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Reconnaissance and detailed geochemical surveys for gold in eastern Nova Scotia using plants, lake sediment, soil and till

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ABSTRACT

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Reconnaissance-level geochemical surveys of similar sample density and areal extent were conducted using lake sediment and twigs of balsam fir (*Abies balsamea*). Both sample media successfully delineate Au districts in eastern Nova Scotia. A moderately good spatial relationship between the data sets for Au and As suggests that either sample medium may be used to identify gold-bearing zones.

Detailed sampling near gold mineralization permitted comparison of distribution patterns of Au, As and Sb in outer bark of red spruce (*Picea rubens*), and several size fractions of till and B-horizon soil. Gold and As are enriched in all sample media (and in most size fractions) over a zone of glacial dispersal from the concealed mineralization. Appreciable enrichment of Sb occurs only in the spruce bark. Results show that either soil or spruce bark could be used to establish targets for more labour-intensive close-spaced sampling of heavy mineral concentrates in till.

INTRODUCTION

There are no published studies that compare reconnaissance geochemical surveys using lake sediment and vegetation. Similarly, there is no record of a detailed study that compares the geochemical responses of vegetation, soil and till around Au mineralization. This paper provides comparisons from the glaciated and forested terrain of eastern Nova Scotia, Canada.

In recent years, reconnaissance-level geochemical surveys in Nova Scotia have involved lake sediment (Rogers et al., 1984, 1985; Ryan et al., 1988), stream sediment (Rogers, 1989; Mills, 1989), and vegetation (Dunn, 1988; Dunn et al., 1989). Multi-element data sets from the lake sediment and biogeochemical surveys are of similar areal extent (5000 km^2), sample density (1 per 8 km^2), and analytical method (instrumental neutron activation anal-

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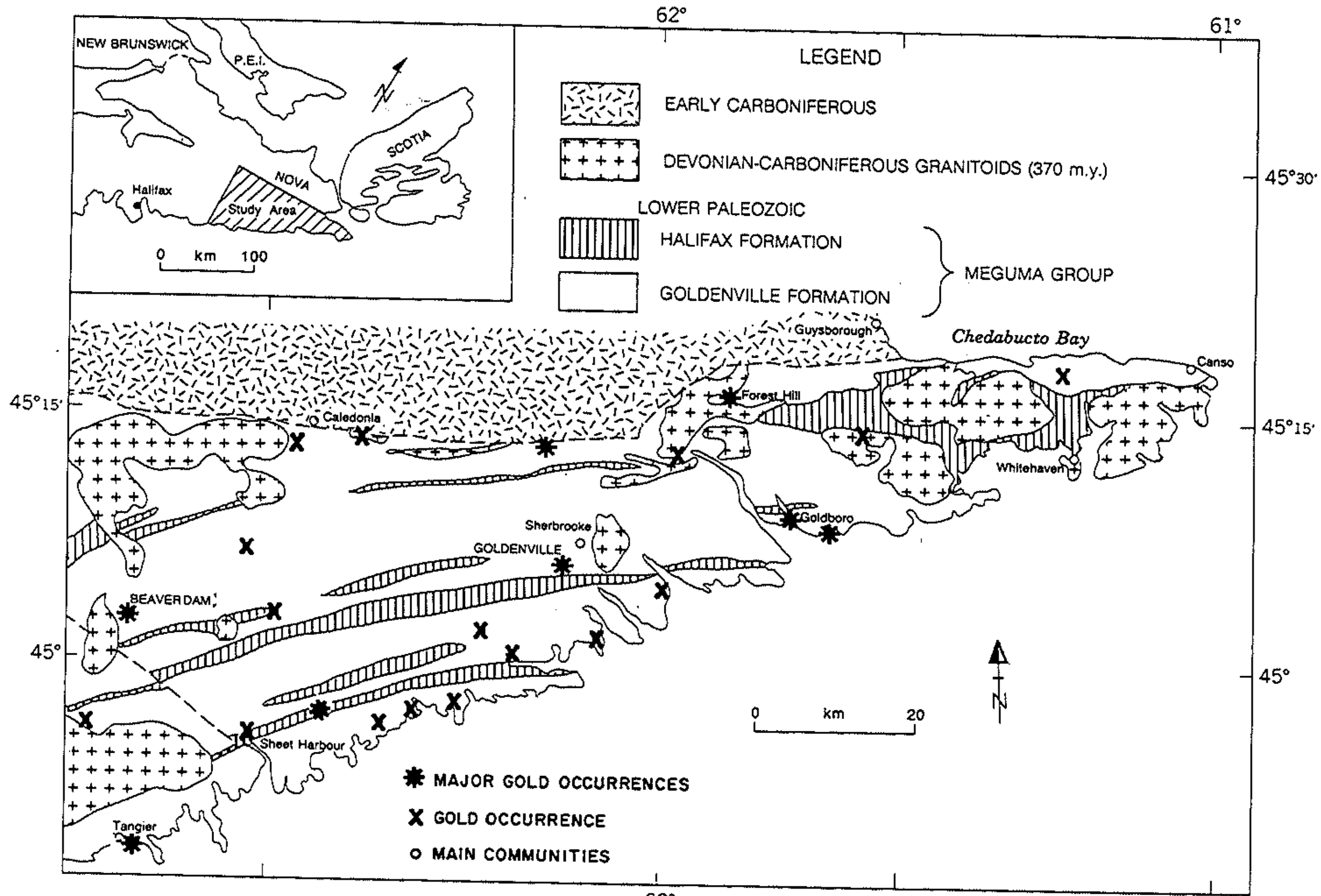


Fig. 1. Location map showing communities, gold occurrences and main geological units.

ysis—INAA). Consequently, there arises the opportunity to compare the efficiency and effectiveness of these surveys in detecting Au mineralization.

Near Beaver Dam (Fig. 1), detailed studies of soil and till have determined the distribution of Au, As and Sb in several size fractions (Coker et al., 1988). A subsequent biogeochemical survey permits comparison of metal distribution patterns in spruce bark with those of the clastic sediments.

GEOLOGICAL SETTING AND MINERALIZATION

The area under consideration (Fig. 1) is dominated by Meguma Group (MG) metasediments of Cambro-Ordovician age. This sequence comprises Goldenville Formation turbidites overlain conformably by black slates of the Halifax Formation. Granitic bodies, locally of batholithic properties, intruded the MG during the Acadian Orogeny (370 Ma). Within the study area most of the intrusions are small in surface outcrop. Deformation associated with the Orogeny produced tight to isoclinal upright folds, and regional metamorphism of greenschist to amphibolite facies. Northeast-trending anticlines form dome-like structures which are associated, locally, with areas of Au enrichment (Smith and Kontak, 1987; Kontak and Smith, 1987).

Most of the significant gold deposits of Nova Scotia occur within the MG, especially in turbidites of the Goldenville Formation. Typical mineralization is native gold in quartz veins with or without pyrite, pyrrhotite, arsenopyrite, loellingite, sphalerite, galena, chalcopyrite and carbonate. Extensive zones of silicic, carbonate and phyllic alteration occur around these deposits and in proximity to large-scale shear zones. (Kontak and Smith, 1987).

GLACIAL HISTORY

Four periods of Wisconsin-age ice-flow are recognized in Nova Scotia, although only the first two affected most of the study area (Stea et al., 1988). The ice moved first toward the southeast, depositing homogeneous silty till, especially along the south coast. The second phase had a southerly direction, depositing distinctive reddish clay-rich till (the Lawrencetown Till) over much of the area. Evidence of subsequent phases of ice movement, also to the south and southwest, is present only in the west portion of the area under investigation. The net result of the glacial activity is an extensive cover of tills, usually only a few metres thick, and drumlin 'fields' which mask the bedrock.

FOREST COVER AND PHYSIOGRAPHY

There is a cover of spruce and fir forest of moderate density which is characteristic of the eastern boreal forest of North America. Dominant species are balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*), with some white spruce (*Picea glauca*) and rare black spruce (*Picea mariana*). Among the deciduous species the most common is shrub alder (mainly *Alnus crispa*, but with *Alnus rugosa* in the wet areas), and local stands of trembling aspen (*Populus tremuloides*), birch (*Betula* spp.), and maple (*Acer* spp.).

There are low rolling hills with an abundance of small lakes and peat bogs linked by meandering streams. The granitic bodies in the east are expressed by more rugged scenery and are sparsely forested.

SAMPLE COLLECTION

Reconnaissance surveys

Centre-lake sediment samples of gyttja (organic-rich ooze) were collected from approximately 500 lakes (Bingley and Richardson, 1978; Rogers et al., 1985) using a technique developed at the Geological Survey of Canada (Hornbrook and Garrett, 1976). This method permits the recovery of samples from a lake bed by means of a hollow gravity corer that is dropped from a float-equipped helicopter.

For the biogeochemical survey, the procedure was to collect a 200-g composite sample of balsam fir twig and needle growth of the last 5 to 7 years at each of approximately 600 sites adjacent to available roads and tracks (Dunn, 1988). A consistent amount of growth was sampled at each site in order to integrate variations in chemical composition of the twigs along their lengths. Such changes occur as a result of differences in the climate from one year to the next and, with annual addition of wood tissue, the changes in the ratio of twig wood to twig bark. This ratio is significant in that the chemistry and ash yield of the two tissue types are substantially different.

Both sample suites were analyzed for 35 elements by INAA. Balsam fir was selected because it is the most abundant tree throughout the study area, and the twigs are easy to collect. Whereas the outer bark of conifers is commonly an informative and practical sample medium, this is not true of balsam fir because its outer bark is only a thin skin shrouding sticky sap-laden blisters, making it messy and difficult to collect.

Detailed surveys

Red spruce is the most common species in the Beaver Dam area. Samples of outer bark weighing 30–50 g were scraped from the tree trunk with a blunt knife, avoiding obvious contaminants such as moss and sap globules. The loose, dead, outer scales were chosen because they are easy and practical to collect (in dense forest the foliage is often out of reach) and many heavy metals, notably Au, As and Sb, are enriched in outer bark. It is important not to mix inner bark with some samples (hence the use of the blunt knife), because the bark layers have substantially different chemical compositions (Dunn, 1988).

Samples of B-horizon soil developed on till were collected, and samples of fresh till from below the the zone of surface weathering and leaching (locally up to 3 m deep) were excavated from pits by a back-hoe. Each till sample comprised 6–8 kg of material (Coker et al., 1988).

SAMPLE PREPARATION AND ANALYSIS

Lake sediment samples were air dried, disaggregated in a ball mill, and sieved to obtain a 20-g portion of the -200 mesh fraction for INAA (Rogers et al., 1985). Collection and quality control methods of Garrett et al. (1980) were followed.

Vegetation samples were air dried for several weeks, and then ashed at 470°C. Ash samples weighing from 0.5 to 1 g were encapsulated and submitted for multi-element INAA. Quality control was similar to that for the lake sediment.

Two 500-g portions of each till sample, and all of each soil sample, were dried and sieved to obtain five size fractions. Heavy-mineral concentrates (HMC) were recovered from the remaining 5–7 kg of till by sieving to <2 mm, concentrating on a shaking table and heavy-liquid (S.G. 3.3) separation. Analysis was by INAA, and quality control was similar to that for the lake sediment and vegetation.

RECONNAISSANCE SURVEYS

General considerations

The distribution of lakes is such that a fairly even sampling grid could be obtained for lake sediment (Fig. 2a). Access to sample sites for the biogeochemical survey was by roads and trails resulting in an uneven distribution pattern (Fig. 2b). The biogeochemical survey extended farther to the north and west than that of the lake sediment to include the Beaver Dam area (Fig. 1). The lake sediment was collected in 1976 when Au at Beaver Dam was known, but had received little attention. The biogeochemical survey was conducted in 1987 when significant new discoveries had been made in that area.

No attempt was made to collect biogeochemical samples from near the lakes that were sampled. The intent was to examine patterns of metal distribution from the different types of survey rather than to contrast metal distribution at specific sites.

The chemistry of each lake sediment sample is represented as an average composition for the catchment basin of the lake (i.e., Catchment Basin Analysis (CBA—Ellwood et al., 1986; Wright et al., 1988). This approach recog-

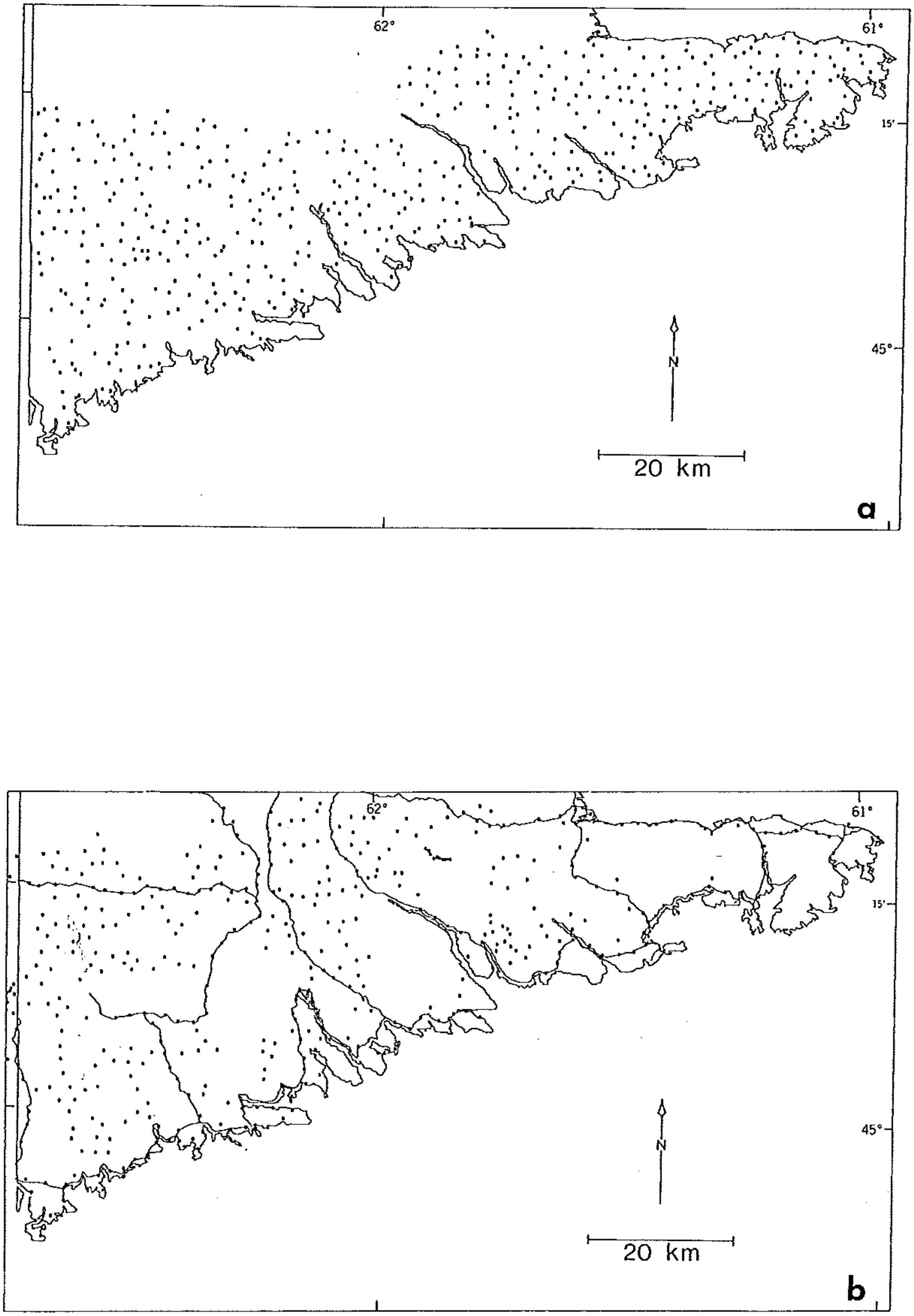


Fig. 2. (a) Distribution of lake sediment samples. (b) Distribution of balsam fir sample points and major highways.

nizes both hydromorphic and clastic dispersion models for the chemistry of the lake sediment (Rogers and Garrett, 1987; Rogers, 1988).

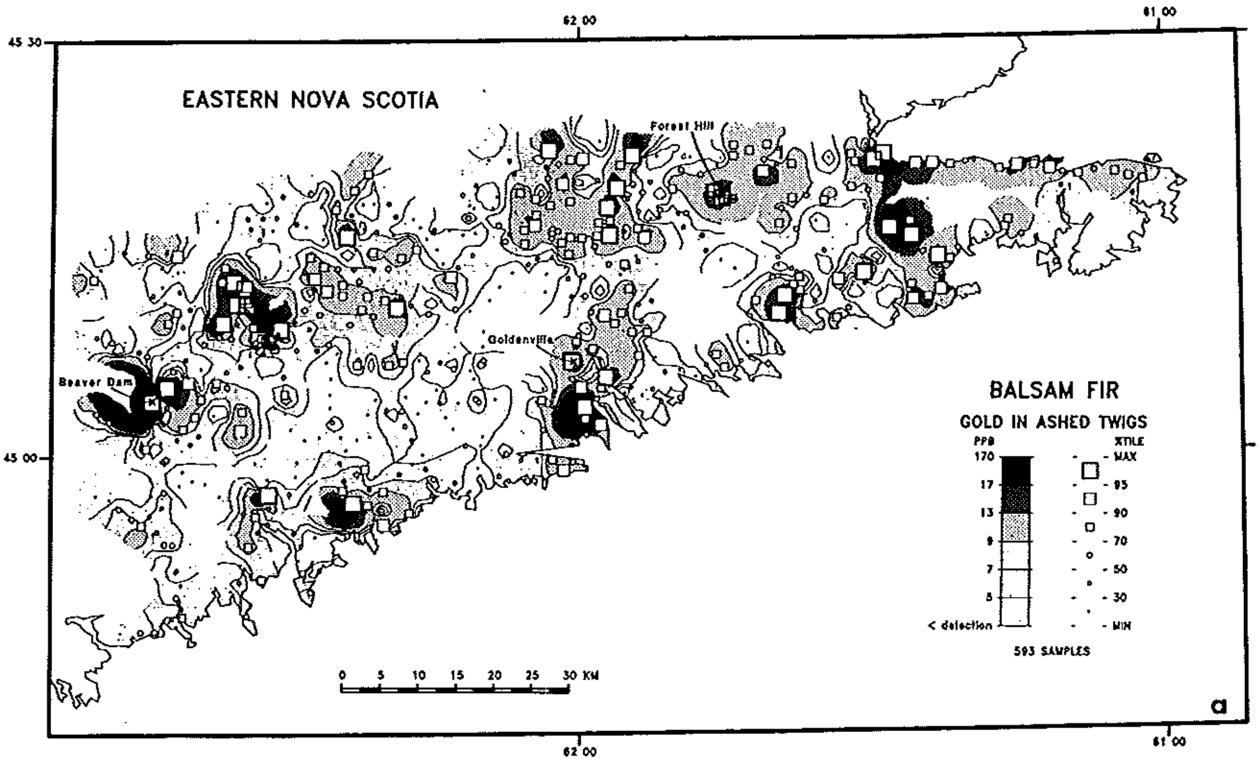
Biogeochemical sample sites were not always at the lowest point of a catchment basin, and it is unreasonable to depict the biogeochemical data with respect to catchment basins. The average area of each catchment basin in this part of Nova Scotia is approximately 6 km^2, whereas the area chemically represented by each tree is variable. The chemistry of a tree reflects, to a degree, the soil chemistry of a geographic point. However, roots extract metals from both soil and groundwater, and migrating water may contain elements dissolved from a source, 10s, 100s or even 1000s of metres distant. Furthermore, that source may be smeared by glacial dispersion. As a consequence, a tree may reflect the substrate chemistry over a large area, and the size of this area is indeterminate. The problem of handling such point data to produce two-dimensional plots has been addressed in some detail by George et al. (in press). For this study each vegetation sample site was assigned an area of influence of 5 km^2 in order to graphically represent the data (Dunn et al., 1989), and to facilitate comparison of lake sediment and vegetation chemistry (Figs. 3 and 4).

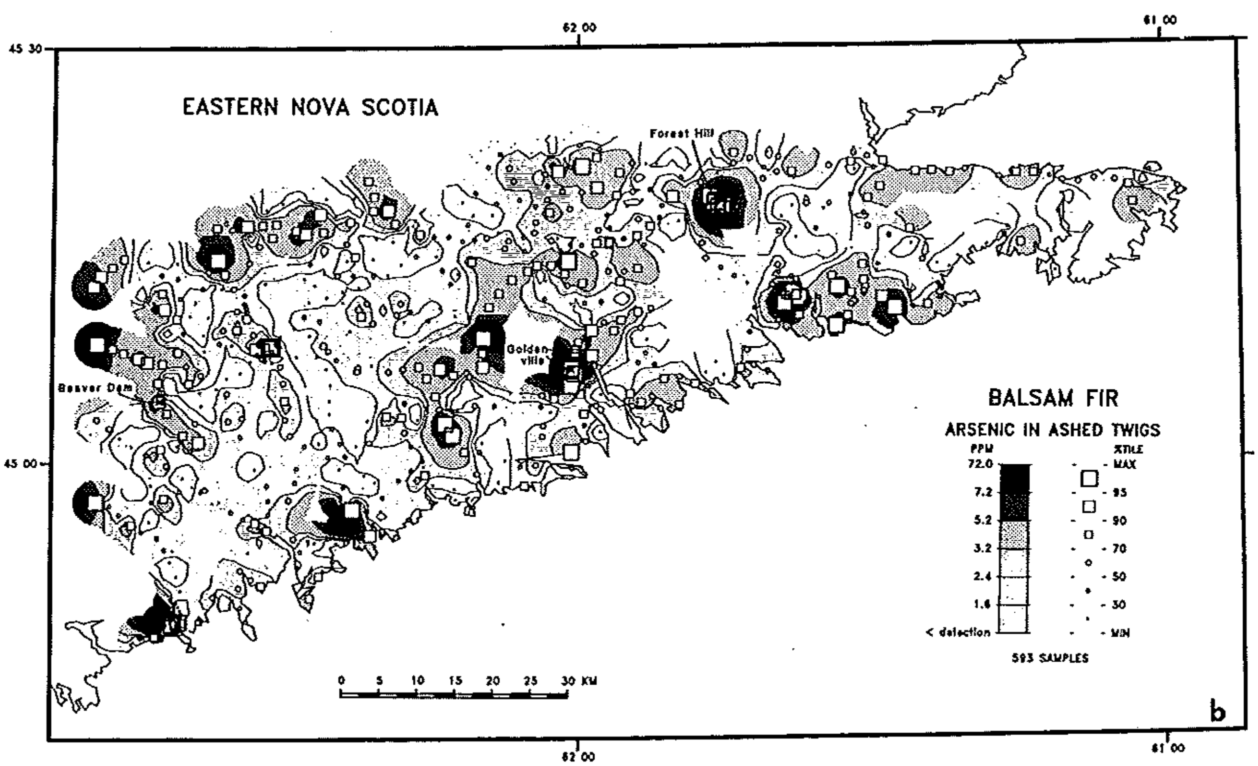
The response of each sample medium to known mineralization and geologic controls was examined by single-element maps and multivariate analysis to identify common associations. In this synopsis of the data, comparison is made of distribution patterns of only the three elements most characteristic of the mineralization—Au, As and Sb.

Balsam fir

Gold in the ash of balsam fir twigs ranges from <5 to 170 ppb. Most of the 20 gold 'districts' in the study area are identified by several sample sites where balsam fir contains Au concentrations in the upper 10% of the data—greater than 13 ppb (Fig. 3a). Several 'new' areas of Au enrichment are indicated, especially along major shear zones near the margins of the eastern granites, and over the Carboniferous rocks in the north of the study area. Recent stream sediment data confirm that there is Au enrichment in this area (Rogers, 1989). It has been suggested that there may be paleoplacers in the Carboniferous, derived from the erosion of Meguma Group rocks (Ryan et al., 1988).

Arsenic, <1–72 ppm (Fig. 3b), has distribution and local enrichment patterns similar to those of Au and exhibits a marked spatial correlation with known Au mineralization. Antimony concentration in the balsam fir is low (maximum of 1.6 ppm, Fig. 3c) because the twigs only concentrate this element in areas of high enrichment. Balsam fir establishes a barrier to Sb transport into its twigs. As a result, the pattern of Sb distribution in the balsam fir twigs show only a weak relationship to zones of Au mineralization (Fig. 3c). In contrast, spruce bark is able to accumulate more Sb, and the Au-rich areas


62 00
61 00
45 30
45 00
EASTERN NOVA SCOTIA
Forest Hill
Goldenville
Beaver Dam
BALSAM FIR
GOLD IN ASHED TWIGS
PPB
170
17
13
9
7
5
< detection
%TILE
MAX
95
90
70
50
30
MIN
593 SAMPLES
0 5 10 15 20 25 30 KM
a


62 00
61 00
45 30
45 00
EASTERN NOVA SCOTIA
Forest Hill
Golden-ville
Beaver Dam
BALSAM FIR
ARSENIC IN ASHED TWIGS
PPM
72.0
7.2
5.2
3.2
2.4
1.6
< detection
%TILE
MAX
95
90
70
50
30
MIN
593 SAMPLES
0 5 10 15 20 25 30 KM
b

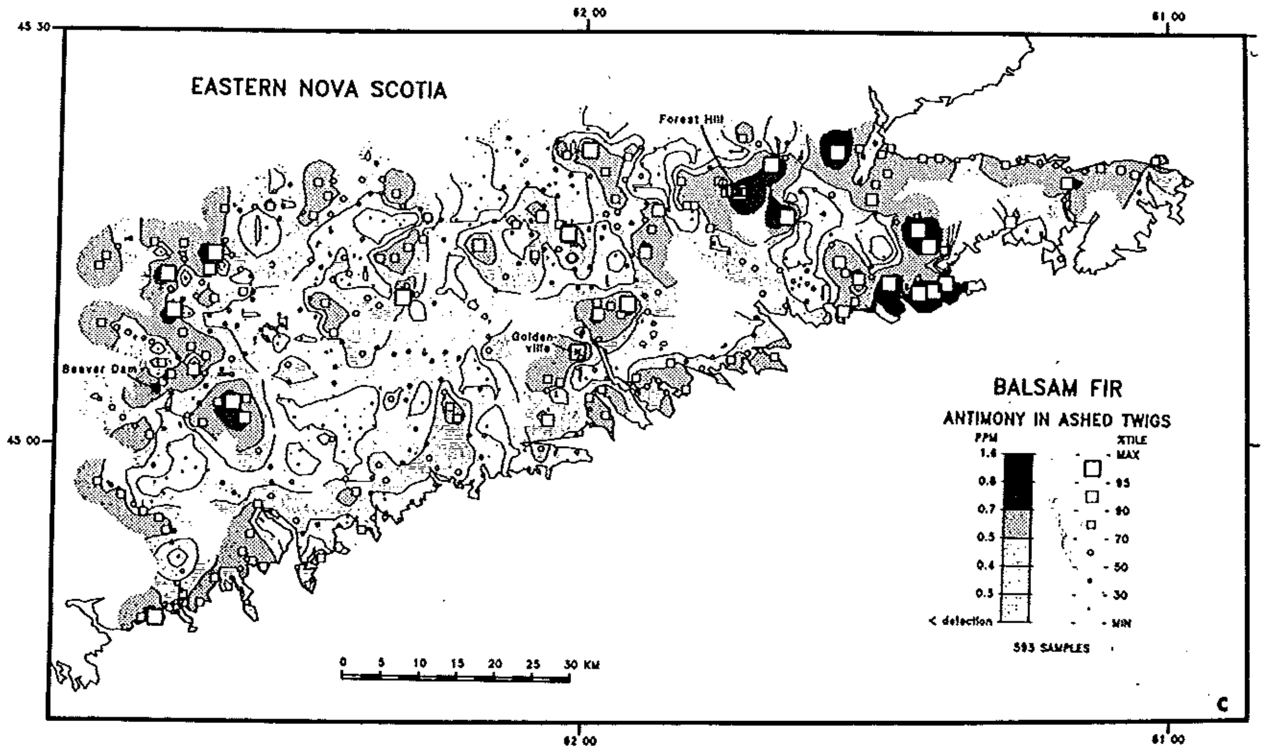


Fig. 3. Metal content of ashed balsam fir twigs: (a) gold; (b) arsenic; (c) antimony.

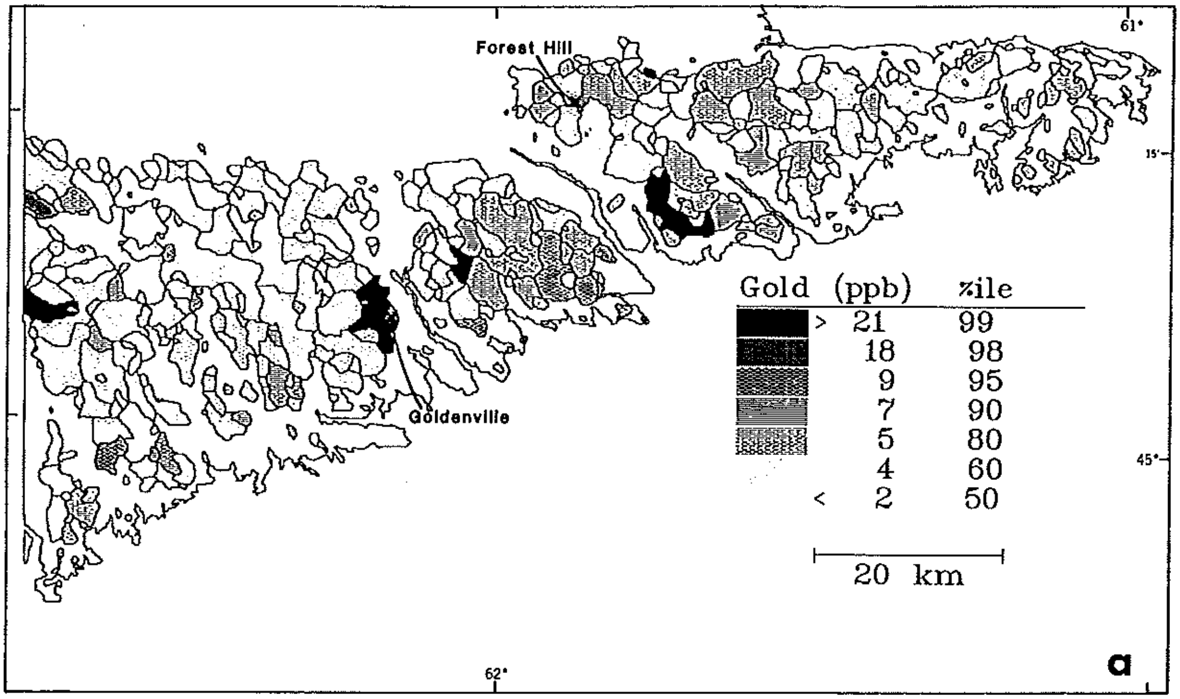
of Goldenville, Forest Hill, and Beaver Dam (Fig. 1) have Sb concentrations that are an order of magnitude greater than those in the balsam fir twigs (Dunn, 1988).

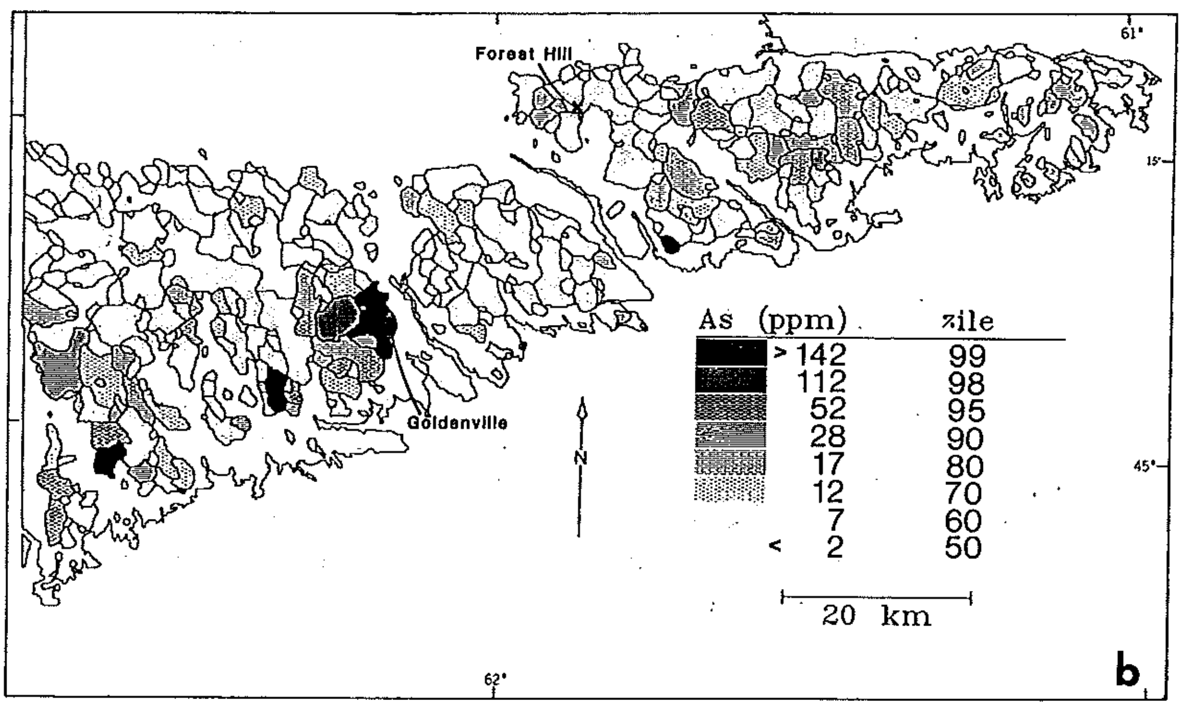
Zones of weak W enrichment in the balsam fir are present near some areas of Au mineralization and adjacent to some of the granitic bodies, particularly in the west (near Tangier—Fig. 1).

Lake sediment

The Au response in lake sediment is considerably greater than the regional background (median value of 3 ppb Au) for most of the known zones of mineralization, with a maximum of 529 ppb (Fig. 4a). Extreme local concentrations of Au may result from the inclusion of free Au particles in the sediment. Enrichment occurs around the eastern granites and in a poorly exposed area to the east of Sherbrooke (Figs. 1 and 4a).

Arsenic is also enriched in the Au districts, with concentrations up to 266 ppm (Fig. 4b). Antimony levels are now, with a maximum concentration (1.3 ppm) close to that of the balsam fir. The Sb distribution (Fig. 4c) is broadly similar to that of As (Fig. 4b).


Forest Hill
Goldenville
Gold (ppb) %ile
> 21 99
18 98
9 95
7 90
5 80
4 60
< 2 50
20 km
61°
15'
45°
62°
a


Forest Hill
Goldenville
N
As (ppm) %ile
> 142 99
112 98
52 95
28 90
17 80
12 70
7 60
< 2 50
20 km
61°
15'
45°
62°
b

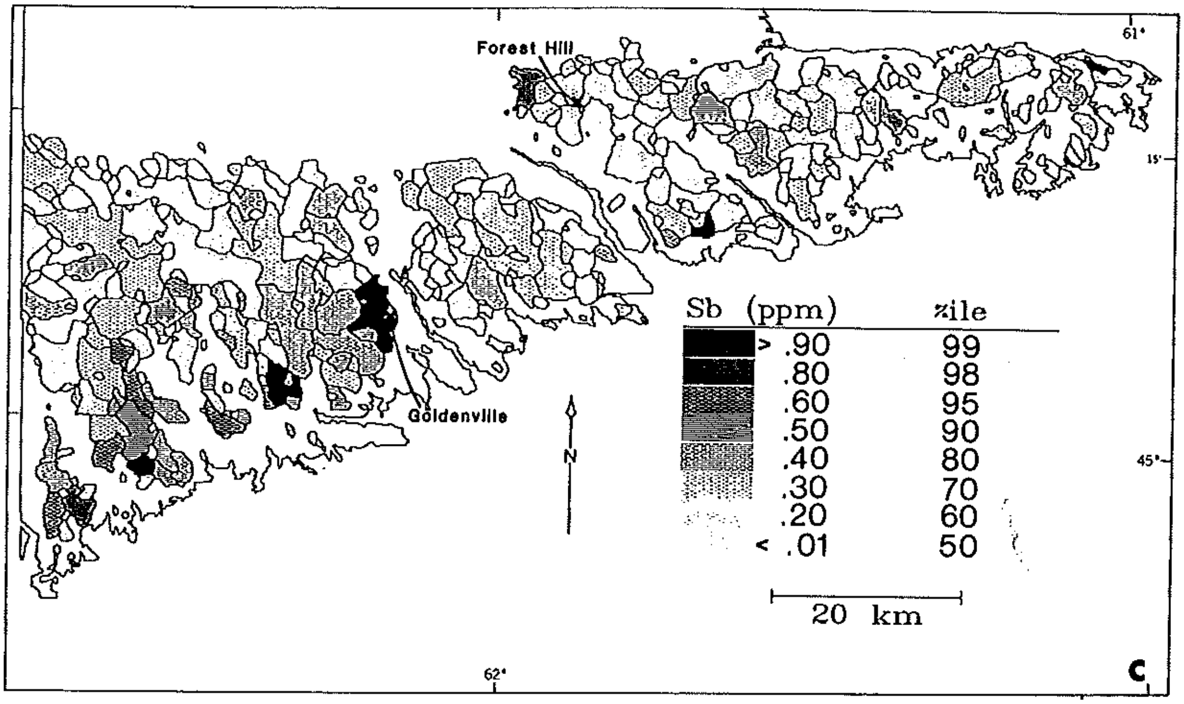


Fig. 4. Metal content of dried lake sediment by lake catchment basin: (a) gold; (b) arsenic; (c) antimony.

Comparison of sample media

Mathematical modelling of the data sets using variograms (George et al., in press) determined that kriging is an effective way of portraying elements common to both the lake sediment and vegetation. Each sample location was ascribed an area of influence, which permitted examination of the areas of overlap, expressed as percentiles. This comparison of the spatial relationships between elements from the two sample media was achieved by using a micro-computer based Geographical Information System (GIS), 'SPANS', developed by Tydac Corporation, Canada.

Many permutations of elements and percentiles were examined, of which two are shown here. Figure 5 has combined the data sets for Au and As from areas where concentrations are > 70th percentile. The area coded '*1*' shows coincident anomalies; '*2*' shows where there is a biogeochemical anomaly, but lake sediment values are below the 70th percentile; '*3*' shows the converse—a lake sediment anomaly, but biogeochemical values below the 70th percentile; and '*4*' indicates areas where both sample media have Au concentrations below the 70th percentile. The blank areas are those for which there is no coincident sample coverage.

Of note are the areas of coincident Au enrichment (Fig. 5a) at Goldenville, Forest Hill, Goldboro, and around the eastern granites (cf. Fig. 1). Several

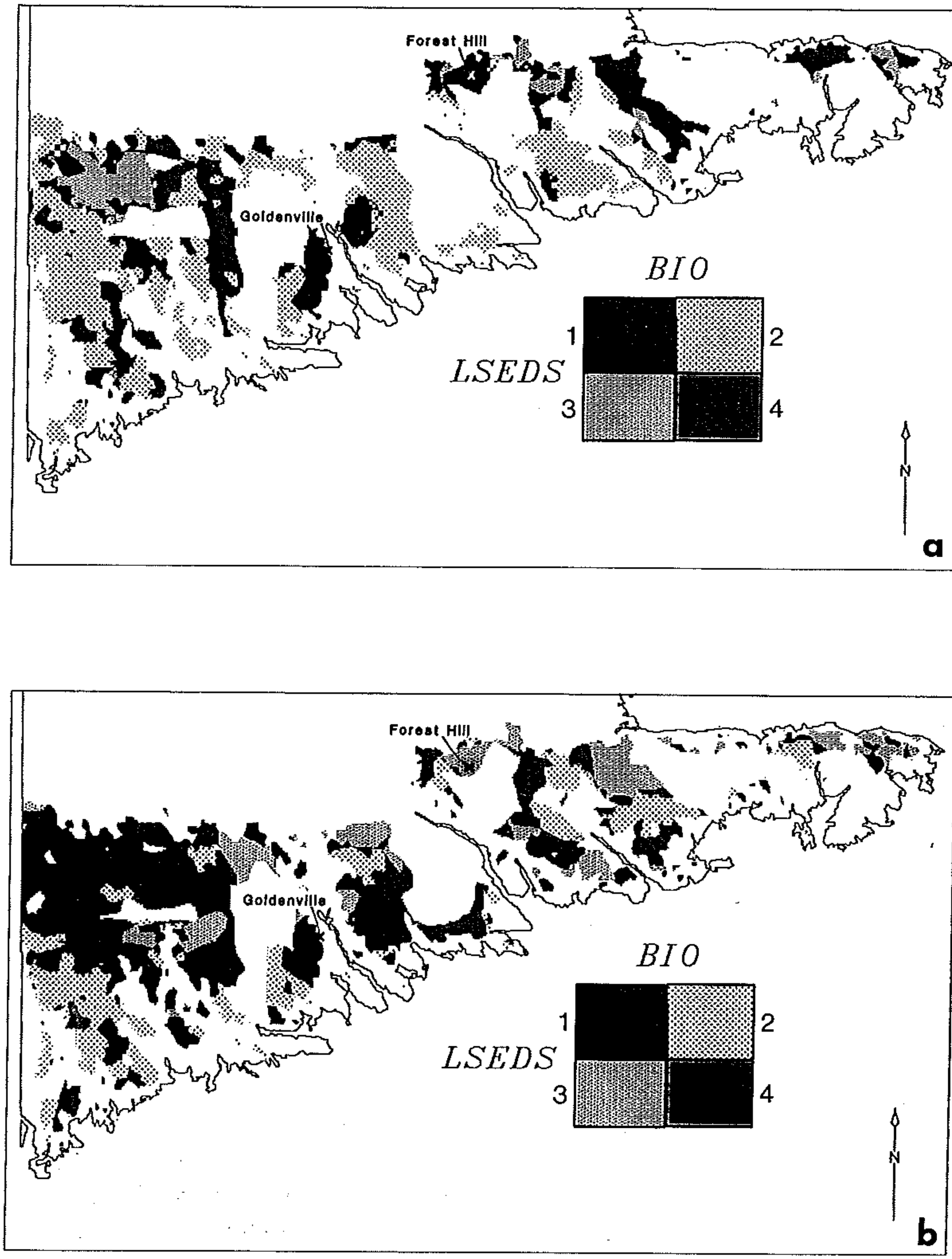


Fig. 5. Distribution of areas where Au (Fig. 5a) and As (Fig. 5b) in lake sediment (LSEDS) and balsam fir twig ash (BIO) are greater than the 70th percentile of each data set: **1**=coincident anomalies of both sample media; **2**=BIO>70th percentile, LSEDS<70th percentile; **3**=LSEDS>70th percentile, BIO<70th percentile; **4**=LSEDS and BIO both below 70th percentile. Blank areas indicate no coincident sample coverage.

other areas have coincident Au enrichment in vegetation and lake sediment, suggesting that they may be worthy of more investigation.

The map of anomaly overlap for As (Fig. 5b) shows that Goldenville and north of Goldboro are the largest areas of As enrichment. Small areas of coincident anomalies are related to known Au mineralization. Around the margins of the eastern granites and west of Goldenville, As enrichment is present in both lake sediment and vegetation where no mineralization has been reported.

No map has been produced for Sb. Visual comparison of Figures 3c and 4c indicates weak correlation between the sample media due to the barrier to Sb uptake by the balsam fir twigs.

There is moderately good spatial relationship between the lake sediment and biogeochemical data on these overlap maps, suggesting that either medium may be sampled to focus on zones of Au and As enrichment. The advantage of integrating the data sets is that anomalies can be 'stacked'. The rather conservative 70th percentile comparison shown here provides a broad focus for more detailed exploration. By taking higher percentiles, the areas of overlap become smaller and give more focus.

DETAILED SURVEYS

Site description

Zones of Au mineralization in the Beaver Dam area are situated near the western extremity of the biogeochemical reconnaissance survey area (Fig. 1). The site selected for a comparison of the geochemical response of several different sampling media is known as the Mill Shaft, located approximately 1 km west of the principal Au zone at Beaver Dam. At Mill Shaft, narrow Au-bearing quartz veins occur in quartzite and argillite of the Goldenville Formation. The Au is concentrated within the grains and along grain boundaries of pyrrhotite and chalcopyrite. Associated minerals include arsenopyrite, galena, sphalerite, stibnite, scheelite, tourmaline and carbonates (Coker et al., 1988). The dominant structure is a westward-trending overturned fold cut by a series of northwesterly oriented fault zones. Glacial deposits are generally less than 5 m thick (thickening locally to 25 m) and are composed of gravel to sand-rich till. Glaciofluvial gravels are interfingered with the till in the lower part of the sequence.

The area is poorly drained with local boggy areas, and covered by typical boreal forest dominated by red spruce and balsam fir. The biogeochemical survey incorporated the boggy areas where it was suspected that auriferous zones extended, but where till and soil sampling would have been impractical.

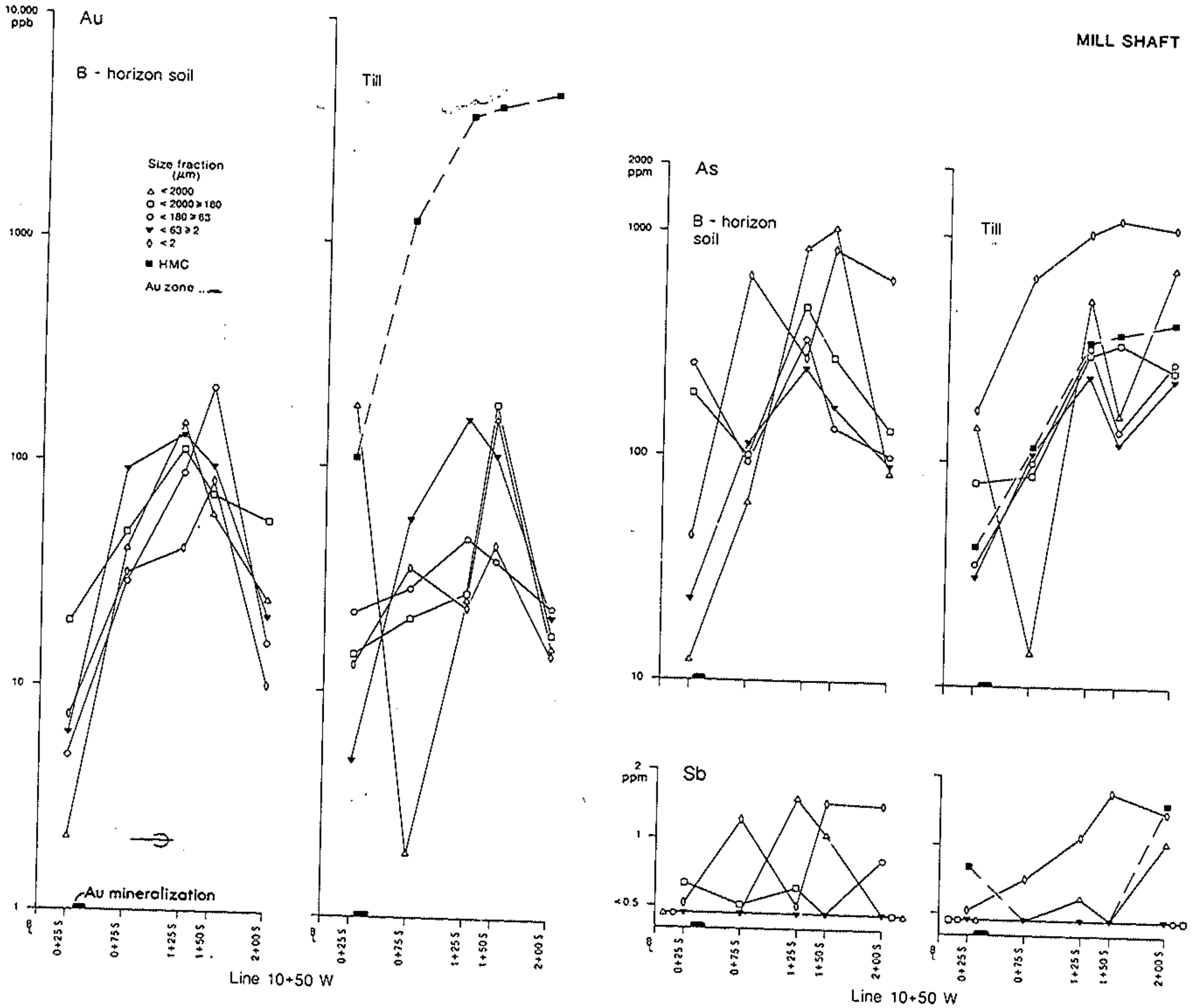


Fig. 6. Mill Shaft grid. Concentrations of Au (ppb), As (ppm), and Sb (ppm) in different fractions of B-horizon soil and till from sites southward (left to right on graphs) along the traverse (10+50W) indicated on Fig. 7. The fraction indicated as <2000 μm is a portion of the entire soil or till sample that has been sieved to <2000 μm and pulverized to <75 μm (modified after Coker et al., 1988).

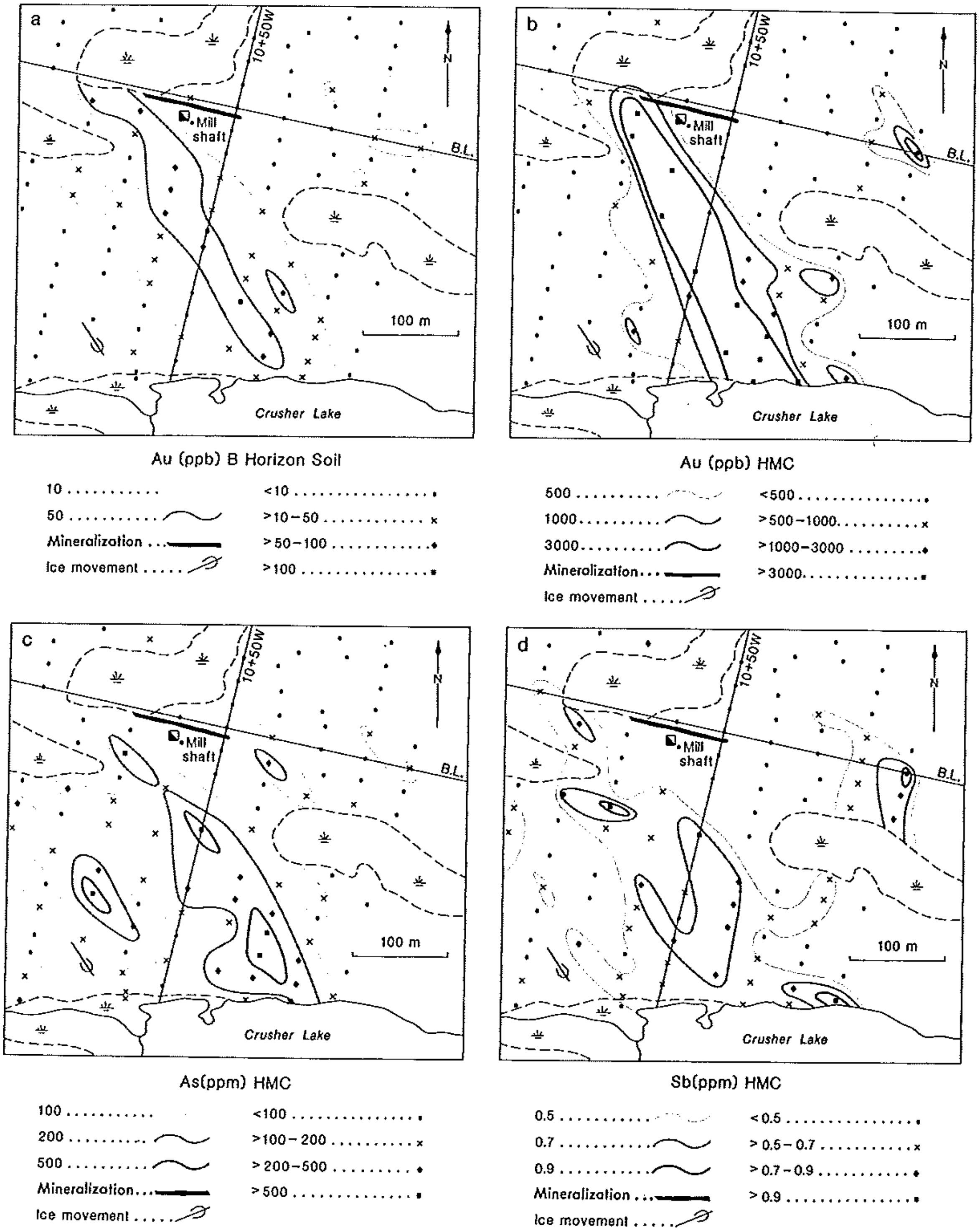
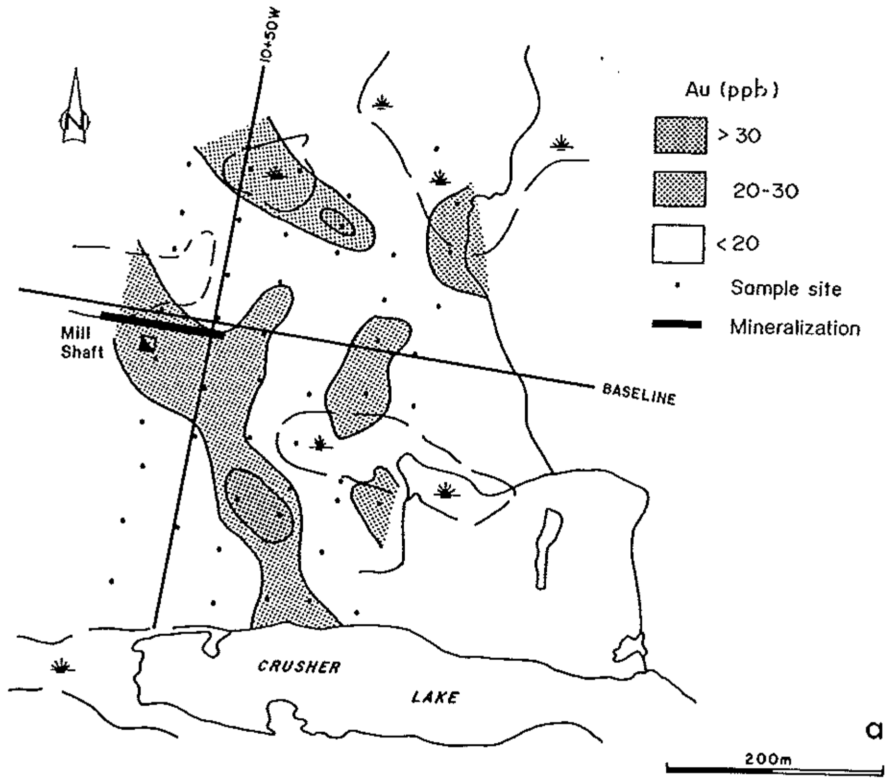
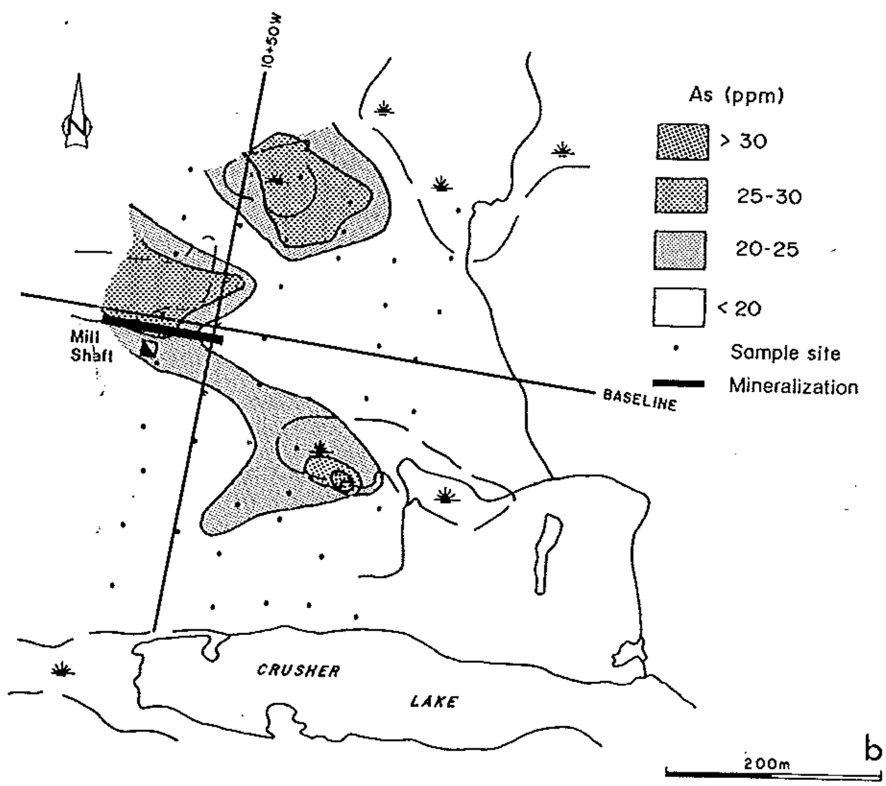


Fig. 7. Mill Shaft Grid. Contoured data of metal concentrations in selected sample media: (a) Au in <2 mm (<2000 μm) fraction of B-horizon soil; and (b) Au, (c) As and (d) Sb in HMC from the till (modified after Coker et al., 1988).


10+50W
Au (ppb)
> 30
20-30
< 20
Sample site
Mineralization
Mill
Shaft
BASELINE
CRUSHER
LAKE
a
200m


10+50W
As (ppm)
> 30
25-30
20-25
< 20
Sample site
Mineralization
Mill
Shaft
BASELINE
CRUSHER
LAKE
b
200m

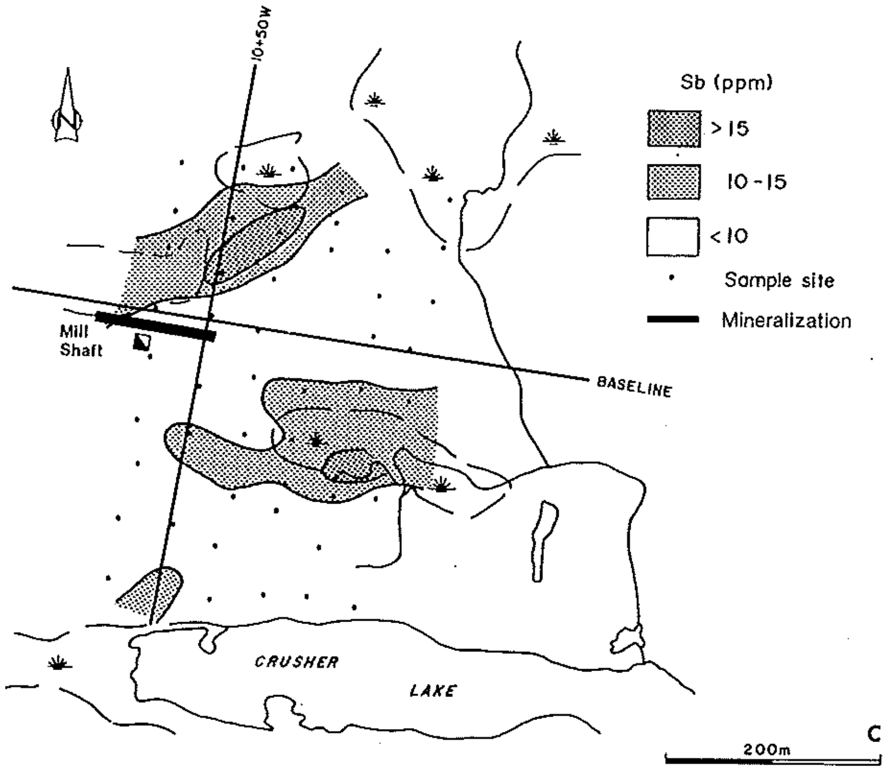


Fig. 8. Mill Shaft grid. Contoured data of (a) Au, (b) As and (c) Sb concentrations in ashed red spruce outer bark scales.

Soil and till

Figure 6 summarizes the patterns of Au, As and Sb in various size fractions of B-horizon soil and till (and in HMC from the till), along a profile which crosses the dispersal train from the Au deposit. All size fractions of the soil exhibit Au enrichment down-ice (south) from the mineralized zone, and concentrations of Au and As are similar in most particle sizes. The Au distribution in the till is less homogeneous: only the <63 to >2 μm fraction of the till shows close similarity to the soil. Arsenic distribution is broadly similar to that of Au, but Sb patterns are erratic, with low concentrations (<2 ppm) in all fractions.

The analysis of size fractions of the soil shows that, in this environment, similar information may be obtained from analysis of any grain size. For till the picture is more complicated, and the HMC provided the most useful information.

The patterns shown in Figure 7 (<2 mm fraction of B-horizon soil, and HMC of till) indicate dispersal of Au and As in a fan about 100 m wide, that extends about 300 m down-ice from the mineralized zone. The head of each fan is about 50 m to the south of the Au-bearing quartz vein. Antimony has patchy areas of slight enrichment weakly related to the mineralized zone.

Spruce bark and balsam fir

Concentrations of Au, As and Sb in the ash of red spruce bark are shown in Figure 8. The zone of down-ice dispersal of Au and As is evident, and the northwest head of each fan is over the Au-bearing vein. This pattern is coincident with a boulder train of vein quartz on the surface (I. Lawyer, pers. commun., 1989). In addition, both metals are concentrated in samples from the boggy area north of the mineralized zone, suggesting that closer investigation is warranted (Rogers and Dunn, 1989).

Antimony in spruce bark (Fig. 8c) is more than an order of magnitude more concentrated than in any of the clastic samples. The zones of maximum concentration in the bark occur to the north and south of the known mineralization, not above or down-ice from it. This 'rabbit ears' type of anomaly has been noted in other environments (Govett, 1976; Smee, 1983; Dunn, 1983), and the possibility of a local electrochemical cell related to mineralization has been invoked as a cause. Whether or not this is the process is a matter for conjecture, but the highest Sb concentrations occur in proximity to the wet areas, suggesting preferential enrichment controlled by local physicochemical conditions. Throughout the Mill Shaft study area, spruce bark samples contain Sb concentrations higher than normal for this medium, demonstrating a general enrichment of Sb in the substrate. Selenium, which may also be related to the mineralization (Dunn, 1988), is similarly concentrated in most bark samples but is not detected in the clastic media.

Balsam fir twigs were collected at many of the same sites as the spruce bark. Both Au and As were enriched in sites from around the bog to the north of the mineralized zone, and at several sites in the dispersion fan. In general, the concentrations of both metals were lower than in the spruce bark, and the dispersion patterns were more diffuse.

SUMMARY AND CONCLUSIONS

Lake sediment and balsam fir twigs were sampled over a 5000 km^2 area of eastern Nova Scotia, at a sample density of approximately 1 per 8 km^2. No attempt was made to sample both media at the same sites, and the surveys were conducted 12 years apart. Broadly similar geochemical dispersal patterns in both media successfully outline the main gold districts and indicate several areas of Au potential where Au mineralization is not known. Patterns of Sb distribution are less clearly related to the Au-bearing zones.

The spatial relationship between areas of metal enrichment in the two sample media was examined by using a microcomputer-based GIS system. Areas where Au and As concentrations are greater than the 70th percentile in both media identify the main gold camps, and identify other areas worthy of further investigation.

Detailed sampling of B-horizon soil, till and red spruce outer bark from the vicinity of the Mill Shaft gold-bearing quartz vein, permitted evaluation of the relative merits of these sample media in outlining mineralization. In this environment, the <2 mm fraction of the whole soil sample is as informative as the analysis of any finer grain size; for the till, however, the heavy-mineral concentrates and the <63 to >2 um fractions proved to be the most useful.

Patterns of Au and As enrichment in B-horizon soil, HMC of the till, and the spruce bark ash all define a zone of glacial dispersal of metals from the mineralized zone. Antimony is enriched only in the spruce bark, and anomalies are displaced to the north and south of the mineralized zone suggesting some physicochemical control. Both the soil and bark outline the zone of Au dispersal; however, bark has the advantage that trees grow in boggy areas where soils are absent or poorly developed and difficult to collect. Furthermore, bark may be collected in winter when the soils are frozen and snow-covered.

The patterns of Au and As in HMC from the till provide a clear indication of the mineralization. However, bulk till sampling is time consuming, and HMC preparation is more costly than for the other sample media. Consequently, a preliminary evaluation of the mineral potential of a property may be achieved quickly and inexpensively by a soil or vegetation survey, in order to provide a focus for the more expensive HMC survey.

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