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LANDSAT MSS AND AIRBORNE GEOPHYSICAL DATA COMBINED FOR MAPPING GRANITE IN SOUTHWEST NOVA SCOTIA

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I ABSTRACT

The South Mountain Batholith underlying most of S.W. Nova Scotia has been described as a cogenetic suite of granitoid plutons intruding lower Paleozoic metasediments. The study area, located at the western tip of this batholith, includes both a granodiorite and a monzogranite pluton, intruding into metagreywackes. All rock types are covered by 5-20 m. of glacial till. A major Sn-Cu-Zn ore body occurs within the test site near the village of East Kemptville. Three radioelements (K, eU, eTh) and the 3 radioelement ratios of a high sensitivity airborne gamma-ray spectrometric survey have been registered to a geometrically corrected LANDSAT MSS (DICS) scene and the whole data set analysed using an image analysis system. The 2 plutons and the metasediments were mapped using a modified parallelpiped classification and both plutons were further subdivided into 8 'phases' using the eU and eTh content. Two differentiation trends are recognized in the monzogranite, one associated with the normal crystallization processes, and a second trend involving deuteric alteration which is associated with the E. Kemptville mineralization. Areas for further exploration are outlined.

II INTRODUCTION

Airborne gamma ray spectrometric data in Canada are commonly published as contour maps of the total count, the 3 radioelements (K, eU, eTh), and 3 element ratios (eU/K, eU/eTh, eTh/K) along with a profile for each flight line showing traces of all radioelements, ratios, altimeter and total field magnetics. Even for a modest survey like this, with more than 40 maps and profiles, analysis is a formidable task using only hard copy maps.

This study was designed to show how multilayered gamma-ray spectrometer data can be manipulated on an image analysis system to discriminate between areas underlain by granitic rocks and areas underlain by metasedimentary rocks, both having a continuous cover of glacial till. The study was later extended to identify and map two kinds of granitic rocks (monzogranite and granodiorite) that coexist in the study area. The work led to a third goal, which was to partition each of the granitoids into 'phases' based on the geochemical differentiation of the 2 magmas as they cooled. This final activity led to the recognition of 2 distinct differentiation trends within the Davis Lake Pluton, a granite pluton particularly rich in volatiles. One of these differentiation trends is presumed to be responsible for the major tin, copper, zinc deposit of East Kemptville that will be brought into production in the fall of 1985.

Thanks are due to J.M. Carson, K.A. Richardson and K.L. Ford, Geological Survey of Canada, for providing the radiometric data and for reviewing this paper, and to D. Williams, J. Harris and L. Neilly who were responsible for most of the processing of the data which was carried out at the Radarsat Project Office in Ottawa.

III STUDY AREA

The study area, 45 km by 25 km in size (Figure 1), is located almost entirely in the Yarmouth and Digby counties of southwestern Nova Scotia.

Lake Rossignol which lends its name to the area is 30 km to the east. The topography consists of low rounded hills, and the intervening hollows are swampy or lake filled. Local relief is in the order of 15 to 30 metres. While till covers the entire area, boulders are particularly common over granitic terrain. A dense secondary growth of trees and bushes flourishes over granitic areas.

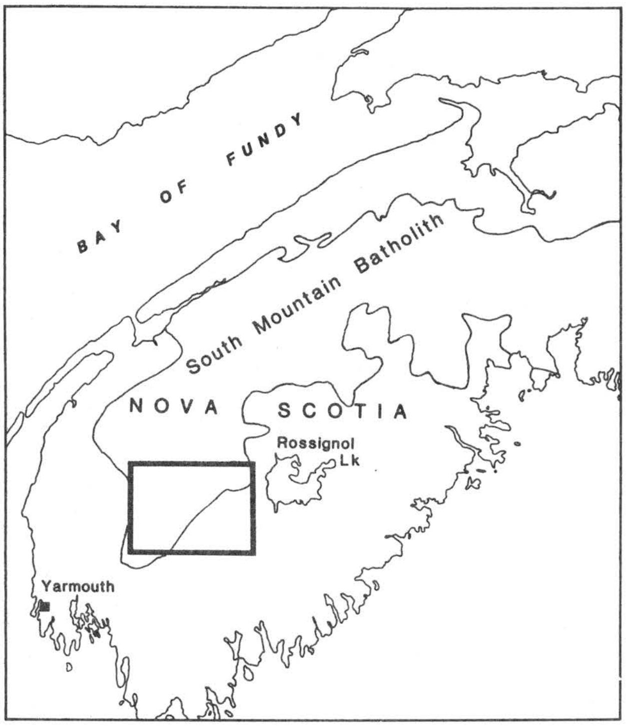

Figure 1. Lake Rossignol study area and the South Mountain Batholith.

IV GEOLOGY

The South Mountain Batholith is a large, arcuate, granitic complex of late Devonian to early Carboniferous age, 200 km long and up to 50 km wide, which underlies the greater part of southwestern Nova Scotia. The eastern and central parts of the complex are reasonably well known while the western portion has been mapped only at the reconnaissance level (F.C. Taylor, 1979).

Chatterjee and Muecke (1982) described the Batholith as consisting of a series of plutons whose compositions range from early crystallizing biotite granodiorite to muscovite-biotite monzogranite followed by leucocratic monzogranite. The plutons all appear to be members of a cogenetic suite.

The Rossignol study area lies at the southwestern tip of the South Mountain Batholith. Taylor's geology map (Fig. 2) of the area shows an undivided granite underlying about two thirds of the area, with metasedimentary rocks of the Cambro-Ordovician Meguma Group occupying the southeastern portion and a triangular re-entrant in the southwest. The metasediments are dominated by metagreywackes of the Goldenville Formation. A limited area of Halifax Formation slates and schists is believed present near the edge of the granite in the northeast of the study area, although there are no outcrops. The metagreywackes form tight near-vertical folds with a northeast regional trend characteristic of the Arcadian orogeny. The granite boundary crosses the fold structures indicating an intrusive relationship. There are no fractures on Taylor's map.

In Pleistocene times the entire area was glaciated and all rock units are now entirely obscured by five to twenty metres of till with very few outcrops. The main movement of the last ice sheet was to the southeast which is confirmed by the orientation of the many drumlins and elongate lakes which occur in the eastern part of the area.

In 1976, an exploration programme was started which led to the discovery of a large tin, copper, zinc deposit near the village of East Kemptville, in the southwest quadrant of the study area. The East Kemptville deposit (Fig. 6) will be the only primary tin mine in North America when it goes into production in the Fall of 1985. The annual production is estimated to be 45,000 tonnes of tin concentrate, 1,500 tonnes of copper and 2,400 tonnes of zinc concentrate with proven reserves for 17 years (Whitaker, 1983). The main orezone fills a local infold of the granite margin.

The granite underlying the ore zone is a muscovite-biotite monzogranite that has, at least locally, been affected by late magmatic or post crystallization alteration processes which are assumed to be related to the formation of the ore body itself. These alteration processes have locally greisenized, sericitized and brecciated the rock. This granite is now known as the Davis Lake Pluton. Its boundaries are not well defined and its relationship to the granodiorite which occurs at the northwest and northeast corners of the study area is still unknown.

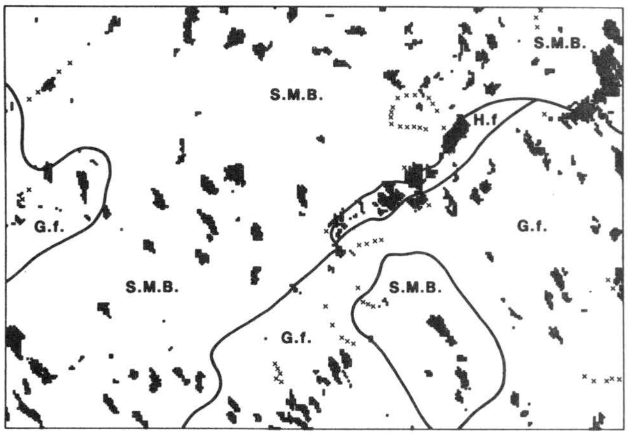

Figure 2. Geology map, based on Taylor (1969) SMB, South Mountain Batholith; G.F., Goldenville Formation; H.F., Halifax Formation; X, outcrop, Lakes are taken from the LANDSAT MSS (DICS) scene.

V DATA SETS

The high sensitivity airborne gamma ray survey was flown in 1978 by the Geological Survey of Canada, and published in 1981 as Geophysical Series Map 35121(3G). The survey contains 40 east-west lines flown one kilometre apart. The information was recorded digitally and later compiled and presented in units of radioelement concentration. Figure 3 shows the distribution of Potassium in percent, Figure 4 shows the distribution of eU in ppm, and Figure 5 shows the distribution of eTh, also in ppm. Gamma ray spectrometer technology has been described by Grasty (1976) and the techniques used to correct and compile the results have been described by Grasty and Darnley (1971). For this investigation a CCT of six radiometric variables (K, eU, eTh and the ratios eU/K, eU/eTh, and eTh/K) were resampled to a 100 by 100 metre grid and scaled to 0-255 DN levels. The data were registered to a geometrically corrected LANDSAT MSS (DICS) image.

The Digital Image Corrected Scene (DICS) LANDSAT image is a standard product of the Canada Centre for Remote Sensing. The image is geometrically registered to a National Topographic Series (NTS) map sheet, the scan lines are parallel to lines of latitude, and pixels represent 50 by 50 metres. The brightness values of the four channels are stretched to the full DN range (0-255) of the tape. The complete data set (6 channels of radiometric data and four channels of LANDSAT MSS) was investigated using a DIPIX ARIES II image analysis system. Hard copy outputs were produced using an Applicon color jet plotter.

Airborne magnetic data were also acquired, but because there is little magnetic relief and no contrast between granite and sediment, they were not used in this study.

VI ANALYSIS AND RESULTS

A DELINEATION OF GRANITES

A variety of processes and combinations of processes were applied to the spectrometric data. These include band composites, ratios, band stretches, level slices and a principal components (3 radioelements, 3 ratios) transformation. The most helpful product was a 3 band colour composite produced by slicing each of the radiometric channels. All K values above 1.5% were coded blue, eU values above 2 ppm were coded red, and eTh values above 5 ppm were coded green. Where any two elements are above the given threshold, new colours are formed (K + eU = magenta, K + eTh = cyan, eU + eTh = yellow). White appears where all 3 elements exceed the threshold, and black when none of them does. The threshold values were chosen by visual estimation at a location where the granite-sediment boundary was most easily identified. This was where the spectrometric gradient in all 3 elements was steepest. This first stage of the investigation produced several striking results.

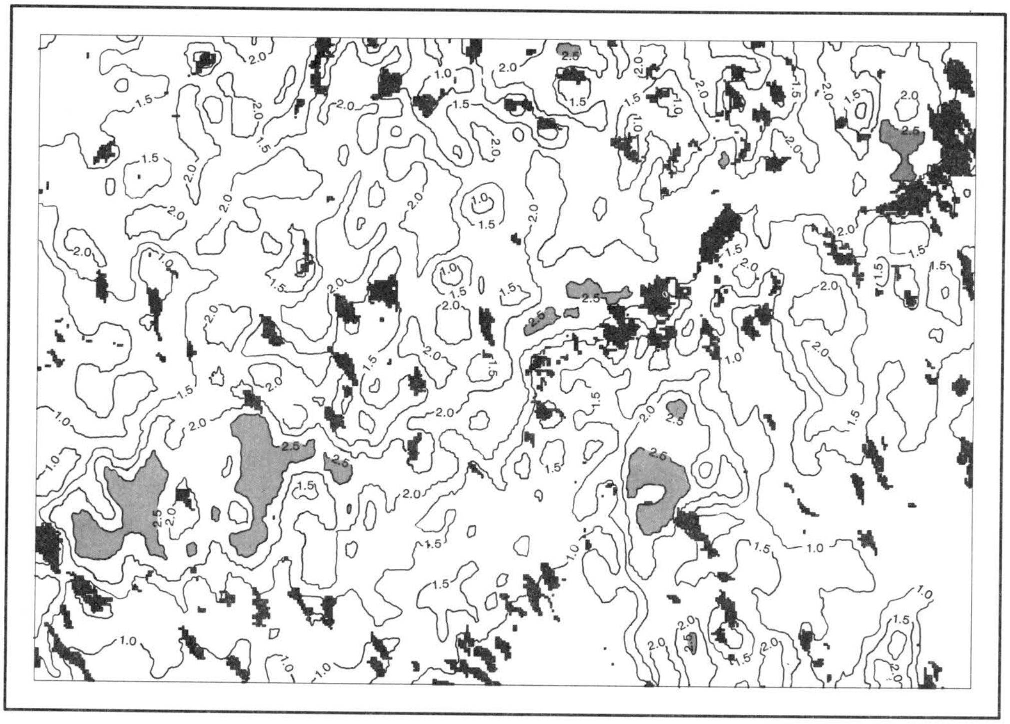

Figure 3. Distribution of Potassium (in percent).

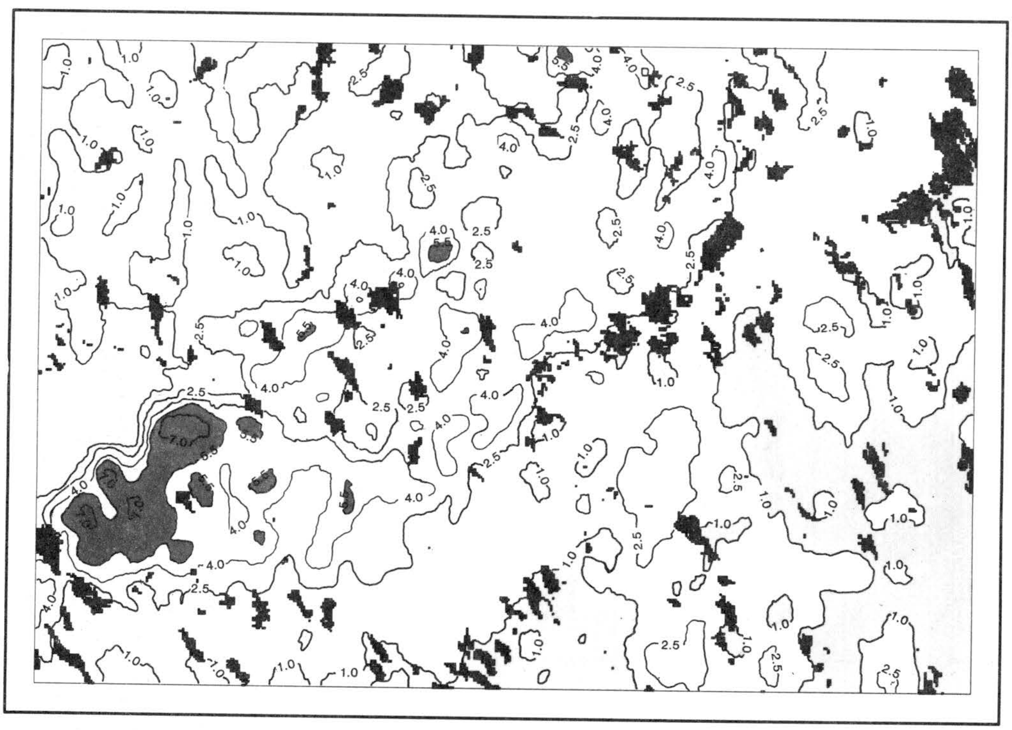

Figure 4. Distribution of equivalent Uranium (in ppm).

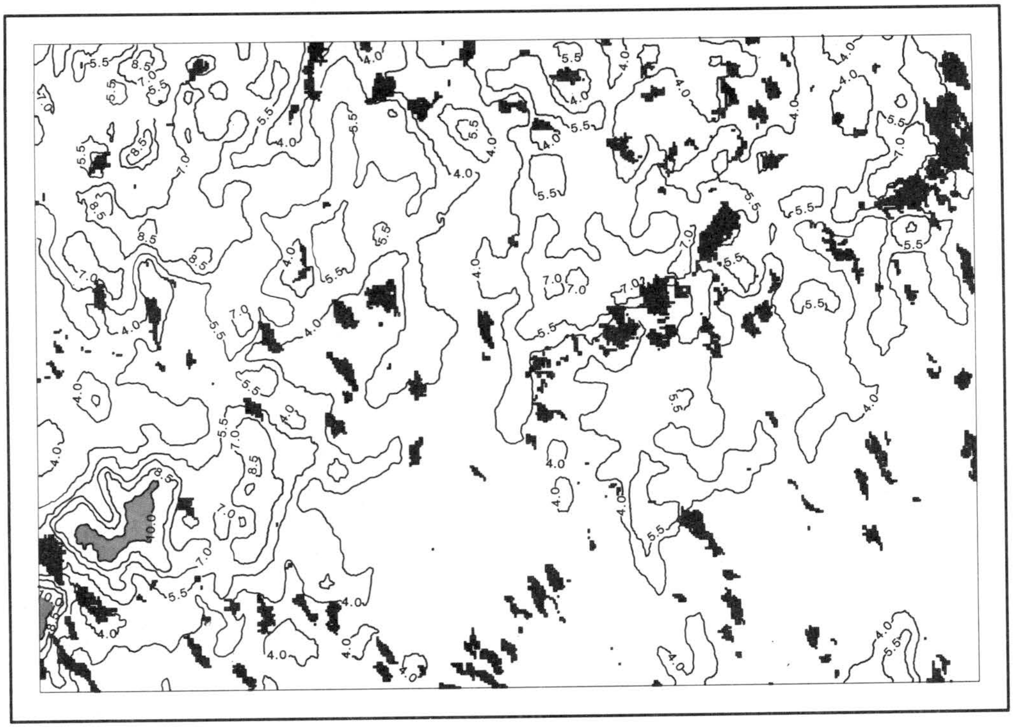

Figure 5. Distribution of equivalent Thorium (in ppm).

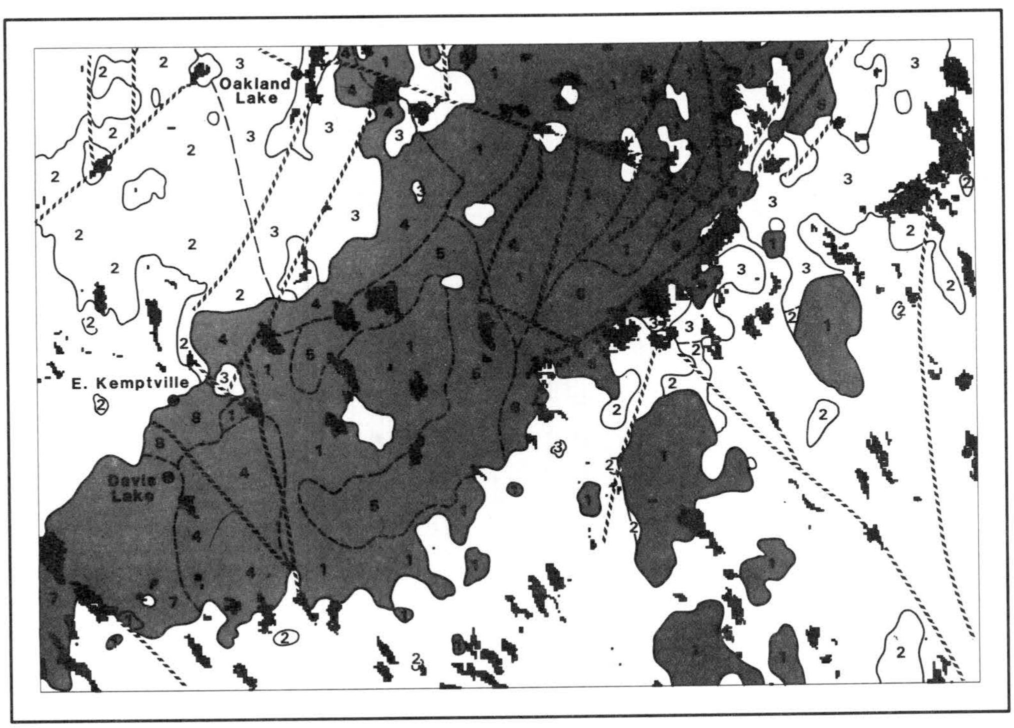

Figure 6. Davis Lake pluton (dark grey), granodiorite (pale grey), metasediment and swamp (white). Granitic phases, separated by dashed lines, are numbered. Granodiorite: 2 = outer, 3 = inner; Davis Lake pluton: 1 = main body, 4 = NW margin, 5 = Horseshoe, 6 = SE margin, 7 = SW tip, 8 = E. Kemptville.

The colour-slice map provides an excellent separation between metasediments (no element or one element above threshold) and granites (2 or 3 elements above threshold). The same map also separates areas of granodiorite (K and eTh above threshold) from the Davis Lake Pluton (eU, and K, and locally eU, K and eTh above threshold). Granodiorite underlies the northwest and northeast quadrants of the study area, while the Davis Lake Pluton takes the shape of a NE-SW lens, the NE extremity of which is embedded in granodiorite, and its SW end surrounded by metasediments. This division is seen on Figure 6 where the metasediments appear white, the granodiorite is pale grey, and the Davis Lake Pluton dark grey.

Numerous small (1-5 km diameter) granitic stocks are scattered about the S.E. quadrant and a single one occurs in the western metasedimentary re-entrant. This pattern of intrusive granites is much more complex than Taylor's geology map indicates. Some of the stocks have the high K and eTh associated with granodiorite, others are radiometrically similar to the Davis Lake Pluton.

B GRANITIC PHASES

The second part of the investigation was concerned with subdividing the granodiorite and the Davis Lake Pluton. This was done by visual examination of the radioelement maps, the ratio maps and the principal component maps. The statistics (mean and standard deviation for each element) for each of the granitic 'phases' that were identified were calculated using the image analysis system.

The separation of the granitoid rocks into phases has two purposes, it provides information about how the plutons crystallized, and, in the case of the Davis Lake Pluton, it may also indicate other areas of potential tin mineralization.

Granodiorite An 'inner' (core) and an 'outer' (shell) phase was identified, based on 1-2 ppm higher eTh in the 'outer' phase. The two phases are best seen on the eTh and the eTh/K ratio maps.

Davis Lake Pluton

1. The Southwest Tip phase was identified because it contains the highest values in all 3 radioelements.

2. Southeast Margin phase. Potassium values are high along a 1 km wide zone following the southeast edge of the pluton. eU values are also higher here. Higher eTh occurs where the margin is against granodiorite.

3. Northwest Margin phase. There is a modest increase in eTh and K levels.

4. East Kemptville phase. A lozenge shaped area 3 km across, with a sharp boundary. An area of average eU and low eTh, it can be seen on the 3 element colour composite, the eU/eTh ratio map and the 6th principal component map. The East Kemptville ore body is located on the outer (western) edge of this phase.

5. Horseshoe phase. Shaped like an inverted horseshoe, this arcuate zone lies across the middle of the pluton with eU and eTh values similar to the East Kemptville phase, it can be seen on the 3 element colour composite, the eU/eTh ratio map and the 6th principal component map.

6. All parts of the pluton not otherwise categorized are described as the Main Body phase.

The location of each granitic phase is shown on Figure 6.

The mean and standard deviation for each element in each of the granitoid 'phases' are shown on Figure 7.

The granodiorite is easily recognized because it combines low eU levels with relatively high values in eTh.

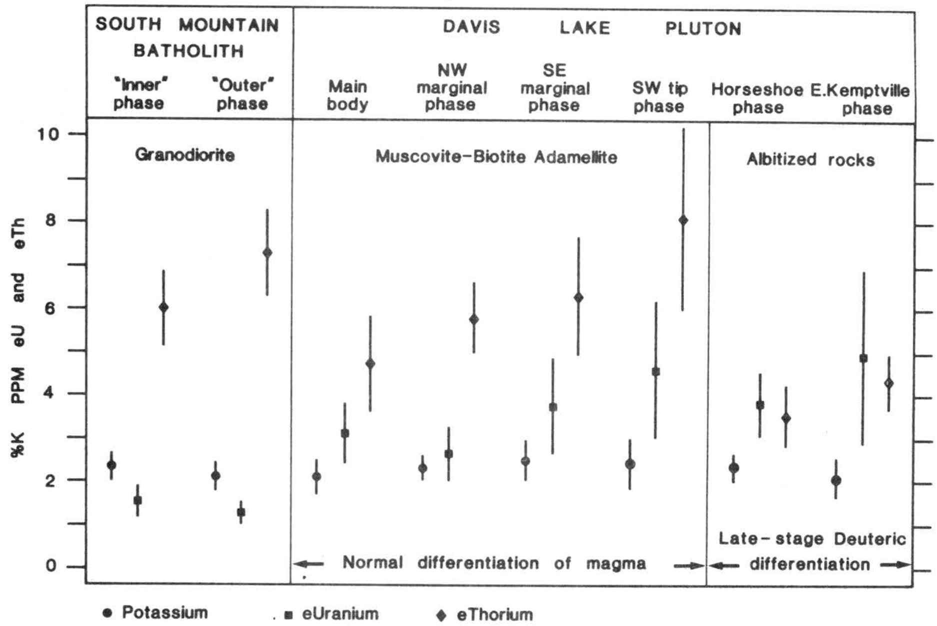

Figure 7. Means and standard deviations for K, eU and eTh for each phase of the Davis Lake pluton and the granodiorite.

The Davis Lake Pluton phases form 2 groups. The larger group includes the Main Body, the NW and SE Margins and the SW Tip. In this group, the eTh levels are always greater than the eU and both elements increase or decrease together. The radioelement distribution of the 4 phases in this group typifies the normal crystal differentiation processes which occur in a granite magma as it cools. Uranium and thorium appear to have migrated to the outer margins and to the southwestern tip of the intrusion, to be concentrated there when the granite cooled.

The smaller group contains evidence of a second differentiation process superimposed on the Davis Lake Pluton. In both the E. Kemptville and Horseshoe phases, eU is equal to or greater than the eTh, and the eTh levels are lower than any of the other phases. For reasons that are not clear it is likely that the thorium in these 2 areas may have been removed by the alteration processes after most of the rest of the pluton had crystallized. What is important is that these alteration processes also redistributed tin, copper and zinc elements, some of which were deposited to form the E. Kemptville orebody. One presumes that the area of the Horseshoe phase also represents an area favourable for the deposition of tin mineralization.

Because the ground is almost entirely hidden by secondary tree growth, most of the information content of the MSS (DICS) image is textural rather than spectral. This was confirmed using an unsupervised classification. All but one of the clusters were related to vegetation, and the class boundaries did not associate with any rock unit. The granitic rocks are more easily recognized by a smooth topography with freely draining soils and with scattered rectangular to sub-rounded lakes. Areas underlain by sediment have a pattern of lakes elongated NW-SE parallel to the direction of glacial movement. Drumlins are also very common and are easily recognized because the vegetation cover is light or absent along the tops of the ridges. A few of the larger granite bosses can be resolved on the image by their smoother texture. The DICS image also provides evidence of a brittle fracture pattern. Fractures (Figure 6) appear to be concentrated along the NW and SE margins of the Davis Lake Pluton. A few fractures can also be seen crossing the Pluton.

VII CONCLUSIONS

Airborne gamma ray data can be used to separate areas of granite from areas of metasediment, even when all the rocks are covered by till. The K channel provides most information but significant levels of eU or eTh are needed to confirm the presence of granite. Two bodies of granite with distinct radioelement characteristics were identified. The granodiorite is characterized by a very low eU/eTh ratio (approx. 0.25) which is mainly due to low eU values. In the Davis Lake pluton, eU values are always greater than 2 ppm, and two distinct differentiation processes have been recognized. One of these trends represents the normal process of crystallization. Here the eU/eTh ratio is always about 0.5, even though absolute values of eU and eTh vary. This trend is not associated with any known mineralization.

The second trend results from late stage alteration processes. The eU/eTh ratio is 1.0 or more, mainly brought about by thorium depletion. This trend is apparently associated with a major tin-copper-zinc deposit. Similar processes affecting granites in other parts of the South Mountain Batholith have been described by Ford (1982), and by Maurice and Charbonneau (1983).

The role of the MSS (DICS) scene was not insignificant. By providing a view of the terrain surface it influenced the analysis of the radiometric data. It also provided specific information about the distribution of glacial material and was used to identify a brittle fracture pattern. The lake pattern file derived from the MSS scene was superimposed on all of the output maps, making comparisons between the different maps much easier.

This study would not have been completed without the use of a digital image analysis system. Visual comparisons of the different data sets permits normal geological reasoning to be applied to the study of multi-layered data sets. The IAS makes pixel-to-pixel classifications and statistical analyses possible and simplifies the generation of complex output maps.

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