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Airborne gamma-ray spectrometry over the Endako porphyry molybdenum district in central British Columbia[1]

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Abstract: In 1995 airborne gamma-ray spectrometric data were acquired over the Endako porphyry molybdenum district in central British Columbia. Here we analyze these data together with surficial and lithogeochemical data to assess their utility as an aid to geological mapping and mineral exploration. Our results show that individual surficial units (e.g. till, glaciolacustrine, alluvium, etc.) cannot be distinguished in airborne data or geochemical analyses of surficial deposits. We observe small differences in mean radioelement concentrations between mapped bedrock units, even in areas of thick overburden; however, as all such differences are statistically insignificant, individual bedrock units cannot be uniquely identified by their radioelement response alone. We conclude that airborne spectrometry has limited mapping application where variations in bedrock compositions are subtle. Unlike other porphyry molybdenum occurrences in Canada, those in our study area are characterized by modest enrichments in both K and eTh relative to the host rock and significant eTh/K depletions are not observed.

Résumé : En 1995, un levé aérien par spectrométrie à rayons gamma a été réalisé dans le district du gisement porphyrique de molybdène d'Endako, dans la partie centrale de la Colombie-Britannique. L'analyse des données recueillies et des données sur les dépôts superficiels et sur la lithogéochimie visait à établir leur valeur pour la cartographie géologique et l'exploration minérale. Selon les résultats obtenus, on ne peut pas distinguer les unités superficielles individuelles (p. ex. till, sédiments glaciolacustres, alluvions, etc.) en utilisant les données aériennes ou les analyses géochimiques des dépôts superficiels. Nous avons noté de petites différences dans les concentrations moyennes des radio-éléments entre les unités cartographiées du substratum rocheux, même si la couverture de dépôts meubles est épaisse. Mais, comme ces différences ne sont pas statistiquement significatives, on ne peut pas faire uniquement appel aux radio-éléments pour identifier les unités particulières du substratum rocheux. En conclusion, la spectrométrie aérienne a des applications limitées en cartographie si la composition du substratum rocheux ne varie que faiblement. Contrairement aux autres gisements porphyriques de molybdène qui existent au Canada, ceux de la présente analyse sont modérément enrichis en K et eTh par rapport à la roche encaissante. Aucun appauvrissement significatif de eTh/K n'a été observé.

[1] Contribution to the Nechako NATMAP Project

INTRODUCTION

In 1995, as part of the Nechako NATMAP project, an airborne gamma-ray spectrometry survey was conducted over the Endako molybdenum mine and adjacent area (covering portions of NTS 93 K/2, 3 and 93 F/15 1:50 000 map sheets, Fig. 1). The spectrometric system consisted of a 36.6 L sodium iodide detector attached to a 256 channel Exploranium GR820 spectrometer. A total of 1300 line kilometres of data were acquired using a CESSNA 404 aircraft. Flight lines were east trending and flown at an average line spacing of 500 m and an average mean terrain clearance of 100 m (Shives and Holman, 1998). Radioelement potassium (K), equivalent thorium (eTh), and equivalent uranium (eU) concentrations were corrected for cosmic and background emissions, Compton scatter, and altitude variations. In addition to spectrometry data, total-field magnetic (Lowe et al., 1998), and VLF-EM data were also acquired as part of the same survey.

In general, the survey area is dominated by flat-topped hills and broad valleys and is extensively covered with till and other surficial deposits. Bedrock is comprised primarily of granodioritic to granitic phases of the Francois Lake Plutonic Suite and, to a lesser extent, by older and typically more mafic phases of the composite Endako Batholith (Anderson et al., 1998). Eocene rhyolite of the Ootsa Lake Group and basalt of the Endako Group overlie the Francois Lake Plutonic Suite primarily in the northwest part of the survey area.

There are thirty-four porphyry mineral occurrences recorded in the provincial MINFILE data base for the survey area. The majority of these are hosted in the Endako (8), Nithi (7), and Casey (6) phases of the Francois Lake Plutonic Suite. The world-class Endako porphyry molybdenum deposit, which was discovered in 1927 and opened as a mine by Placer Dome Ltd. in 1965, lies entirely within the Endako phase of the Francois Lake Plutonic Suite (Fig. 1a). According to the B.C. MINFILE database, in 1998, the mine accounted for 80% of British Columbia's molybdenum production.

The objectives of this study were to assess the utility of the gamma-ray spectrometric data for geological mapping and mineral exploration in this poorly exposed portion of the Nechako plateau. Much has been published on the capacity of spectrometric data to differentiate felsic from mafic rock units in a variety of geological settings, even where there is extensive surficial cover (e.g. Shives et al., 1995, 1997, O'Reilly et al., 1988). Generally, K and Th concentrations decrease with decreasing silica content. As much of the study area is underlain by granitic and granodioritic phases of the Francois Lake Plutonic Suite, the data in this study provided an opportunity to test if more subtle compositional differences in bedrock units could be differentiated. Our analysis, which was primarily undertaken using GIS technologies, incorporated lithogeochemical and surficial geochemical data.

In addition, several case histories from porphyry mining districts (Geological Survey of Canada, 1992, 1994; Shives et al. (1995) and references therein) show that alteration associated with the mineralizing process frequently results in a relative enrichment of potassium which can be distinguished from normal lithological potassium variations by characteristic depletions in the eTh/K ratios. Potassium feldspar, sericite, and kaolinite are common alteration products associated with mineralization at the Endako mine (Kimura et al., 1976). Consequently, depleted eTh/K ratios in these areas were expected.

All of the data acquired in the airborne survey are available in digital format and as selected 1:50 000 scale hard copy images. The interested reader is encouraged to consult Shives and Holman (1998) for details which are not included in this publication.

GEOLOGICAL SETTING

Surficial geology

Figure 1b shows the distribution of surficial units in the survey area as mapped by Plouffe (1996a, b). Glacial till covers most of the region and, in most areas, it is less than 1 m thick, although notable areas of greater thickness occur in the central and south eastern portions of the study area. Glaciolacustrine and alluvial deposits are, for the most part, restricted to the main river valleys and swampy ground that extend east-southeast through the central and south-central part of the survey area. In the Endako and Nithi river valleys, these units are typically greater than 2 m thick. Minor deposits of colluvium and glaciofluvial deposits are scattered throughout the region.

Bedrock geology

Much of the surveyed area is underlain by the Endako Batholith (Fig. 1a). The Francois Lake Plutonic Suite, the youngest and most evolved package of rocks in the batholith, is also host to the majority of the porphyry mineral occurrences in the region. The Francois Lake Plutonic Suite has been divided into two subsuites: the older suite includes the Glennanan and its two subphases, as well as the Nithi phase; the younger suite includes the Endako, Francois, and Casey phases.

The Glennanan phase (unit lJFG) is a white to pink, potassium feldspar porphyritic, coarse-grained, biotite-, hornblende-granite to granodiorite (Whalen and Struik, 1997). It is generally lithologically uniform, massive, and unaltered. The Tatin Lake subphase (unit lJFGt) is a younger, more felsic subphase of the Glennanan phase. It is a beige to pink, fine- to medium-grained, equigranular to potassium feldspar porphyritic-, biotite-granite and includes a hornblende- biotite granodiorite component (Whalen et al., 1998). The Hanson Lake subphase (unit lJFGh) is grey to white, coarse- to medium-grained, feldspar-porphyritic hornblende-biotite granodiorite to quartz monzonite (Whalen et al., 1998). It forms a single body in the north-central study area and is also more felsic than the Glenannan phase.

The Nithi phase (unit lJFN) is a coarse-grained, beige to orange, equigranular to potassium feldspar porphyritic, biotite-granodiorite (Whalen and Struik, 1997). It has a crumbly weathering pattern and is locally intensely altered. Where the

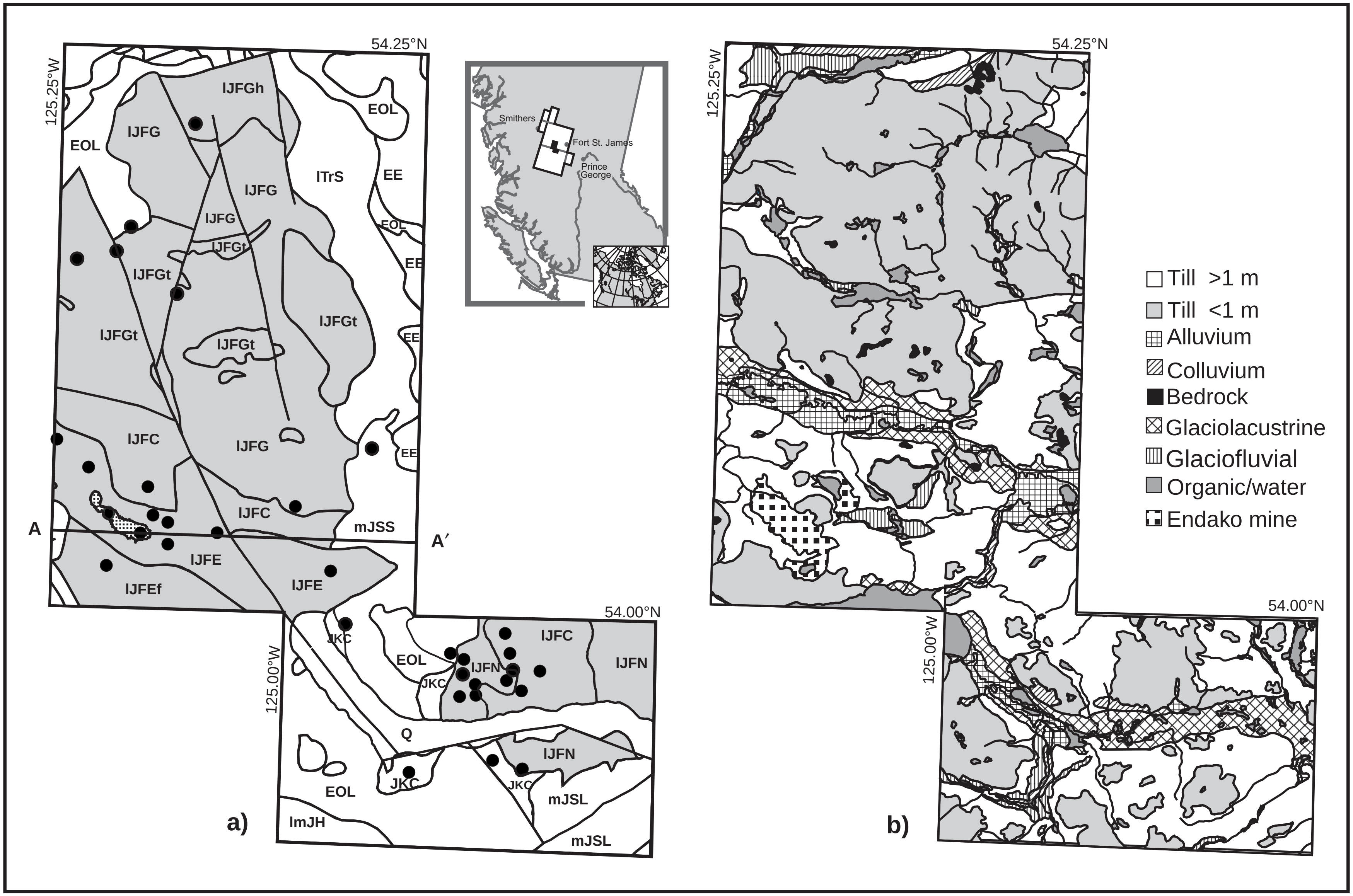

***Figure 1. a)** Bedrock geology (*compiled by *Anderson et al., 1998). Known mineral occurrences are shown as large black dots. The extent of the Endako porphyry molybdenum open-pit mine is stippled. The area is underlain primarily by the Nithi (*lJFN*), Glennanan (*lJFG*), Hanson Lake (*lJFGh*), Tatin Lake (*lJFGt*), Endako (*lJFE*), Francois (*lJFEf*) and Casey (*lJFC*) phases of the Francois Lake Plutonic Suite (shown in grey). Abbreviations of other units are as follows:* Q, *Quaternary deposits;* EE, *Endako Group;* EOL, *Ootsa Lake Group;* JKC, *Caledonia phase;* lmJH, *Hazelton Group;* mJSL, *Limit Lake phase;* mJSS, *Stellako phase;* lTrS, *Stern Creek phase. The airborne survey was conducted as part of the Nechako NATMAP Project (white area in inset map);* ***b)** Surficial geology* (*from Plouffe, 1996a, b). Major water drainages are shown in black.*

Casey and Nithi phases are in contact, they are characterized by veining, alteration, and several mineralized occurrences (Anderson et al., 1997).

The Endako phase (unit lJFE) is a coarse-grained, dark pink to orange, biotite-hornblende granodiorite to granite. It is subprophyritic with potassium feldspar and is dominantly fresh with unaltered mafic minerals, except in the vicinity the Endako porphyry molybdenum deposit (Whalen et al., 1998). The Francois subphase (unit lJFEf), which is exposed to the south of the Endako phase, consists of medium-grained, equigranular biotite- (± hornblende) granodiorite to granite. It is strongly altered and mafic minerals have been chloritized. The potassium feldspar is typically brick red (Whalen et al., 1998). Where fresh, the Francois subphase resembles the Endako phase, but is more evolved and altered.

The Casey phase is the youngest and most felsic phase of the Francois Lake Plutonic Suite. It is a fine- to medium- grained, dark pink, granophyric biotite granite or aplitic granite. It contains miarolitic cavities, some portions of which contain potassium feldspar and ovoid quartz-eye phenocrysts. Mafic minerals are oxidized or chloritized (Whalen and Struik, 1997).

Older plutons in the Endako Batholith, including the Stern Creek, Stellako, and Limit Lake phases, are exposed along the periphery of the Francois Lake Plutonic Suite. These phases range from late Triassic to mid-Jurassic and in composition from biotite-hornblende diorite to granodiorite and quartz monzonite (Anderson et al., 1997). Younger volcanic rocks of the Eocene Ootsa Lake and Endako groups outcrop in the northeast and northwest corners of the study area. The Ootsa Lake Group is composed predominantly of rhyolitic, dacitic, and andesitic flows, as well as pyroclastic and volcaniclastic rocks. The Endako Group is comprised predominantly of pyroxene- and plagioclase-phyric basalt (Anderson and Snyder, 1998).

RESULTS OF ANALYSIS

Surficial

There is a strong visual correlation between the mapped surficial geology and measured airborne radioelement concentrations (Fig. 2). In general, for the airborne data, all three radioelements appear depleted in alluvial and glaciolacustrine deposits relative to coarser grained colluvial and glaciofluvial deposits. These observations are also recognized in quantitative statistical analyses of the airborne data (Fig. 3); however, we note that both the thickness of the surficial cover and the presence of water have a significant influence on measured radioelement concentrations. Absolute radioelement levels decrease with increasing overburden thickness and water content. In the survey area, we note that the glaciolacustine and alluvial deposits that yielded the lowest radioelement concentrations are generally thicker than other surficial units and are mostly confined to the main river channels and swampy ground.

Surficial geochemistry does not support the apparent correlations observed in the airborne data (Fig. 2). Instrumental Neutron Activation Analysis (INAA) and Inductively Coupled Plasma Mass Spectrometry (ICP) of surficial materials (A. Plouffe, pers. comm., 1999) indicate that till, glaciolacustrine, alluvium, and glaciofluvial units have almost identical K concentrations, which is rather surprising as they have quite different clay concentrations. Till and alluvium have comparable and higher eTh concentrations relative to other surficial units; however, we note that only a limited number of glaciolacustrine, colluvium, and glaciofluvial samples were available for analysis (Fig. 3).

In our survey area, airborne data show that K concentrations of glaciofluvial deposits are only 0.2% higher than those of till. By comparison, there is a 1.2% increase in K concentration of glaciofluvial deposits relative to till at the Mt. Milligan porphyry Cu-Au deposit (Shives et al., 1997). This facilitated the ready use of airborne gamma-ray spectrometry for surficial mapping in that area. In our study area, the lack of a significant radiometric contrast between surficial units in either airborne data or surficial geochemistry suggests surficial deposits are locally derived (*see also* discussion of bedrock analysis below).

In general, we note that radioelement concentrations decrease with increasing till thickness; however, no such correlation is observed in areas underlain by the Endako and Casey phases of the Francois Lake Plutonic Suite (Fig. 2). In these areas, high K concentrations are observed irrespective of till thickness. As the Endako and Casey phases have the highest K concentrations of any in the Francois Lake Plutonic Suite, this too suggests that the till is locally derived. Similarly, in the southeast survey area, thin till yields relatively low K and eTh concentrations. There, the underlying bedrock is the Limit Lake phase, an older and more mafic unit of the Endako Batholith, containing less K and eTh than the Francois Lake Plutonic Suite (J.B. Whalen, pers. comm., 2000).

In summary, this analysis shows that airborne radiometric data cannot be used to differentiate surficial deposits in this area. The presence of water, the thickness of overburden, and the nature of the underlying bedrock dominate the measured airborne radioelement concentrations.

Bedrock

There is a poor visual correlation between the airborne gamma-ray spectrometry data and the mapped bedrock geology (Fig. 4). Visually, no geological unit can be distinguished by its radioelement response alone; however, the younger and more felsic Casey and Endako phases of the Francois Lake Plutonic Suite do appear to have higher K and eTh concentrations and lower eTh/K ratios than other phases of the suite. Figure 5 compares mean K, eTh, and eTh/K concentrations over the mapped extent of individual phases in the Francois Lake Plutonic Suite with those at outcrop and mineral localities within each phase. It is clear from an analysis of these data that mean radioelement differences between individual phases of the Francois Lake Plutonic Suite are indeed small even when the comparison is restricted to outcrop localities. Maximum mean K, eTh, and eU difference between phases of the Francois Lake Plutonic Suite are less than 0.8%, less than 2 ppm, and less than 0.5 ppm, respectively.

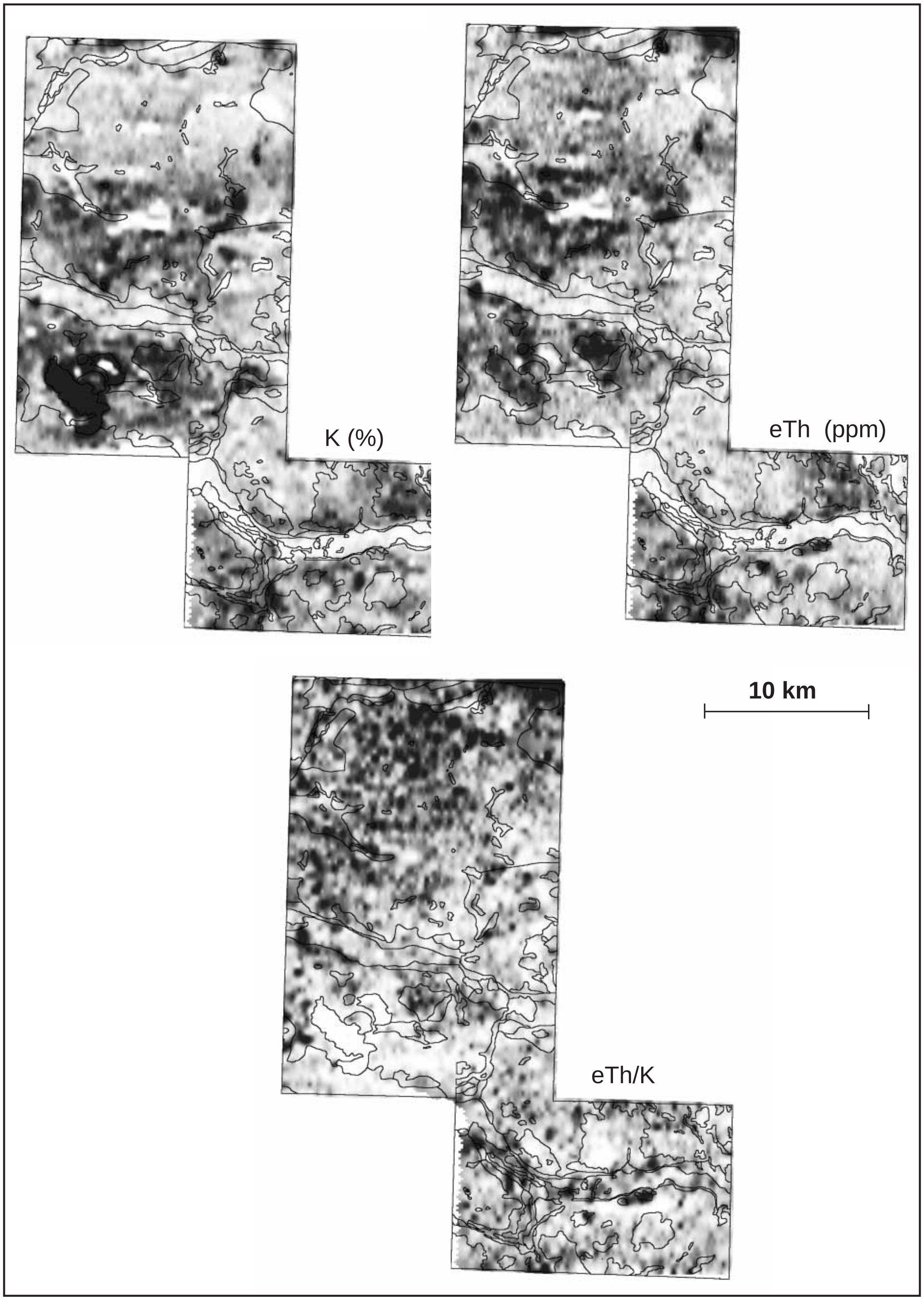

Figure 2. *Measured K (%), eTh (ppm), and eTh/K concentrations with superimposed surficial geology. High concentrations are shown in dark shades and low concentrations in light shades.*

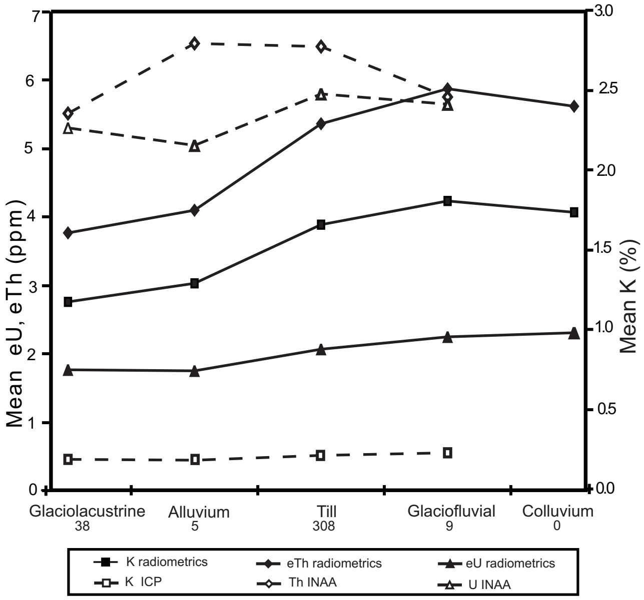

Figure 3. *Comparison of mean airborne radioelement concentrations (K (%), eTh (ppm), and eU (ppm)) with surficial geochemistry analyses. The number of surficial samples analyzed is indicated beneath each unit.*

We note that statistically, mean K and eTh concentrations in the Casey phase are not significantly higher than any other in the Francois Lake Plutonic Suite. We also note that although the Endako, Francois, and Nithi phases have lower mean eTh/K ratios than others in the suite, these phases cannot be distinguished one from the other. In addition, the ratio ranges of these three phases overlap significantly with those of other phases in the suite.

Figure 6 compares mean airborne radioelement concentrations determined at outcrop localities within each phase of the Francois Lake Plutonic Suite with available lithogeochemistry data (J.B. Whalen, pers. comm., 2000). Despite the limited number of lithogeochemical analyses and the exclusive sampling of unaltered bedrock, trends observed in these two data sets are well correlated. Radioelement differences between phases of the Francois Lake Plutonic Suite are also small in lithogeochemical analyses.

O'Reilly et al. (1998) and Shives et al. (1997) present radiometric case histories which demonstrate the utility of airborne gamma-ray spectrometry as a bedrock mapping tool when compositional differences in the underlying bedrock are significantly larger. In most of their studies, bedrock was comprised of both mafic and felsic components.

More importantly, we note that for all phases of the Francois Lake Plutonic Suite mean radioelement concentrations are higher at outcrop localities relative to those observed over the mapped extent of the individual phase, but that observed trends between phases are well correlated. This implies that the radiometric response of bedrock in this region can be detected even in areas of thick surficial cover and implies that the cover must be locally derived.

MINERAL OCCURRENCES

Visually (Fig. 1a), relative enrichments of all three radioelements are observed in broad regions encompassing the Endako mine and Nithi Mountain, where bedrock exposures are either complete or significantly greater than elsewhere in the survey area. In addition, modest eTh/K depletions are also observed in these areas (Fig. 7a). However, we note that depleted ratio concentrations are not restricted to the open pit mine or other mineral localities in these areas, but occur in broad areas encompassing them. This is in notable contrast to other porphyry districts in Canada. For example, airborne gamma-ray spectrometry data over the Mt. Milligan Cu-Au (Mo) deposit in central British Columbia and the Casino Au-Cu-Mo deposit in Yukon Territory (Fig. 7b) show pronounced eTh/K depletions which are clearly associated with the alteration zones encompassing those deposits (Shives et al., 1997). This suggests that alteration associated with mineralization in the Endako survey area is both poorly focused spatially and weaker than observed in other porphyry districts.

An examination of Figure 6 shows that mean K concentrations at mineral localities are modestly increased relative to those at outcrop localities within the Nithi, Glennanan, Tatin Lake, and Endako phases of the Francois Lake Plutonic Suite. They are modestly decreased in all other phases. Noteworthy, however, is the increase in mean eTh concentrations at mineral localities within the Nithi, Glennanan, Endako, and Francois phases compared to those at outcrop localities. As a consequence, low eTh/K ratios are not diagnostic of mineralization in this area.

SUMMARY

This study shows that both the thickness of the surficial cover and the presence of water have a significant influence on measured airborne radioelement concentrations. Absolute radioelement levels decrease with increasing overburden thickness and water content. Individual surficial units cannot be distinguished on the airborne data or in geochemical analyses of the surficial deposits.

Small differences in mean K, eTh, and/or eU concentrations are observed between the mapped bedrock units in both airborne spectrometry and lithogeochemistry data. These differences persist even in areas of thick overburden; however, in no case are they statistically significant, and as a consequence individual bedrock units cannot be uniquely identified on the basis of their total radioelement response.

Finally, this analysis shows that potassium alteration associated with mineralization with this survey area is poorly focused and very much weaker than observed in other porphyry districts in Canada.

ACKNOWLEDGMENTS

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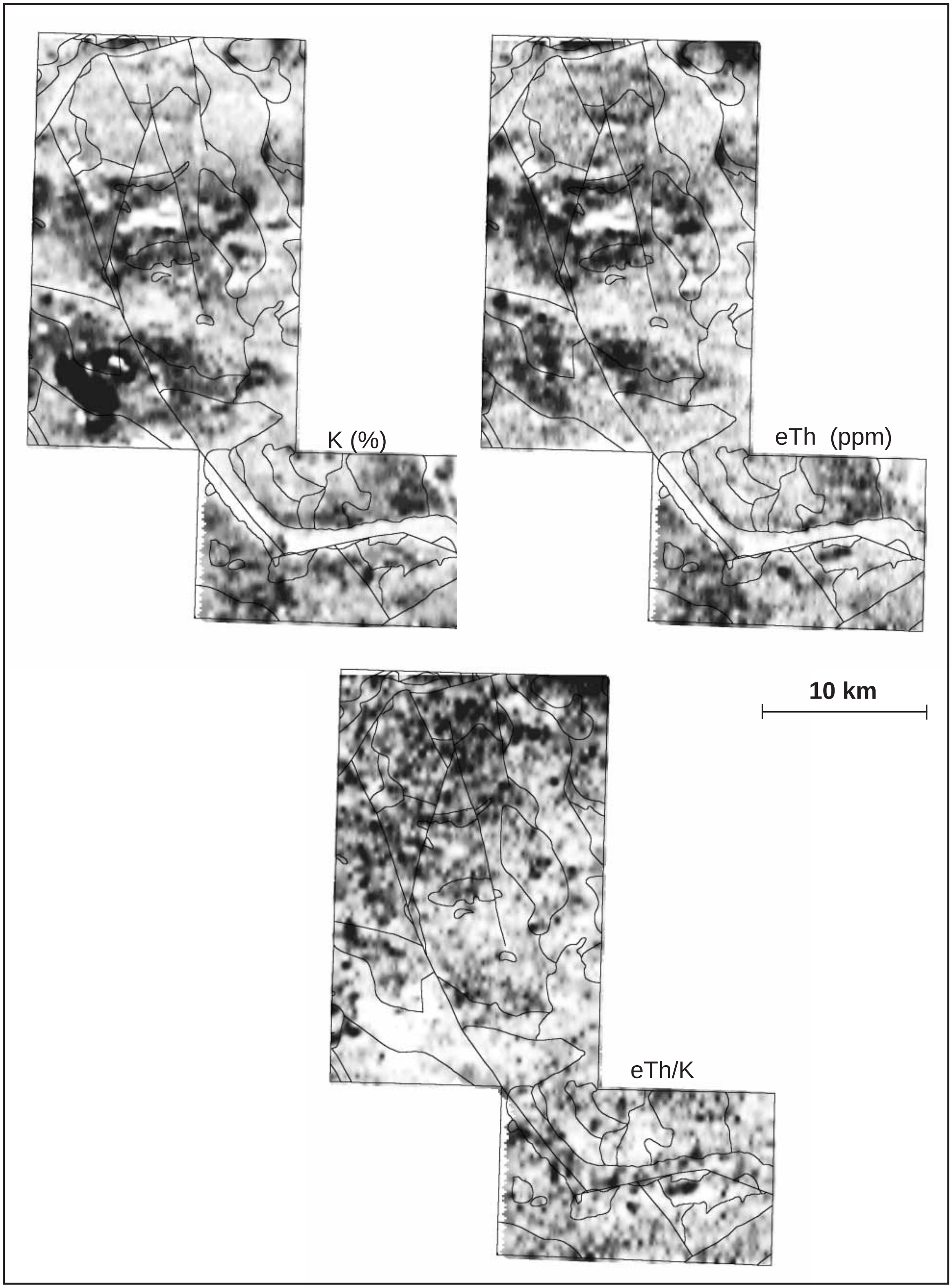

Figure 4. *Measured K (%), eTh (ppm), and eTh/K concentrations with superimposed bedrock geology. High concentrations are shown in dark shades and low concentrations in light shades.*

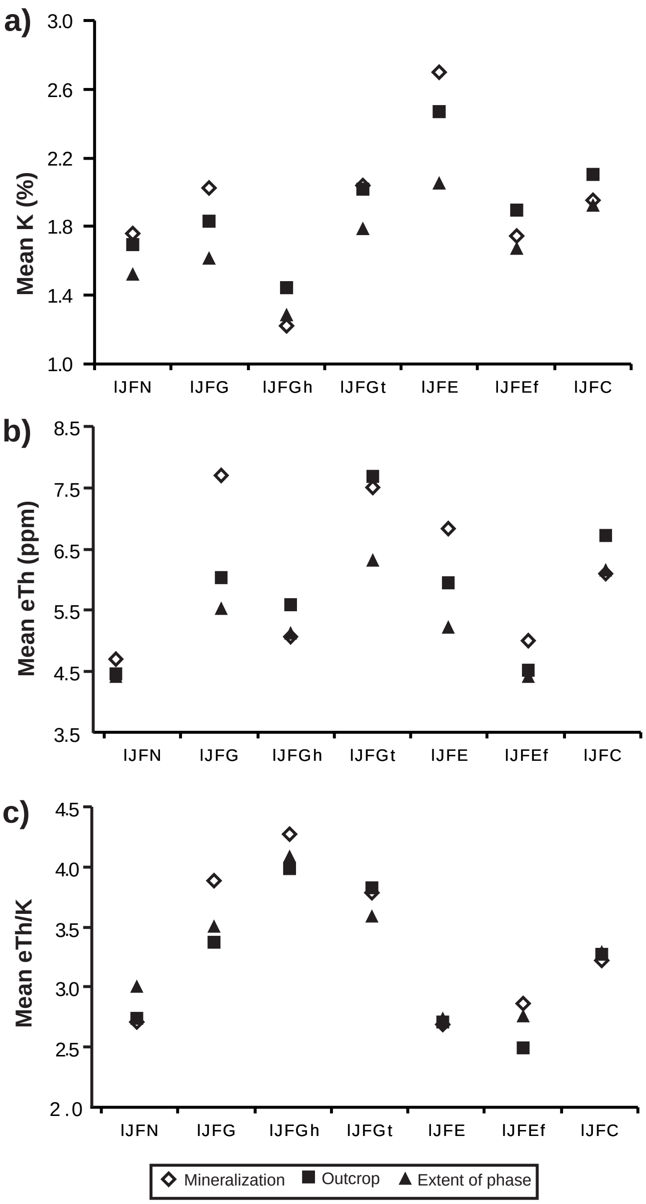

Figure 5. *Comparison of mean airborne concentrations measured at mineralized localities, outcrop localities, and over the entire map extent of the phase:* ***a)*** *K (%);* ***b)*** *eTh (ppm), and* ***c)*** *eTh/K. Unit abbreviations are as follows: Nithi (*lJFN*), Glennanan (*lJFG*), Hanson Lake (*lJFGh*), Tatin Lake (*lJFGt*), Endako (*lJFE*), Francois (*lJFEf*), and Casey (*lJFC*) phases of the Francois Lake Plutonic Suite (shown in grey)*

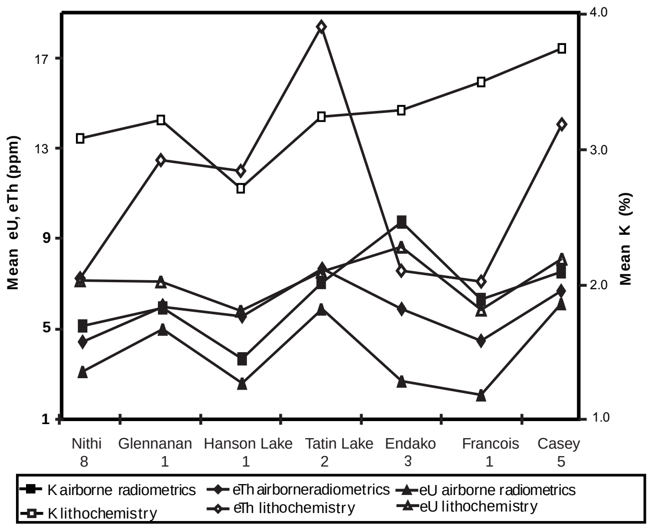

Figure 6. *Comparison of mean airborne radioelement concentrations (K (%), eTh (ppm), and eU (ppm)) with lithogeochemisty analyses. The number of lithochemistry samples analyzed is indicated beneath each unit.*

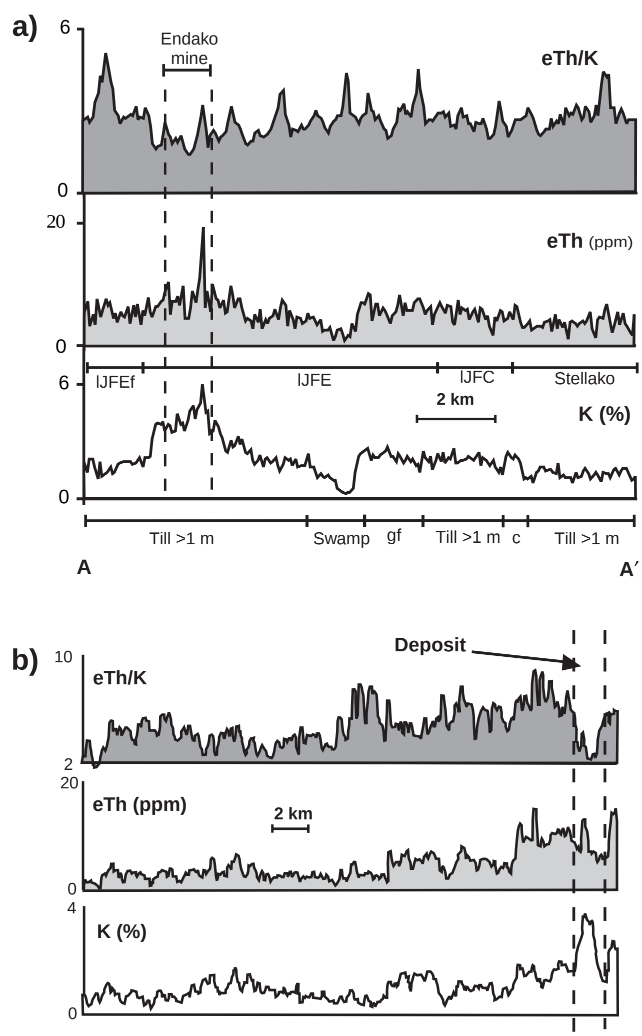

Figure 7. a) *Stacked radioelement profiles along flight line 20320 over the Endako mine (line A-A′, Fig. 1a). The mapped extent of surficial and bedrock units is indicated beneath the eTh and K profiles, respectively. Abbreviations:* gf*, glaciofluvial;* c*, colluvium; Endako (*lJFE*), Francois (*lJFEf*), and Casey (*lJFC*) phases of the Francois Lake Plutonic Suite;* ***b)*** *eTh/K profile over the Casino porphyry Cu-Au deposit, Yukon Territory (*from *Shives et al., 1997).*

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