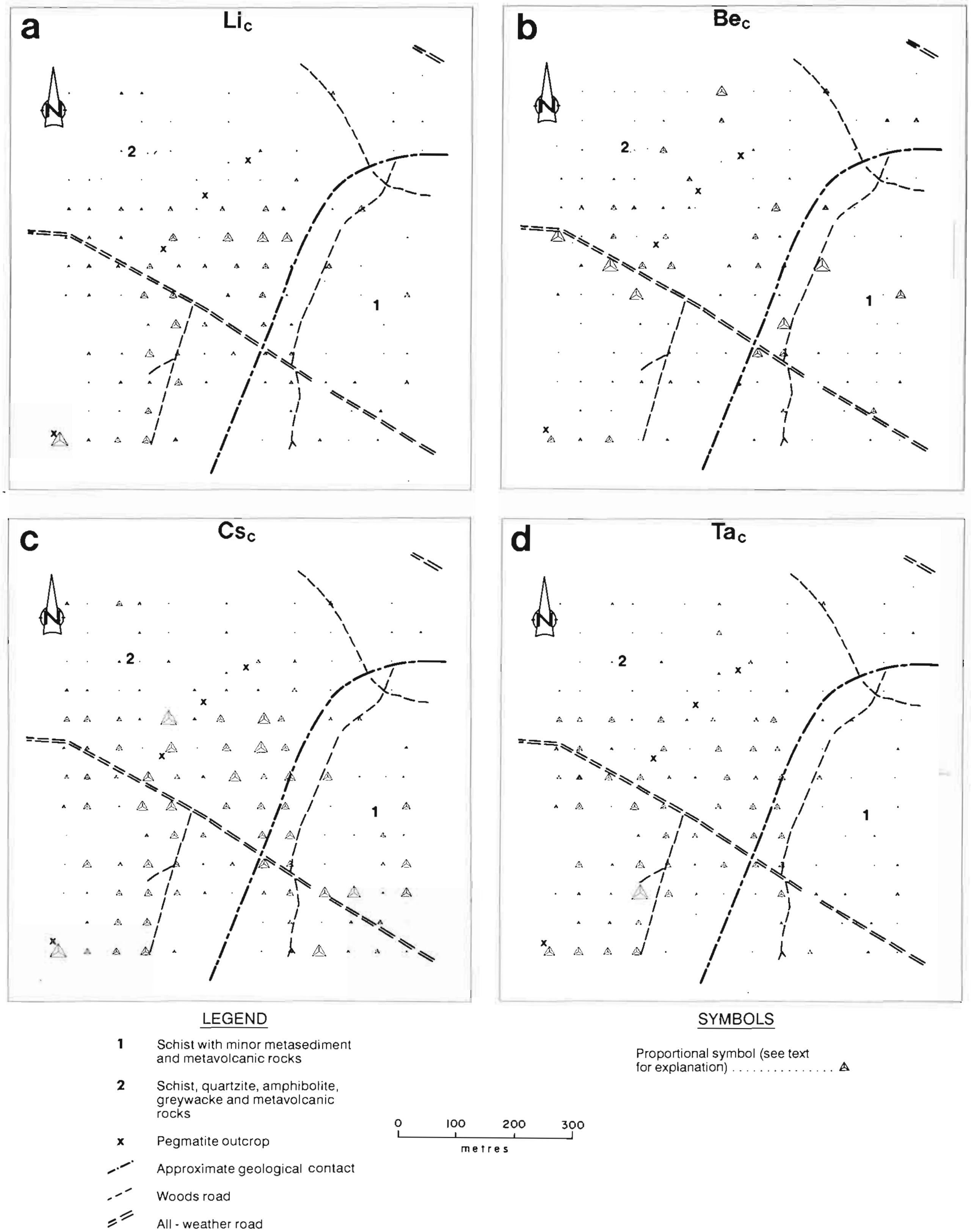

Figure 12. Proportional symbol plots for humus ash (data corrected for organic contents; from MacDonald *et al.*, 1992b) from the area of spodumene ± beryl pegmatites near Brazil Lake. Note the close spatial relationship between high lithium concentrations in humus and outcrops of rare-metal pegmatite, indicated by Xs on each plot.

eqU/eqTh. In addition, cryptic normal and reverse compositional zoning in both Stage 1 and 2 plutons, such as in the Halifax, Salmontail and New Ross plutons (MacDonald and Horne, 1988; Horne *et al.*, 1989; MacDonald *et al.*, 1992b), are also evident in much of the radiometric data.

Complex radiometric patterns in some parts of the South Mountain Batholith and other Meguma Zone granitic bodies are difficult to explain in terms of the observed rock types (O'Reilly *et al.*, 1988). Some of these patterns reflect the presence of large-scale alteration features, including albitization and K-feldspathization, or highly specialized leucogranite bodies (Chatterjee and Muecke, 1982; O'Reilly *et al.*, 1988; Ford, 1993). In other areas, observed radiometric patterns are best explained by the dispersion of granitic and non-granitic rock in the complex series of Pleistocene deposits that overlie the batholith (O'Reilly *et al.*, 1988; Finck *et al.*, 1988).

It should be stressed that spectrometric data can be used at various scales to interpret different bedrock and surficial features. On a large scale, data can be used to define batholith- and pluton-scale compositional trends. On a more local scale, these data can also be used to define individual granite-granite or granite-metasediment contacts (MacDonald *et al.*, 1992b). Spectrometric data can also be used as exploration tools to delineate high response areas with intense greisenization, albitization and K-feldspathization associated with greisen-type and U-bearing vein-type mineralized zones, such as the Millet Brook deposit (Chatterjee *et al.*, 1982). In addition, radiometric response can be used to define specialized leucogranites that commonly host pegmatite-type deposits. Finally, the presence of intense alteration zones at the former New Ross Mn mines (O'Reilly, 1992) indicates that radiometric data may be useful in outlining these types of vein-style deposits.

The chief drawback with airborne gamma-ray spectrometrie surveys is the difficulty in distinguishing between the contributions from each of the various geological features outlined above. For example, an area of very high eqU and eqU/eqTh may reflect the presence of a specialized granite, which may or may not contain mineralized or intensely altered zones. In addition, the actual shape of the anomaly may have been changed significantly by glacial dispersion. It should be stressed that data from radiometric surveys must be evaluated in light of all these factors.

Other Geophysical Techniques

Several other geophysical techniques, including electromagnetic (EM), very low frequency (VLF), resistivity, induced potential (IP), and gravity methods, have been employed with varying degrees of success over the batholith. Most techniques have been used by private-sector exploration companies; however, some government surveys have also been conducted.

Gravity data for the batholith mostly originate from regional surveys (6 km spacing) by the Geological Survey of Canada (Miller and MacDonald, 1993). These data indicate the presence of two gravity lows centred over the Davis Lake and New Ross plutons, which are interpreted as representing the thickest portions of the batholith. In general, detailed gravity surveys have not been used extensively in the batholith. The most notable exceptions include: (1) delineation of a negative gravity anomaly near Caledonia, Queens County, by Biliton Canada (MacGillivray, 1982), which was interpreted as representing a buried granite cupola. This is consistent with the presence of polymetallic W-Sn-bearing quartz-greisen veins and associated breccia pipes and mineralized skarns (O'Reilly, 1985) in this area; and (2) recognition of an inflection in the granite-metasediment contact north of the East Kemptville tin deposit, which was interpreted by Pitre and Richardson (1989) to be a critical factor in formation of the Duck Pond tin deposit.

MacDonald *et al.* (1992b) noted that rocks of the batholith do not contain magnetite or significant quantities of other minerals with high magnetic susceptibility. Accordingly, regional magnetic and vertical gradiometer surveys outline the batholith as an area of relatively flat magnetic response, particularly when compared to the highly responsive metasedimentary rocks of the Meguma Group (Miller and MacDonald, 1993). Detailed magnetic surveys have not been extensively used for exploration in the batholith. However, magnetic techniques could possibly be used to explore for mineral deposits containing high modal proportions of hematite, most notably vein-type deposits, and pyrite, such as some of the greisen- and breccia-type deposits. Magnetic techniques are not applicable for delineating pegmatite-type mineral deposits.

Electrical geophysical methods, including induced polarization (IP) and self potential (SP), have been successfully used to define sulphide- and oxide-bearing zones within the batholith. Corey and Horne (1989) used IP to delineate the extent of sulphide zones along the trace of the Tobeatic Fault Zone at the south-western margin of the batholith. Corey (1983) used electrical geophysical techniques to detect arsenopyrite-bearing albitite dykes in the Upper New Cornwall area, Lunenburg County.

Electromagnetic (EM), very low frequency (VLF), and resistivity techniques are sensitive to subsurface conductors such as sulphide- and graphite-bearing zones and have been used effectively in the batholith. For example Corey (1983) identified alteration zones (albitization, greisenization) in the Upper New Cornwall area using VLF and resistivity surveys. VLF and EM methods are also very useful for identifying clay-rich layers, such as at Millet Brook, New Ross manganese mines, and the Little Tobeatic Lake breccia-type occurrence (McKenzie, 1988). Resistivity surveys are particularly effective for outlining the presence of water-bearing zones, including mineralized veins and associated fracture zones at the Millet Brook U-Cu-Ag deposit (Chatterjee *et al.*, 1985).

Discussion and Summary

Mineral exploration in the past several decades has focused principally on the potential for greisen- and vein-type mineral deposits throughout the batholith with sporadic exploration for breccia-type metal deposits along the southern margin of the Davis Lake Pluton (MacDonald, 1994). This activity led to discovery of the greisen-style, polymetallic tin deposit at East Kemptville, the vein-type U-Cu-Ag deposit at Millet Brook, and numerous other occurrences. Most mineral occurrences have been noted to have characteristic geochemical and geophysical responses. The geochemical signatures of the four main deposit types have been noted to reflect their different mineralogy and associated alteration mineral assemblages; subsequently, future geochemical programs should consider utilizing statistical techniques to establish multi-element anomalies. This may assist in differentiating between styles of mineralization. For example, it may be possible to distinguish F anomalies associated with vein-type mineralization (U-Cu-Mn-P-**F**-Ag) from greisen (Sn-W-Mo-As-Cu-Pb-Zn-Bi-Au-Ag-B-**F**-P-Na-K) or pegmatite (Mo-Sn-W-Cu-Nb-Ta-Be-B-**F**) deposits by looking at the associated elemental assemblages.

Lake sediment surveys have been shown to reflect large-scale bedrock (and presumably till) features, including metallogenic domains (Rogers *et al.*, 1990; Fig. 4) and metal-rich regions of the batholith (e.g. New Ross, East Kemptville, Long Lake; Figs. 2 and 3). However, it should be noted that lake sediments will have limited application for detailed mineral exploration, owing to the relative size of the catchment basins and the nature of lake sediment deposition.

Till surveys have been shown to be an effective exploration method for pin-pointing the location of granite-hosted mineral deposits in the batholith, particularly when coupled with other geochemical and geophysical techniques (e.g. lake sediment geochemistry, gamma-ray spectrometry). Explorationists have used detailed till surveys extensively to define trenching and drilling targets. Finck and Stea (1995) note that the surficial geology overlying the batholith comprises several till sheets with varying compositions and proportions of distal and local components. It is critical that future till exploration programs consider these factors, particularly when anomaly vs.background thresholds are established.

Biogeochemical techniques have not been used routinely for mineral exploration in the batholith; however, it is clear from initial studies that plant tissue can be used to detect several different types of deposit. Consequently, the potential of using biogeochemical techniques should be considered in future programs, particularly in light of their relative cost-effectiveness. Biogeochemical surveys should be coupled with till studies to aid in interpretation of data.

Lithogeochemical analysis provides detailed information regarding primary dispersion and degree of fractionation in both Stage 1 and Stage 2 plutons. Accordingly, this information can be used to target areas with potential for vein-type (e.g. New Ross Mn mines) or greisen-type deposits (e.g. East Kemptville deposit) that have been demonstrated to occur in highly fractionated parts of normally zoned plutons. Similarly, lithogeochemical analysis can be used to define individual bodies of highly fractionated leucomonzogranite and leucogranite, which commonly host pegmatite- and greisen-type mineral deposits (e.g. New Ross area). Lithogeochemistry is not particularly suited for establishing target areas for breccia-type deposits, which are fault-controlled and may cross-cut less fractionated granites and/or metasedimentary host rocks.

Geochemical analysis of organic soil (i.e. humus) can provide a cost-effective exploration method for granite-hosted mineralization. However, it should be noted that geochemical analysis of ashed humus is strongly influenced by the organic content of samples (MacDonald *et al.*, 1992a).

Geochemical exploration for vein-type Fe-Mn deposits, such as the New Ross Mn mines, is somewhat problematic in light of the paucity of enrichment in granophile elements such as U, Ta, Rb in these deposits. It is difficult to use Mn or Fe as diagnostic exploration elements since they are strongly affected by surficial hydromorphic processes and are enriched in low-lying, swampy areas. It may be possible to remove the hydromorphic effects by some data correction procedure, possibly entailing Loss on Ignition values which indicate the amount of organic content in each sample. It is also possible that indicator elements may be established for this type of mineralization. For example, ore zones at New Ross Mn mines have high modal proportions of fluorapatite and, subsequently, high concentrations of F and P_2O_5. The possibility of using these and other elements as pathfinders for Mn-Fe deposits warrants evaluation.

Airborne gamma-ray spectrometric techniques are especially useful for detecting vein-type U-Cu-Ag deposits and can also be utilized to delineate specialized bodies that commonly host greisen- and vein-type deposits. Spectrometric surveys may also be used to detect hydrothermal alteration including potassic zones that routinely are associated with greisen-style mineral occurrences.

Vein- and breccia-type deposits are localized along shear and fault zones, as evidenced by the Tobeatic Lake (Pb-Zn-Ba-Au-Ag) breccia occurrences, the Millet Brook U-Cu-Ag deposit, and the New Ross Mn mines deposits. Several geophysical techniques can be used to explore for these types of mineralization, including VLF, IP, EM and SP surveys.

Future exploration programs should employ a combination of geochemical and geophysical techniques and will assuredly benefit from the extensive data sets that have been generated by both provincial and federal government surveys, along with mineral industry assessment work. Exploration programs that combine available bedrock and surficial geological information, geochemistry and geophysical data, and basic prospecting, should lead to the discovery of additional granite-related deposits in or around the South Mountain Batholith.

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