



GEOLOGICAL SURVEY OF CANADA
OPEN FILE 2757

**Reconnaissance biogeochemical survey
of southwestern Nova Scotia:
Part 2 – balsam fir twigs
(Parts of NTS 20 O,P, 21 A,B)**

C.E. Dunn, S.W. Adcock, W.A. Spirito

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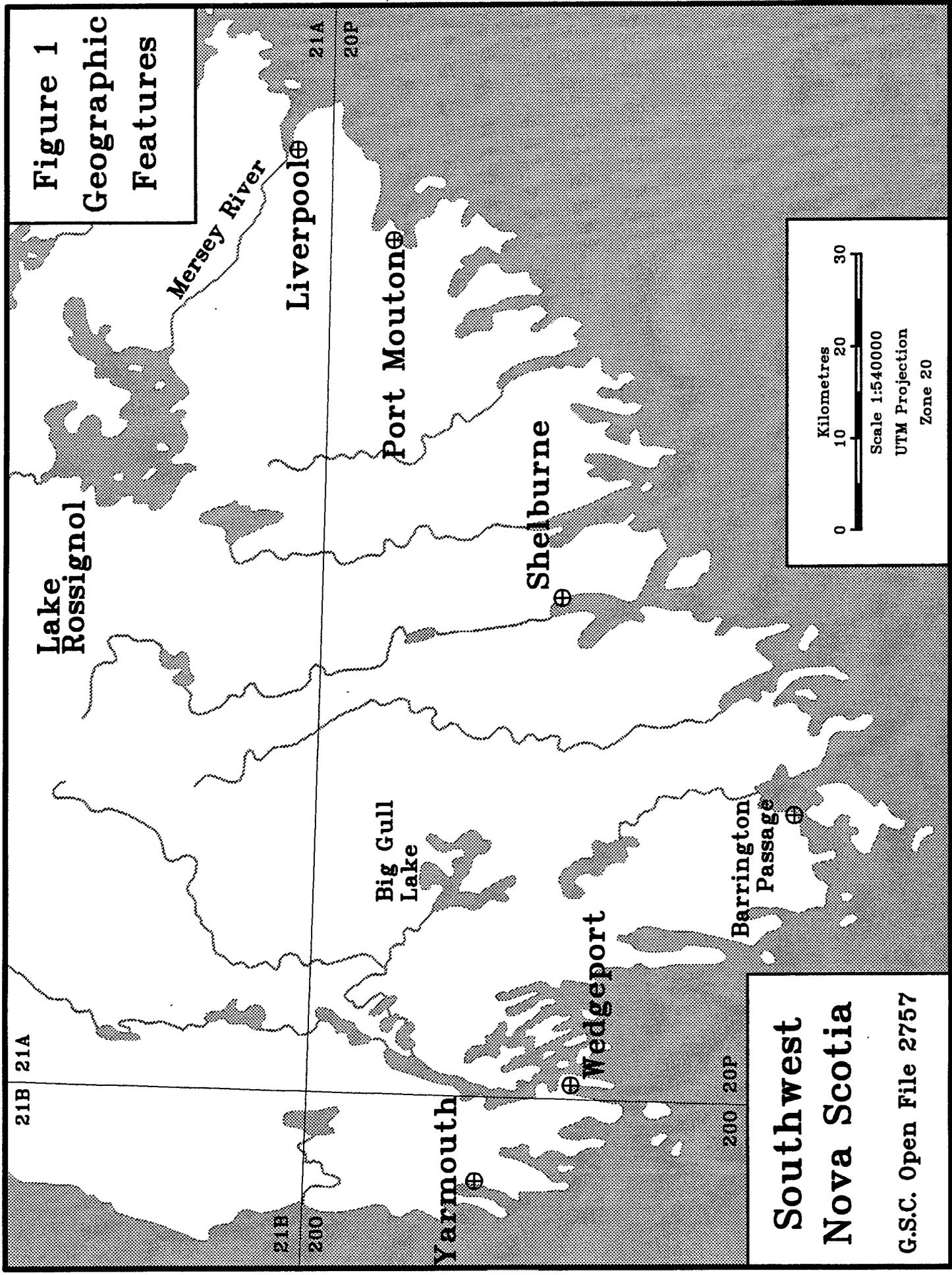


Figure 1
Geographic
Features

Kilometres
0 10 20 30
Scale 1:540000
UTM Projection
Zone 20

Southwest
Nova Scotia
G.S.C. Open File 2757

Reconnaissance Biogeochemical Survey - SW Nova Scotia: Balsam Fir Twigs

RECONNAISSANCE BIOGEOCHEMICAL SURVEY OF SOUTHWESTERN NOVA SCOTIA: PART 2 - BALSAM FIR TWIGS

C.E. Dunn, S.W. Adcock, and W.A. Spirito

INTRODUCTION

This Open File contains data from a reconnaissance biogeochemical survey in southwestern Nova Scotia. The survey was conducted in May, 1991, by the Geological Survey of Canada under the Canada - Nova Scotia Cooperation Agreement on Mineral Development (1990 - 1992). It represents the second of a series of biogeochemical Open Files of different tree tissues from several species in the same area. The first Open File of this series (Dunn et al., 1992) presented data from the outer bark of red spruce (*Picea rubens*).

Field observations, data listings, statistical summaries, a geology and sample location map, and element distribution maps are presented. The maps show element concentrations in the ash of twigs from balsam fir (*Abies balsamea*). Instrumental neutron activation analysis (INAA) was used for determining 35 elements, of which 30 were in sufficient concentration to be detected and quantified. In addition data are included for 16 elements determined by inductively-coupled plasma emission spectrometry (ICP-ES). All data reported are concentrations in ash remaining after controlled ignition at 470°C. For balsam fir, the ashing process concentrates the elements with little or no loss of elements except for a few of high volatility (e.g. Br and Hg).

The value to exploration of reconnaissance geochemical surveys that involve the collection of lake or stream sediments and waters has been extensively tried, tested and documented. In 1987 a reconnaissance biogeochemical reconnaissance survey of similar magnitude to that reported here, also using balsam fir twigs, was conducted in southeastern Nova Scotia. Results were published as an Open File (Dunn et al., 1989), and interpretive accounts are given in Dunn (1988, 1990), Rogers and Dunn, 1989, Dunn et al. (1991), and Rogers and Dunn (1993).

Unlike other geochemical sample media, plants *require* certain elements for their existence. Zinc, for example, is needed for plant metabolism. Therefore, subtle differences in Zn concentrations between sample sites are more likely to reflect the health of the plant than significant differences in the chemistry of the substrate. However, major differences in Zn concentrations may reflect the presence of Zn mineralization.

The Zn example illustrates that biogeochemical data should be interpreted with caution and the text notes provided for each element should be considered. Biogeochemistry is a complex science involving the interaction of organic and inorganic processes that are controlled by many

physicochemical parameters. However, despite these complexities, careful and systematic collection and preparation of vegetation samples can provide cost-effective new insight, not readily obtainable by other means, to the chemistry of the substrate and its groundwaters.

The data listed in Appendix A are available in digital form from:

GSC Bookstore
Geological Survey of Canada
601 Booth St.
Ottawa
Ontario, K1A 0E8 Tel: (613) 995-4342 Fax: (613) 943-0646

The data will be supplied on an MS-DOS (IBM-PC) 3.5" 1.44 Mb diskette, as both an RBASE UNLOAD file (ASCII format; can be read by any text editing software; can be imported directly into an RBASE database), and as a .DBF file, which can be read by any DBASE-compatible software.

CREDITS

Survey design, direction, and sampling methodology: C.E.Dunn.

Field party leader: S.W. Adcock.

Sub-party leaders: P. James and G. Benteau, assisted by C. Logan, S. Alvarado, R. Johnson, and S. Phaneuf.

Sample Preparation: undertaken and supervised by R. Cardinal, with the assistance of S. Lambert, C. Logan, S. Alvarado, and M. Peters.

Data Management: W.A. Spirito and S.W. Adcock.

Computer Programming: S.W. Adcock developed a program to operate on a UNIX workstation for plotting the maps.

Instrumental Neutron Activation Analysis: by contract to Activation Laboratories Ltd., Ancaster, Ontario.

Inductively-Coupled Plasma Emission Spectrometry: by contract to Min-En Laboratories Ltd., Vancouver, B.C.

SURVEY DESCRIPTION AND METHODOLOGY

Scope of Survey

During a three week period, commencing early in May, 1991, samples were collected from approximately 500 sites within a 5000 sq.km area of southwestern Nova Scotia. Although the average sample density was 1 per 10 sq. km the sampling grid was irregular because of difficulty in accessing some areas. In general, samples were collected at 2 km intervals along driveable roads and tracks, with limited helicopter support for accessing remote areas. Three trucks were used, each with a crew of two. At each sample location vegetation samples were selected from a site at

least 50 m from a highway, or 10 m from a little-used track.

Sample locations

Samples were located in the field from 1:10000 LRIS (Land Registration Information Service) maps, supplemented by 1:50000 NTS maps in a few areas. The 1:10000 maps use the Nova Scotia modified transverse Mercator (MTM) projection, in conjunction with the ATS77 datum (Kouba, 1978; LRIS, no date). The ATS77 datum is a precursor and very similar to the NAD83 datum. The 1:50000 maps use the NAD27 datum and the usual UTM projection. A program (CONV77) was purchased from LRIS to convert MTM coordinates to UTM coordinates, based on the ATS77 datum. Unfortunately, conversion from ATS77 to NAD27 is complex, and not practical for the present project. Therefore, the UTM coordinates listed in Appendix A for samples collected using the 1:10000 base maps are based on the ATS77 datum. A geographic location's UTM coordinates for the NAD27 and ATS77 data may differ by up to a few hundred metres. This difference is not important when plotted on a scale of 1:250000, but if a user wishes to determine the exact location for a particular sample, care should be taken to use maps based on the appropriate datum. [The next generation of NTS 1:50000 maps will be based on the NAD83 datum.]

Sample Collection

An orientation survey of the area conducted in October, 1990, showed that the most common species are balsam fir (*Abies balsamea*), red spruce (*Picea rubens*), and tamarack (*Larix laricina*). Chemical analysis of twigs from these species and the outer bark of the spruce and tamarack indicated that each was sensitive to a particular range of elements, but that the red spruce bark had generally higher concentrations of trace metals than the other tissues that were collected. At each sample station outer bark of red spruce, outer bark of tamarack, and the twigs of red spruce, tamarack, and balsam fir were collected, if available. Balsam fir twigs were obtained at 455 sites.

At each sample location 200 - 250 g of fresh twigs and needles were snipped from balsam fir using standard anvil-type, teflon-coated, garden pruning snips. Twig samples were placed in heavy-duty brown paper hardware bags (approximately 25 x 35 cm) and secured with masking tape. There are seasonal variations in the chemistry of twigs, therefore the survey was completed as quickly as possible (three weeks).

Usually 5 - 7 twigs, each comprising 5 - 7 years of growth, provided the required amount of material. Within the survey area this amount of growth was commonly 35 - 40 cm of twig. Where growth was more spindly (e.g. dense forest) and annual growth increments were shorter, up to 10 years of growth was collected. Although there is annual variation in the metal uptake and storage of many chemical elements (some accumulating near the twig ends), the over-riding factor for consideration in a biogeochemical sampling programme is the *diameter* of the twig. It is

important to maintain a consistent ratio of twig bark to twig wood, because many of the heavy metals are located in the bark, and not in the woody tissue of the twig. If this ratio changes substantially, then variations in element content may be attributable to mixing thick with thin twigs, providing false anomalies. For the balsam fir survey the twig diameter at most locations was approximately 5 mm where twig growth was 5 - 7 years old.

Sample Preparation and Analysis

After the samples were air-dried for several weeks in a greenhouse, the needles were separated from the twigs. Balsam fir needles have a different chemical composition from the twigs (lower levels of most heavy and base metals in the needles). The ratio of needle to twig may vary substantially among sample locations, so if twigs are not separated from needles some false anomalies may be generated which are simply a function of different twig to needle ratios.

Approximately 50 g of dry twigs were weighed into aluminum trays. The trays were placed in a pottery kiln, and the temperature slowly raised (over 2 - 3 hours) to 470°C. After a further 12 hours no charcoal remained, and the twigs were reduced to approximately 1 g of ash. Half was accurately weighed and compacted into small polyethylene vials, suitable for instrumental neutron activation analysis (INAA), and submitted for the determination of 35 elements (maps are provided for 30 of these elements - concentrations of Ag, Hg, Ir, and Tb were all below the detection levels of 2 ppm, 1 ppm, 2 ppb, and 0.5 ppm, respectively); reproducibility of data for Mo by INAA was poor at the low levels present (mostly <2 ppm), therefore no map of Mo by INAA is included and instead there is a map of Mo determined by ICP-ES. ICP-ES is the preferred method for Mo at concentrations of only a few ppm. Appropriate standards and duplicates were inserted to ensure quality control. The precision obtained varied between elements and with element concentration. Of the elements reported here, most samples contained levels substantially higher than detection limits, thereby providing analytical precision of better than +/- 10 percent.

The remaining half of the ash sample was submitted for multi-element ICP-ES analysis, following an aqua regia digestion. For most elements this extraction is 'total', although for some (e.g. Al, B) it is only partial. However, the analytical precision was good for most elements, such that the relative element distribution patterns are meaningful even if the absolute concentrations are only partial.

Analytical Quality Control

Included within each block of 20 samples prepared for analysis there was one standard ash sample (V2), and one duplicate ash sample. These provided controls on accuracy and precision, respectively. Data on mean values and standard deviations obtained for each element in a standard ash sample are given in Tables 1 and 2. Tables 3 and 4 contain the raw data from which these determinations were made. Tables 5 and 6 list the analytical data obtained on the duplicate pairs; graphical representation of the data for three elements determined by INAA (Au, As, Zn), and

three determined by ICP-ES (Ni, Cu, and Pb) is presented in Figure 2. Reproducibility is good for these elements, with the exception of Au at concentrations below 10 ppb. Tables 7 and 8 show the determination (detection) limits quoted for each element by the analytical laboratories, and the substitution values used for statistical calculations where analyses were below these levels.

**Table 1: Mean and Standard Deviation for Standard V2
Analyzed by INA (N=20)**

Element			Mean	Standard Deviation
Gold	ppb	Au	14	2
Arsenic	ppm	As	2.7	2.7
Barium	ppm	Ba	2730	187
Bromine	ppm	Br	18	3
Calcium	%	Ca	26.7	2.3
Cobalt	ppm	Co	4	0.5
Chromium	ppm	Cr	30	4
Cesium	ppm	Cs	2.8	0.3
Iron	%	Fe	1.6	0.4
Hafnium	ppm	Hf	1.4	0.2
Potassium	%	K	7.6	0.6
Sodium	ppm	Na	5632	248
Rubidium	ppm	Rb	196	15
Antimony	ppm	Sb	1.3	0.2
Scandium	ppm	Sc	1.1	0.4
Selenium	ppm	Se	*	*
Tin	%	Sn	0.030	0.025
Strontium	ppm	Sr	1390	186
Tantalum	ppm	Ta	**	**
Thorium	ppm	Th	1.1	0.2
Uranium	ppm	U	0.6	0.2
Tungsten	ppm	W	*	*
Zinc	ppm	Zn	2365	114
Lanthanum	ppm	La	4.2	0.4
Cerium	ppm	Ce	8	2
Neodymium	ppm	Nd	**	**
Samarium	ppm	Sm	0.5	0.1
Europium	ppm	Eu	0.02	0.09
Ytterbium	ppm	Yb	0.17	0.11
Lutetium	ppm	Lu	**	**

* all below determination limit

** 75% or greater below determination limit

Table 2: Mean and Standard Deviation for V2 Analyzed by ICP-ES (N=20)

Element			Mean	Standard Deviation
Silver	ppm	Ag	15.1	0.9
Aluminum	ppm	Al	7805	435
Boron	ppm	B	176	9
Beryllium	ppm	Be	*	*
Cadmium	ppm	Cd	3.5	0.8
Copper	ppm	Cu	143	31
Gallium	ppm	Ga	4	3
Lithium	ppm	Li	2	1
Magnesium	ppm	Mg	33582	1791
Manganese	ppm	Mn	17683	859
Molybdenum	ppm	Mo	4	1
Nickel	ppm	Ni	45	2
Phosphorus	ppm	P	10990	695
Lead	ppm	Pb	385	83
Titanium	ppm	Ti	497	44
Vanadium	ppm	V	18	1

* 95% of values below determination limit

** 65% of values below determination limit

Reconnaissance Biogeochemical Survey - SW Nova Scotia: Balsam Fir Twigs

Table 3: Standard V2 - concentrations in ash determined by INAA

Au	As	Ba	Br	Ca	Co	Cr	Cs	Fe	Hf	K	Na	Rb	Sb	Sc	Se	Sn	Sr	Ta	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Yb	Lu	
ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina	ina
ppb	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	
14	2.7	2800	18	25.8	4	29	2.6	1.55	1.4	7.22	5450	190	1.3	1.1	<2	<0.006	1700	<0.5	1.3	0.8	<1	2300	3.9	8	<5	0.5	<0.02	<0.05	<0.05	
15	2.6	2900	16	27.3	4	28	2.7	1.19	1.6	7.64	5830	200	1.3	1.1	<2	0.032	1700	<0.5	1.3	0.6	<1	2300	4.3	9	<5	0.5	<0.02	0.13	0.06	
12	2.2	2900	17	24.9	4	26	2.8	1.1	1.4	7.13	5530	200	1.3	1.1	<2	0.029	1700	<0.5	1.2	0.9	<1	2200	4.3	9	<5	0.6	<0.02	0.25	0.06	
18	2.3	3000	18	29.9	4	35	3.4	1.25	1.7	8.98	5540	220	1.3	1.1	<2	0.085	1400	<0.5	1.4	0.9	<1	2400	4.4	10	11	0.7	<0.02	0.3	0.08	
15	2.9	2700	24	28.8	4	29	2.8	1.41	1.6	7.7	5780	210	1.4	1.1	<2	0.035	1200	0.8	1.6	<0.1	<1	2500	4.5	13	12	0.7	<0.02	0.31	<0.05	
12	2.1	2700	17	26	4	29	2.9	1.23	1.5	7.1	5010	180	1.3	1.1	<2	0.034	1700	<0.5	1.1	0.8	<1	2200	4.2	8	<5	0.5	0.31	0.22	<0.05	
14	1.8	2800	17	26.3	5	29	3.1	1.29	1.5	7.19	5420	190	1.2	1	<2	0.047	1200	<0.5	1.3	0.7	<1	2400	4.5	7	<5	0.6	<0.02	0.19	0.06	
12	1.5	2500	15	24	4	27	2.6	1.85	1.2	7.22	5620	180	1.2	1	<2	0.048	1500	<0.5	0.7	0.6	<1	2300	3.7	6	<5	0.4	<0.02	0.19	<0.05	
10	1.7	2500	15	23.9	4	23	2.4	1.3	1.8	7.31	5430	180	1	0.9	<2	<0.006	1200	<0.5	0.9	0.4	<1	2300	3.6	7	<5	0.5	<0.02	<0.05	<0.05	
11	1.6	2600	16	24.3	4	30	2.4	1.32	1.6	6.42	5540	190	1.1	1.1	<2	<0.007	1400	<0.5	1.1	0.6	<1	2200	4.1	6	<5	0.5	<0.02	<0.05	<0.05	
10	2	2500	15	23.1	4	27	2.5	1.91	1.3	6.78	5450	180	1	0.9	<2	<0.005	1200	1.2	0.7	0.5	<1	2500	3.6	5	<5	0.4	<0.02	0.2	<0.05	
14	1.7	2700	24	28.7	4	28	2.6	1.21	1.3	8.81	5850	190	1.2	1.2	<2	<0.006	1300	<0.5	0.9	0.7	<1	2400	4.2	7	<5	0.5	0.19	0.22	<0.05	
14	1.8	2800	23	29.3	4	39	3.1	2.47	1.4	7.65	5760	210	1.2	1.1	<2	0.07	1300	<0.5	1.1	0.6	<1	2500	4.7	8	12	0.6	<0.02	<0.05	<0.05	
14	2.3	3100	23	30.6	3	28	3.5	1.25	1.3	7.45	5700	220	1.5	1	<2	0.052	1400	<0.5	1.2	0.8	<1	2500	4.7	8	<5	0.6	0.12	<0.05	<0.05	
13	2.3	2400	19	24.6	4	26	2.5	1.47	1.1	8.23	5820	190	1.1	1	<2	<0.005	1500	0.7	0.9	<0.1	<1	2400	4.1	6	<5	0.5	<0.01	0.2	<0.05	
14	2.2	2800	19	29.6	5	37	3.1	2.46	1.5	7.98	6060	210	1.7	1.2	<2	<0.009	1300	0.6	1	0.6	<1	2500	4.7	9	<5	0.6	<0.03	0.35	<0.05	
14	1.8	2800	19	27.6	4	33	3.1	1.77	1.7	7.54	5500	210	1.6	1.1	<2	0.037	1200	<0.5	1.1	0.6	<1	2400	4.3	7	7	0.5	<0.02	<0.05	<0.05	
14	2.2	2900	21	27.8	4	30	2.9	1.32	1.7	7.49	6050	210	1.7	1.2	<2	0.047	1400	0.5	1.1	0.7	<1	2500	4.9	8	<5	0.6	<0.02	0.25	<0.05	
19	14	2700	16	24.1	3	27	2.7	1.55	1	7.93	5830	170	1.4	2.6	<2	0.023	1200	<0.5	0.9	0.6	<1	2300	4.1	7	<5	0.5	<0.02	0.25	0.09	
12	2.2	2500	17	27.5	4	30	2.8	2.11	0.9	7.99	5470	190	1.1	1	<2	0.037	1300	<0.5	1	0.7	<1	2200	4.2	8	<5	0.5	0.13	0.21	<0.05	

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Table 4: Standard V2 - concentrations in ash determined by ICP-ES

Ag	Al	B	Be	Cd	Cu	Ga	Li	Mg	Mn	Mo	Ni	P	Pb	Ti	V
icp	icp	icp	icp	icp	icp	icp	icp	icp	icp	icp	icp	icp	icp	icp	icp
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
15.5	8380	172	<0.2	3.3	136	<2	2	34790	18324	4	45	11140	492	532	18
13.9	7570	162	<0.2	3.3	126	<2	2	31560	16687	3	43	10150	318	489	16
14.6	7610	161	<0.2	2.8	146	<2	<2	33130	17634	4	46	10870	486	537	16
14	7380	161	<0.2	3.4	118	<2	2	31690	16803	4	44	10470	347	496	17
14.5	7530	164	<0.2	3.7	126	<2	2	33180	17319	5	44	10630	336	529	18
14.1	7490	177	<0.2	3.8	141	6	<2	33220	17264	4	45	10550	452	453	17
14.5	7680	182	<0.2	3.2	131	6	<2	34040	17245	4	46	11120	312	496	17
15.7	7810	184	<0.2	4.6	137	6	<2	32440	17568	5	46	10340	441	503	18
16.1	8330	185	<0.2	3.1	148	5	<2	35680	18400	4	48	11610	347	573	18
14.2	7700	167	<0.2	3.3	125	9	<2	32390	17471	4	43	10890	338	498	18
14.7	7630	181	0.2	4.6	127	6	<2	32300	17593	5	45	10490	414	442	18
14.9	7910	184	<0.2	3.9	141	<2	<2	34520	18207	4	47	11460	374	502	18
15.2	7710	186	<0.2	5.3	141	<2	<2	31140	16885	6	43	10020	364	475	18
14.7	7680	180	<0.2	2.9	125	<2	<2	33510	17820	5	48	11260	358	407	18
16.2	7080	187	<0.2	4	127	6	6	32290	17194	6	48	11020	345	408	18
17	8790	188	<0.2	3.8	201	<2	3	38670	20416	4	51	12660	302	501	20
15.3	7800	172	<0.2	2.4	153	<2	<2	34820	17671	4	45	11070	308	521	18
14.3	7440	170	<0.2	2.8	125	<2	<2	32340	16600	4	43	10240	541	487	17
15	7880	179	<0.2	2.4	253	7	<2	34230	17942	3	42	11400	560	539	17
16.8	8710	175	<0.2	3.1	140	8	3	35690	18621	4	45	12400	268	548	18

Reconnaissance Biogeochemical Survey - SW Nova Scotia: Balsam Fir Twigs

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Table 5: Laboratory Duplicates - concentrations in ash determined by INAA

Vial Number	Au ina ppb	As ina ppm	Ba ina ppm	Br ina ppm	Ca ina %	Co ina ppm	Cr ina ppm	Cs ina ppm	Fe ina %	Hf ina ppm	K ina %	Na ina ppm	Rb ina ppm	Sb ina ppm	Sc ina ppm	Se ina ppm	Sn ina %	Sr ina ppm	Ta ina ppm	Th ina ppm	U ina ppm	W ina ppm	Zn ina ppm	La ina ppm	Ce ina ppm	Nd ina ppm	Sm ina ppm	Eu ina ppm	Yb ina ppm	Lu ina ppm
AL91/1088	10	3.7	1300	26	20.6	2	5	4.1	0.24	<0.5	19.3	2110	330	0.9	0.7	<2	<0.007	1200	0.7	<0.1	<0.1	<1	2100	2.1	6	6	0.3	0.21	0.21	<0.05
AL91/1089	5	3.8	1400	21	21.3	3	5	4	0.23	<0.5	16.6	2000	310	0.9	0.6	<2	<0.006	1400	<0.5	0.3	<0.1	<1	2300	2.1	4	<5	0.3	<0.03	0.19	<0.05
AL91/1111	7	5.7	300	18	16.5	2	6	25	0.25	0.7	22.3	2040	1400	0.7	0.8	<2	<0.006	1700	0.7	0.4	1.7	8	2700	2.5	6	<5	0.5	<0.02	0.26	<0.05
AL91/1112	10	4.6	370	22	18.4	2	5	22	0.31	0.7	21.6	2520	1200	0.8	0.8	<2	0.045	1900	1.2	1	2	7	3200	3.3	5	<5	0.5	<0.02	0.38	0.07
AL91/1122	<5	3	1200	23	20.5	3	4	1.1	0.22	<0.5	17.1	2640	120	0.6	0.7	<2	<0.005	1900	<0.5	0.4	<0.1	<1	1700	2.1	3	<5	0.3	<0.02	<0.05	<0.05
AL91/1123	7	2.4	980	24	19.3	3	6	1.5	0.24	0.6	16.5	2610	100	0.8	0.8	<2	<0.005	2000	<0.5	0.4	<0.1	<1	1700	2.7	6	<5	0.4	0.13	0.21	<0.05
AL91/1144	13	6.8	1400	24	23.6	3	10	1.7	0.26	0.6	19.8	1720	240	0.8	0.9	<2	<0.009	1500	0.6	0.6	<0.1	<1	2200	2.7	7	<5	0.4	<0.03	0.25	0.08
AL91/1145	12	5.1	1200	22	21.5	3	7	2.1	0.33	0.6	23.4	2090	350	0.9	0.9	<2	<0.009	1100	1.3	0.8	<0.1	<1	2700	3	6	<5	0.6	<0.03	0.28	0.08
AL91/1165	7	5.2	1400	71	18.4	6	6	1.4	0.3	<0.5	24.4	3560	180	0.7	0.9	<2	<0.008	1700	1.4	0.9	<0.1	3	2100	3.3	10	<5	0.6	0.17	0.35	0.06
AL91/1166	<5	4.3	1300	75	18	6	8	1.3	0.31	1	24	3680	200	0.6	0.9	<2	<0.009	1400	<0.5	0.8	<0.1	<1	2000	3.6	9	<5	0.7	<0.03	0.28	0.06
AL91/1194	<5	4.7	990	34	19.9	3	6	3.8	0.25	<0.5	17.5	2030	240	0.9	0.7	<2	<0.005	1300	<0.5	0.5	<0.1	<1	2300	3.2	6	6	0.6	<0.02	0.2	<0.05
AL91/1195	5	5.3	1100	29	18.1	2	3	3.4	0.26	<0.5	18.2	3060	220	0.7	0.7	<2	<0.006	1700	<0.5	0.5	<0.1	<1	1800	2.8	7	<5	0.5	<0.03	<0.05	<0.05
AL91/1218	<5	2.5	320	53	16.1	4	7	1.9	0.42	1.1	21.2	7060	120	0.6	1.4	<2	<0.007	870	<0.5	0.8	0.6	<1	1500	7.3	13	<5	1.2	0.35	0.65	0.13
AL91/1219	5	4.3	390	39	17.6	3	8	1.6	0.56	1.5	18.2	10500	100	0.6	2	<2	<0.009	960	<0.5	1.8	<0.1	<1	1400	10	17	<5	1.7	0.31	0.83	0.12
AL91/1238	<5	1.8	1000	200	14.1	12	4	4.8	0.24	0.9	24	4510	380	0.7	0.7	<2	<0.01	1300	<0.5	0.2	0.4	1	2500	2.1	6	<5	0.3	<0.03	<0.05	<0.05
AL91/1239	<5	1.5	1000	200	15.1	12	4	5.1	0.25	0.7	25.2	4540	400	0.6	0.7	<2	<0.008	1400	<0.5	0.3	0.5	1	2400	2.2	6	<5	0.3	<0.02	0.29	<0.05
AL91/1270	<5	2.9	1900	20	18.2	3	6	5.7	0.29	<0.5	15.7	1970	220	0.6	0.8	<2	0.029	2500	1.1	0.2	<0.1	<1	1800	3.9	10	8	0.7	<0.03	0.27	<0.05
AL91/1271	<5	1.5	1900	25	20.6	3	5	4.2	0.23	0.9	13.9	1950	210	0.6	0.7	4	<0.006	2200	<0.5	0.3	0.4	<1	1900	3.4	6	<5	0.6	<0.03	0.25	0.06
AL91/1291	6	2.5	2900	30	19.9	5	8	1.9	0.3	<0.5	16.6	1980	200	0.7	0.9	<2	<0.007	2200	<0.5	0.4	<0.1	2	1900	3.5	7	<5	0.6	<0.02	0.3	<0.05
AL91/1292	7	2.8	3300	50	22.4	6	10	1.7	0.38	<0.5	12.1	2760	140	0.9	1.2	<2	<0.008	2200	<0.5	0.5	<0.1	2	2000	5	9	<5	0.8	<0.03	0.33	0.11
AL91/1313	<5	5.3	570	17	18	5	3	6.4	0.29	<0.5	21.1	2500	370	0.4	0.7	<2	<0.005	1200	1.2	<0.1	1.7	9	2600	2.2	4	<5	0.3	<0.02	0.11	0.06
AL91/1314	<5	4.9	610	25	17.1	5	3	7.1	0.28	0.6	23	2500	400	0.4	0.7	<2	<0.005	1200	1.1	0.3	1.3	9	2400	2	3	<5	0.3	<0.02	0.22	<0.05

Reconnaissance Biogeochemical Survey - SW Nova Scotia: Balsam Fir Twigs

GSC Open File 2757, 1994
Table 6: Laboratory Duplicates - concentrations in ash determined by ICP-ES

Packet Number	Ag	Al	B	Be	Cd	Cu	Ga	Li	Mg	Mn	Mo	Ni	P	Pb	Ti	V
	icp ppm															
ICP91/1088	1.4	5990	215	<0.2	8.1	210	<2	<2	31400	18593	3	52	40850	122	69	34
ICP91/1089	0.8	5190	218	<0.2	7.9	194	<2	<2	30120	18041	2	44	37230	136	55	34
ICP91/1111	1.9	14360	225	0.6	5.7	235	4	5	39560	4074	2	22	41090	128	74	26
ICP91/1112	1.8	12640	204	0.7	4.8	216	3	5	34740	3675	<2	20	31940	135	68	28
ICP91/1122	1.6	4710	163	<0.2	5.6	159	3	<2	27290	10597	2	32	26950	78	73	22
ICP91/1123	1.4	4940	170	<0.2	6.9	158	3	<2	28860	8760	2	29	26950	82	81	24
ICP91/1144	0.4	6790	212	<0.2	12.6	168	<2	<2	30990	18006	3	51	32490	115	88	31
ICP91/1145	1.1	7750	211	<0.2	17.7	205	<2	<2	28050	13825	3	51	40760	118	78	33
ICP91/1165	<0.2	4830	198	<0.2	22.8	174	<2	4	28850	47881	2	98	29060	176	93	34
ICP91/1166	<0.2	4670	183	<0.2	21.4	166	<2	4	27760	40702	4	95	30630	171	87	34
ICP91/1194	0.9	4920	219	<0.2	5.1	141	8	<2	28790	12201	2	33	21950	201	63	29
ICP91/1195	1.1	7270	286	0.4	<0.2	156	<2	4	53230	7012	<2	24	32730	183	78	31
ICP91/1218	1.2	5240	180	<0.2	0.7	134	7	<2	30210	9070	<2	23	21930	91	173	26
ICP91/1219	1.2	6070	178	<0.2	0.4	141	7	3	27280	7290	2	23	18910	99	235	31
ICP91/1238	0.6	6270	229	<0.2	11.8	217	<2	<2	38900	21353	2	72	30840	114	85	28
ICP91/1239	0.7	6130	224	<0.2	11.7	215	3	<2	38040	21070	2	73	30540	118	82	28
ICP91/1270	1.7	6940	242	<0.2	10.3	182	8	<2	27260	10497	2	38	27260	162	103	35
ICP91/1271	1.6	6020	247	<0.2	10.9	171	9	<2	27030	10498	2	37	26260	147	101	33
ICP91/1291	1.2	6580	267	0.2	2.8	194	<2	3	37900	12871	3	40	21950	157	101	32
ICP91/1292	1.2	6730	223	0.3	4.2	163	<2	4	35110	15806	3	42	16980	230	124	39
ICP91/1313	2.2	3370	188	0.4	9.9	183	10	4	34620	8042	3	22	29920	76	78	24
ICP91/1314	2.2	2950	185	0.3	7.9	174	10	2	33340	7289	3	23	29730	69	64	23

Reconnaissance Biogeochemical Survey - SW Nova Scotia: Balsam Fir Twigs

GSC Open File 2757, 1994
Table 6 (cont'd): Laboratory Duplicates - concentrations in ash determined by ICP-ES

Packet Number	Ag		Al		B		Be		Cd		Cu		Ga		Li		Mg		Mn		Mo		Ni		P		Pb		Ti	
	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm	icp ppm	ppm
ICP91/1347	1.9	4520	294	<0.2	3.7	152	6	<2	32760	3542	3	20	28260	120	88	50														
ICP91/1348	1.4	4020	305	0.3	2.5	133	<2	31820	3931	2	22	25970	118	103	50															
ICP91/1377	2.1	5030	266	0.2	1.3	137	5	<2	34800	4301	2	19	17170	139	55	28														
ICP91/1378	1.3	5240	247	<0.2	<0.2	127	<2	31310	4345	2	19	17910	111	57	26															
ICP91/1400	1.6	4140	267	<0.2	6.3	154	4	<2	30140	9159	3	30	29710	109	63	32														
ICP91/1401	2	4310	283	<0.2	8	150	4	<2	29790	10265	3	35	26450	142	76	39														
ICP91/1424	3.1	3460	290	<0.2	1.5	116	9	5	32700	11788	3	34	19750	132	44	26														
ICP91/1425	2.9	3470	319	<0.2	1	120	10	5	33840	11137	3	36	22230	135	47	27														
ICP91/1447	1	5370	226	<0.2	19.9	193	<2	8	28000	23461	2	67	36220	99	145	22														
ICP91/1448	0.8	5220	237	<0.2	19.8	193	<2	8	25430	26791	3	68	35720	107	149	23														
ICP91/1467	1.9	4540	243	0.2	<0.2	171	<2	<2	39130	6338	<2	40	31070	67	56	21														
ICP91/1468	1.4	5400	288	0.3	<0.2	177	<2	2	39760	7422	2	44	32460	98	74	28														
ICP91/1494	1.7	4600	323	0.2	0.5	131	2	2	39020	6734	<2	27	19890	101	62	25														
ICP91/1495	1.5	4420	353	0.2	<0.2	128	<2	2	39940	7410	<2	27	18370	104	63	25														
ICP91/1515	1.2	6770	184	<0.2	9.1	211	9	3	31320	12911	2	42	29630	102	78	28														
ICP91/1516	1.2	5940	196	<0.2	9.8	200	9	2	30590	13359	2	46	32120	84	71	23														
ICP91/1538	2.9	8340	152	0.2	6.3	145	10	<2	27840	7638	2	31	24020	99	293	26														
ICP91/1539	2.9	8000	153	0.2	6.2	158	11	<2	27370	7567	2	33	27440	70	243	23														
ICP91/2969	2.3	5360	183	0.4	2.8	158	2	3	42220	3921	<2	26	75740	82	79	19														
ICP91/2970	1.9	5130	178	0.4	2.2	155	2	2	41440	3598	<2	26	74920	77	71	18														

Fig. 2: Scatterplots of analytical duplicate pairs for Au, As, Zn by INAA and Cu, Pb, and Ni by ICP-ES

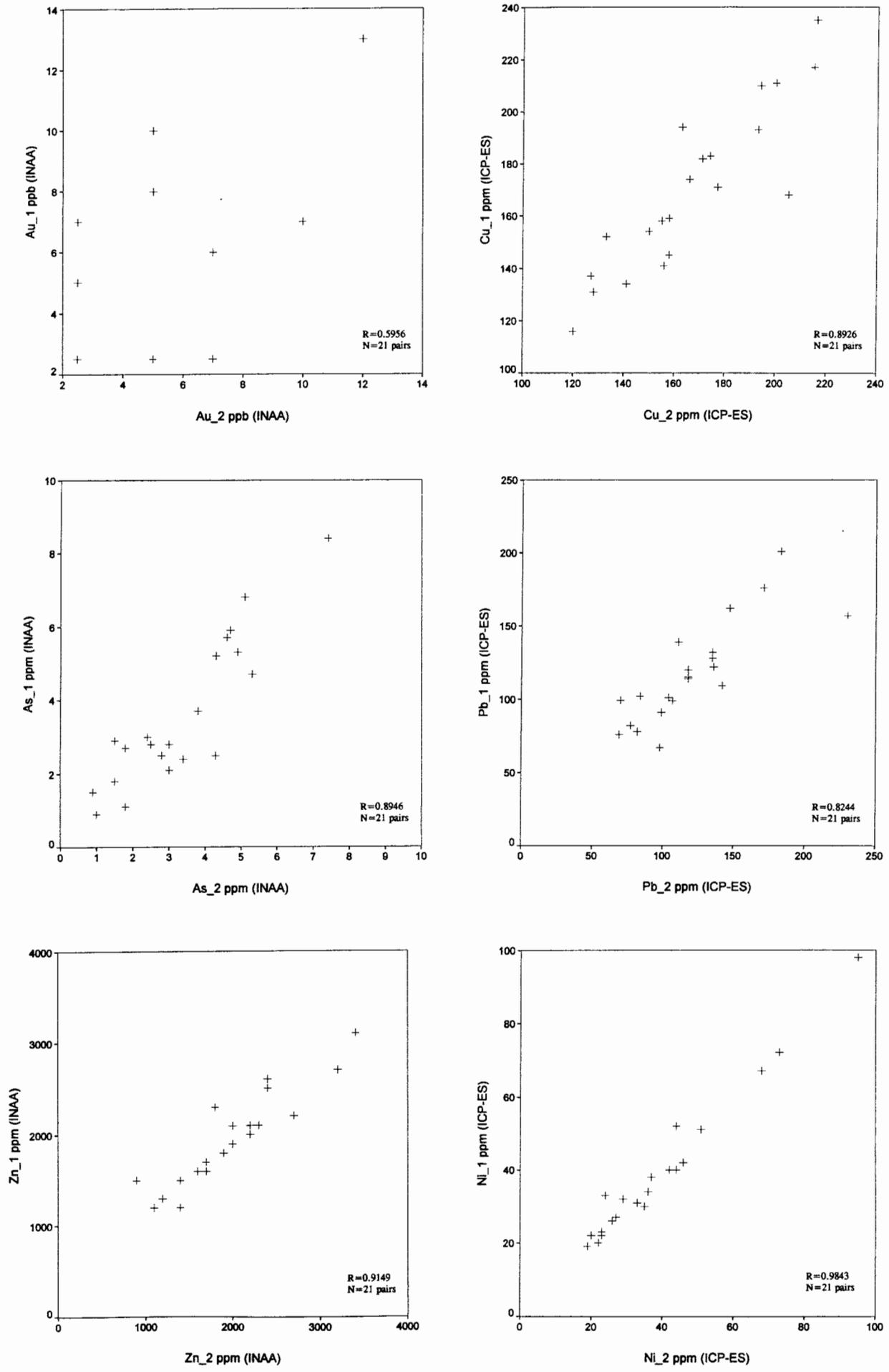


Table 7: Determination Limits and Substitution Values for Elements Analyzed by INA

Element		Units of Measure	Determination Limit	Substitution Value
Gold	Au	ppb	5	2.5
Arsenic	As	ppm	0.5	0.25
Barium	Ba	ppm	10	*
Bromine	Br	ppm	1	*
Calcium	Ca	%	0.2	*
Cobalt	Co	ppm	1	*
Chromium	Cr	ppm	1	0.5
Cesium	Cs	ppm	0.5	0.25
Iron	Fe	%	0.05	*
Hafnium	Hf	ppm	0.5	0.25
Potassium	K	%	0.05	*
Sodium	Na	ppm	10	*
Rubidium	Rb	ppm	5	*
Antimony	Sb	ppm	0.1	*
Scandium	Sc	ppm	0.1	*
Selenium	Se	ppm	2	1
Tin	Sn	%	0.005	0.0025
Strontium	Sr	ppm	300	*
Tantalum	Ta	ppm	0.50	0.25
Thorium	Th	ppm	0.1	0.05
Uranium	U	ppm	0.1	0.05
Tungsten	W	ppm	1	0.5
Zinc	Zn	ppm	20	*
Lanthanum	La	ppm	0.1	*
Cerium	Ce	ppm	3	1.5
Neodymium	Nd	ppm	5	2.5
Samarium	Sm	ppm	0.1	0.05
Europium	Eu	ppm	0.01	0.005
Ytterbium	Yb	ppm	0.05	0.025
Lutetium	Lu	ppm	0.05	0.025

* all values above the determination limit

Table 8: Determination Limits and Substitution Values for Elements Analyzed by ICP-ES

Element		Units of Measure	Determination Limit	Substitution Value
Silver	Ag	ppm	0.2	0.1
Aluminum	Al	ppm	1	*
Boron	B	ppm	1	*
Beryllium	Be	ppm	0.2	0.1
Cadmium	Cd	ppm	0.2	0.1
Copper	Cu	ppm	1	*
Gallium	Ga	ppm	2	1
Lithium	Li	ppm	2	1
Magnesium	Mg	ppm	10	*
Manganese	Mn	ppm	1	*
Molybdenum	Mo	ppm	2	1
Nickel	Ni	ppm	1	*
Phosphorus	P	ppm	10	*
Lead	Pb	ppm	1	*
Titanium	Ti	ppm	10	*
Vanadium	V	ppm	0.1	*

* all values above the determination limit

GEOLOGY

Bedrock and Mineralization

Most of the study area is underlain by turbidites (Goldenville Formation) and slates (Halifax Formation) of the Cambro-Ordovician Meguma Group. Major plutonism of granitic rocks during the Early Carboniferous, notably the South Mountain Batholith in the north, gave rise to extensive folding and faulting, accompanied by regional greenschist to amphibolite grade metamorphism (Taylor, 1967). West of Shelburne, Late Carboniferous intrusion of the Barrington Passage Tonalite (Reynolds et al., 1981) produced a thermal metamorphic overprint (Rogers, 1985). The Shelburne diabase dyke intruded the area during the Early Jurassic.

Keppie (1979) considered that the major folds of the Meguma Group formed at ca. 370 m.y., in the early stages of the Acadian Orogeny, forming north to northeast-trending flexures. A major strike-slip fault (Tobeatic Fault) striking northeastward from the Yarmouth area along the southern margin of the granite, divides the Meguma Terrane into northwest and southeast structural zones (Giles, 1985).

The most notable mineralization in the area is the greisen-hosted tin deposit at East Kemptville, where it is associated with W, U, alkali and base metals. It was mined from 1985 until production ceased in 1992. Mineralization is dominated by cassiterite with topaz, muscovite and zinnwaldite, with associated arsenopyrite, chalcopyrite, fluorite, galena, molybdenite, pyrite, pyrrhotite, sphalerite, and wolframite. Other mineral deposits have been recorded from Duck Pond (Sn), west of East Kemptville; Brazil Lake (Li), northeast of Yarmouth; Dominique (Sn), southeast of Yarmouth. Enrichments of Au, Be and Mo are recorded from across the southern part of the survey area. Details of these and other deposits in the Meguma Terrane can be found in a recent compilation by Sangster (1990).

Geological base map compilation

The transparent geological overlay map provided in the pocket, and the coloured 1:250000 sample location map are digitized computer-plotted compilations derived from the following sources:

- Donohoe, H.V. Jr. and Grantham, R.G. (1989). Geological Highway Map of Nova Scotia, second edition, Atlantic Geoscience Society, Halifax, AGS Special Publication No. 1.
- Ham, L.J. and MacDonald, M.A. (1991). Preliminary geological map of Wentworth Lake, NTS sheet 21A/4 (and part of 20P/13). N.S. Dept. Natural Resources, Open File Map 91-020.
- Hope, T.L., Douma, S.L. and Raeside, R.P. (1988). Geology of the Port Mouton - Lockport area, southwestern Nova Scotia. GSC Open File 1768.
- Rogers, H.D. (1986). Igneous and metamorphic geology of Shelburne and eastern Yarmouth counties, Nova Scotia. GSC Open File 1374.

Rogers, H.D. (1988). Field relations, petrography, and geochemistry of granitoid plutons in the Shelburne area, southern Nova Scotia. GSC Open File 1835.

Taylor, F.C. (1967). Reconnaissance geology of Shelburne map-area, Nova Scotia. GSC Memoir 349.

Quaternary Deposits

The chemistry of trees is influenced partly by the bedrock, but primarily by the chemical composition of groundwaters and surficial deposits. Therefore, consideration of the physical and chemical nature of the glacial deposits is relevant to interpretation of the biogeochemical patterns.

Most of the survey area is covered with Beaver River till which ranges in thickness from 1 - 10 m, with an average of 3 m (Stea, 1982; Stea and Grant, 1982). Drumlin facies are 2 - 20 m thick, elongated toward the southeast in the direction of the dominant ice flow, but more southerly in the Yarmouth area. The dominant till is a light bluish-grey quartzite till with angular, loose clasts that are commonly more than 16 mm in diameter. Locally there are several large (mostly 100 - 200 km²) areas of greyish-orange to yellowish-brown granite till. Areas of slate till, derived from the Meguma slates, are less common. Smaller patches of sandy ablation till, glacial outwash deposits, and ice contact stratified drift are also present.

MAP PRODUCTION AND DATA HANDLING

The maps are all drawn using the Universal Transverse Mercator projection, with a central meridian of 63° (Zone 20). This projection is the same as that used for the 'Geological Map of the Province of Nova Scotia' (Keppie, 1979). Map plots in this Open File were produced by SPARCMAP geochemical mapping software used by the Applied Geochemistry Subdivision of the GSC. Computations were performed on a UNIX workstation, with output to a Hewlett-Packard Laserjet printer (for the small maps) and to a Synergy electrostatic printer (large coloured map). The coastline and drainage were obtained in digital form from Surveys Mapping and Resource Sector of the Dept. of Natural Resources Canada. For the small scale maps, the digital data were purchased from the National Atlas Information Service (NAIS). These data were derived from 1:2 000 000 scale original maps. Features are accurate to about 200 m. This led to some samples which were collected near lakes or the ocean being plotted in the water. The 1:125 000 map was plotted from data purchased from the Canada Centre for Geomatics. These data were derived from the 1:250 000 NTS map sheets, and therefore are much more accurate than the NAIS data. They contain too much detail to be useful as base maps at a scale of 1:500 000.

Element concentrations below analytical detection limits were reduced to half of the detection limit for data plotting and statistical calculations. For samples with duplicate analyses,

data from the first of each duplicate pair was plotted.

The dot maps are based on a method first developed by Bjorklund and Gustavsson (1987). It was used as the primary data presentation method by the Nordkalott project (Bolviken et al., 1986), and since then has become a popular technique at the GSC (Thorleifson and Kristjansson, 1990; McClenaghan, DiLabio and Laurus, 1992). The dot size is proportional to the analytical value, according to the following formula (in FORTRAN notation):

$$\text{RADIUS} = \text{RSYM} * (\text{RA} ** \text{RFOPT} / \text{RV} ** \text{RFOPT})$$

RSYM: the maximum dot radius, defined by the user in millimetres.
RA: the analytical value to be plotted
RV: the analytical value at a specified percentile
RFOPT: an exponent

If RA is greater than RV, then RA is set equal to RV. RV is generally set equal to the analytical value corresponding to the 95th or 98th percentile. All samples with values greater than RV will therefore be plotted with a constant dot size equal to RSYM. If the calculated value of RADIUS drops below a certain minimum radius, as defined by the user, then a dot of that minimum radius is plotted. This ensures that dots do not become minuscule. RFOPT is defined by the user, and is usually set in the range 1 to 2. Increasing RFOPT emphasises those samples with high values.

ELEMENT DISTRIBUTION MAPS

Interpretation of the element distribution maps requires some consideration of the role of chemical elements in plant function. Some comments are given in this section to assist in this interpretation. These notes deal first with those elements determined by INAA, followed by those determined by ICP-ES. This sequence is the same as the element listings in Appendix A and the statistical summary in Appendix B.

For determinations by INAA, elements are arranged alphabetically by chemical symbol, except for the rare earth elements (REE) which are arranged in order of increasing atomic weight - i.e. La, Ce, Nd, Eu, Sm, Yb, as is conventional for REE listings. For determinations by ICP-ES, elements are arranged alphabetically by chemical symbol.

Transparent Overlay

A transparent overlay at the same scale as the element distribution maps is provided to help locate individual samples (identified by sample number on the folded 1:250 000 scale colour map), and to relate their positions to main communities, bedrock geology, mineral deposits and showings, and the East Kemptville multi-element tin deposit. Detailed geology is provided as a large colour map, and additional place names are shown on Fig. 1.

Distribution Maps of Elements Determined by INAA

Gold (Au)

Gold is not known to be essential for plant growth and health. Consequently, patterns of Au distribution reflect zones of relative gold enrichment in soils, groundwaters and near surface rocks. Background levels of Au in the ash of balsam fir twigs are commonly less than 5 ppb Au. Because of the low (ppb) traces of Au that are present, the precision of the INAA on duplicate pairs is not as good as that of most other elements determined by this method, and at concentrations below 10 ppb Au the reproducibility of analyses is poor. In general, Au concentrations in the study area are low (median <5 ppb), but local clusters of samples with relative Au enrichment occur over Meguma Group sediments to the west of the Devonian-Carboniferous granite that forms the South Mountain Batholith (maximum of 31 ppb Au at site #1066). Some of these sites are coincident with enrichment of the 'pathfinder' elements As and Sb.

Arsenic (As)

Arsenic is renowned for its toxicity, yet plants (especially Douglas-fir) can accumulate extraordinary amounts without exhibiting any visible harmful effects (Warren et al., 1964; Dunn and Scagel, 1989). Arsenic is an essential element for the metabolism of carbohydrates in fungi and algae, and a few ppm As in most conifer tissues is to be expected. Zones of relative As enrichment occur near the East Kemptonville mine, and both north and south of Yarmouth.

Barium (Ba)

All samples yielded substantially more barium than the INAA detection limit of 10 ppm Ba. Balsam fir twigs commonly contain approximately 1000 ppm Ba, but some unusually high concentrations occur within the map area, locally up to 7,000 ppm in samples from areas underlain by Goldenville and Halifax formations of the Meguma Group.

Bromine (Br)

Bromine is a volatile element, present in most, if not all terrestrial plants, but it is not known to be an essential element. It can occur in many forms as complexes within plants. Some Br complexes volatilize during the ashing process, causing losses of 30 - 90 percent of the Br contained within the plant tissues. Although there is commonly a Au/Br association in plant ash from zones of mineralization (Dunn, 1986), this is not apparent in the survey area.

It was expected that Br enrichment would occur in shoreline samples, due to the influence of Br-bearing salt spray from the ocean. However, most high concentrations of Br occur as isolated anomalies inland. It is likely that Br from the salt spray volatilized during the ashing process, and that the zones of Br enrichment are related to local chemistry and physicochemical conditions.

Calcium (Ca)

Calcium is a major 'building block' element, essential for the rigidity of cell walls in most plants. The variations in Ca content of the twigs may influence the distribution of some trace elements. For example a statistical analysis of multi-element data sets commonly reveals a strong association of Ca with Ba and Zn. The statistical summary of the Ca data (p. B6) shows there is little variation among trees growing over different substrates

Cobalt (Co)

Traces of Co are required by some plants to assist in the fixation of major nutrients (e.g. N, S). One ppm Co in ash is all that is required by most plants (Kabata-Pendias and Pendias, 1984), but conifer twigs commonly have approximately 5 ppm Co. Within the survey area the median content of Co in the balsam fir twigs is 3 ppm. Plant tissues commonly contain elevated levels of Co over ultramafic rocks, and it has been observed that some plants exhibit Co enrichment in the vicinities of gold mineralization in northern Saskatchewan (Dunn, 1986). The map of southwestern Nova Scotia shows weak enrichment of Co (maximum 20 ppm) over rocks of the White Rock and Halifax formations in the western part of the survey area. This may be related to glacial movement of volcanic rocks from the north (North Mountain Formation).

Chromium (Cr)

Chromium is a non-essential element for which precise INAA data are obtained at low ppm levels. Concentrations are low with respect to the normal range of values for balsam fir twigs (10 - 20 ppm Cr), and appreciably lower than in the same sample medium from over Meguma Group sediments in eastern Nova Scotia (20 - 40 ppm Cr; Dunn et al., 1989). There is relative enrichment of Cr (maximum 28 ppm) in samples from the extreme west where, on average, concentrations of both Cr and Co are mostly four times higher than in trees from elsewhere in the survey area.

Cesium (Cs)

This alkali metal performs no known essential function in plant tissues, and is usually present at less than 3 ppm Cs in conifer twig ash. Although more geochemical partitioning of Cs from Rb occurs in plant tissues than in rocks, both metals are enriched in trees from areas where there are alkali metal-rich phases in granitic bodies. This enrichment is apparent at East Kemptville (up to 59 ppm Cs), at sites approximately 25 km to the northeast, and at a few sites in the Shelburne area near the southern margin of the granite.

Iron (Fe)

Iron is essential for photosynthesis and is a major constituent of chlorophyll. In addition, there is a residual content of Fe which reflects the composition of the substrate. The map of Fe distribution closely parallels that of Cr and, to a lesser extent Co, suggesting a mafic rock association. Statistical analysis of the data (p. B10) shows Fe concentrations over the White

Rock Formation are almost double those of samples from areas underlain by other formations.

Hafnium (Hf)

Ash of conifer twigs commonly contains 1 - 2 ppm Hf. Hafnium levels are usually higher where Fe concentrations are high because the two elements are commonly associated in plants. The uptake of Hf by plants may also be controlled by Zr, due to their close geochemical affinities.

Potassium (K)

Potassium has no structural role in plants, but it serves a number of catalytic roles and is required in large amounts (Bidwell, 1979). It is very important in the overall metabolism of plants. The high concentrations present in balsam fir twigs (median of 20.8%) are normal levels for conifer twigs. There is relative enrichment of K in fir twigs from trees on the Devonian tonalite near Barrington passage (Fig. 1 and p. B12).

Sodium (Na)

The effect of salt-spray from the sea is evident on the Na map, since most of the elevated Na concentrations occur in trees from sites near the shore. Sodium levels are relatively high in the western part of the survey area at sites enriched in Fe. This sympathetic association of Na and Fe is common in plants.

Rubidium (Rb)

There is an antagonism between K and Rb in plants (Kabata-Pendias and Pendias, 1984) because of their competition for the same binding sites, resulting in different distribution patterns for the two elements. Cesium is also involved, but the strong correlation commonly shown between Rb and Cs in trees (cf. maps of Cs and Rb distributions) indicates that antagonism does not occur at the levels of concentration normally found. Background levels of Rb in balsam fir twigs are commonly 200 ppm. Balsam fir twigs from over the Devonian granite contain a median concentration of 300 ppm Rb in ash, with local enrichment up to 1400 ppm Rb. Enrichment of all the alkali metals occurs in the East Kemptville area and 25 km to the northeast on granite of the South Mountain Batholith.

Antimony (Sb)

Excellent analytical precision is obtained for Sb by INAA down to sub-ppm levels in ash. Although Sb can be readily taken up by plants in soluble forms it is considered a non-essential element (Kabata-Pendias and Pendias, 1984) and is usually present at low ppm levels. In general, Sb anomalies are scattered and variations in concentration are very small. The 98th percentile of the data set is only 1.5 ppm Sb indicating a low regional level of Sb.

Scandium (Sc)

Data on the essentiality of Sc in biologic systems are inconclusive (Horovitz, 1988). If required, Sc is needed only in 'ultra-trace' amounts, and therefore its presence in twigs is controlled essentially by the chemistry of the substrate and by the distribution of other elements. In particular, there is a high correlation between Sc and Fe.

Selenium (Se)

Traces of Se are essential for some plants. Selenium occurs in combination with many compounds, some of which break down to release volatile chemical species of Se during the ashing process. Consequently, it is probable that the Se content of the twig ash is not proportional to the total content of the dry tissue. Analytical precision by INAA at low ppm levels of Se is poor. As a result, anomalies are mostly isolated and bear no relationship to known mineralization within the survey area.

Tin (Sn)

Tin analysis by INA has poor sensitivity and yields variable detection levels (approximately 50 - 300 ppm Sn) because of spectral interferences from other elements. For most samples the detection level was approximately 100 ppm Sn. However, for the few samples that were enriched in tin, the reproducibility of the data was good. Samples from within a radius of 5 km from the East Kemptville are highly enriched in Sn, reflecting both natural dispersion and airborne contamination.

Strontium (Sr)

INAA has poor sensitivity to traces of Sr, and analytical precision is inferior to that for most other elements considered in this study. However, Sr concentrations are well above detection limits in all samples, such that the areas of Sr enrichment depict significant regional variations.

Strontium is essential for some plant species, but its general essentiality still needs confirmation. It performs a function similar to Ca in plants, and may be incorporated into their structural components. However, interactions between Ca and Sr are complex and, as demonstrated by the distribution maps for these elements, they do not closely follow one another.

Tantalum (Ta)

Twigs rarely contain more than 1 ppm Ta in ash, therefore, the larger dots on the Ta distribution map indicate sites of unusual enrichment, especially in association with the East Kemptville tin deposits.

Thorium (Th)

Thorium has low solubility and is not essential for plant growth. Its concentration in plant ash is typically < 2 ppm, and even over zones of Th-rich mineralization (e.g. allanite with > 5000 ppm Th in northern Saskatchewan) only a few ppm accumulate in the tissues (Dunn and Hoffman, 1986). A linear northerly trend of relative enrichment of Th occurs over and close to the granite near Shelburne.

Uranium (U)

Although U_3O_8 has high solubility, it rarely exceeds concentrations of more than 2 ppm in plant ash. There are a number of notable exceptions, particularly in northern Saskatchewan where enrichments in spruce twigs are locally more than three orders of magnitude (Dunn, 1983). Uranium-rich phases of granite commonly give rise to concentrations of a few ppm U in twig ash, as shown by the cluster of dots around the mineralization at East Kemptville. Weak enrichment of U and Th occurs in the northwest corner of the survey area.

Tungsten (W)

The detection limit for W by INAA is 2 ppm in ash, which is above the usual concentrations in tree tissues, and analytical precision at this level is poor. This accounts for the lack of W anomalies except for the area of enrichment associated with mineralization at East Kemptville.

Zinc (Zn)

Zinc is essential for carbohydrate and protein metabolism, therefore differences of a few 100 ppm Zn in ash are probably related to the health of the tree rather than subtle changes in substrate chemistry. However, the Zn map shows a range in concentration of 3000 ppm Zn indicating that the regional pattern of Zn distribution is reflecting broad differences across the area, with relative enrichment in the west.

Rare-Earth Elements (REE)

Because of their chemical coherence, these elements are considered as a separate group. INAA can be used to readily determine lanthanum (La), cerium (Ce), neodymium (Nd), samarium (Sm), europium (Eu), terbium (Tb), ytterbium (Yb), and lutetium (Lu). Of these elements, only Tb consistently yields concentrations below the detection level (0.5 ppm) and therefore no map of Tb is included. Maps of these elements show very similar distribution patterns, with slightly elevated concentrations over the White Rock Formation. However, no sample yielded an unusually high concentration of any of the REE, and in general they closely follow Fe.

Distribution Maps of Elements Determined by ICP-ES

Silver (Ag)

Silver is not known to be essential to plant life, and can become toxic to plants by substituting for K in membranes and thereby inhibiting the absorption of other cations by roots (Hendrix and Higinbotham, 1974). However, at the few ppm concentrations present within the study area (and most natural environments) the inhibiting effects of Ag on the uptake of other elements is insignificant. The 50th percentile value of 1.5 ppm Ag in the balsam fir twigs is relatively high for plant ash, and suggests that the analytical procedure may have poor accuracy, although good precision, at levels below 2 ppm Ag. At higher levels accuracy and precision were good. Several multi-site areas of weak Ag enrichment occur within the study area, notably to the east of Yarmouth and in the southeast between Shelburne and Port Mouton.

Aluminum (Al)

All dry vegetation samples were placed in Al trays for ashing, therefore a certain amount of contamination from this source is inevitable. However, the wide range in Al concentrations, the high levels of Al in the samples, and the similarity of Al distribution patterns to those of Fe suggest that areas of *relative* Al enrichment are significant. The aqua regia extraction used is not 'total', but good precision was obtained for duplicate samples. Tests undertaken to compare data obtained on an ash standard by ICP-ES (aqua regia digestion) with some INAA data (determinations for short-lived isotopes) indicate that the acid digestion releases approximately 50% of the Al. There is notable enrichment of Al in balsam fir twigs from the northwestern part of the survey area.

Boron (B)

Borosilicate test tubes were used for the acid digestion of the ash samples. This digestion may release 5 - 10 ppm B from the borosilicate, but this is insignificant in comparison with the 100s ppm B present in the ash. Tests indicate that the analytical procedure provides data which represent about 50% of the true concentrations of B in the samples. Precision, however, is excellent.

Boron is essential for plant growth, and it is believed to play an important role in the translocation of sugars. In general, B uptake is low from Ca-rich soils, but since the study area is not noted for its Ca enrichment there is no obvious relationship between the distribution patterns of these two elements. The median concentrations of B show little variation from one substrate to the next.

Beryllium (Be)

There is usually less than 2 ppm Be in soils, and because it is a non-essential element for plant growth (in high concentrations it is toxic), its presence in the substrate is reflected in the balsam fir twigs by concentrations of less than 1 ppm Be. The map of Be distribution clearly

shows the relative enrichment around East Kemptville, and scattered sites of isolated enrichment. Analytical precision is good to the 0.5 ppm Be level.

Cadmium (Cd)

Although there is a strong geochemical association between Cd and Zn in many geochemical environments, this is not evident in plant tissues because of the *requirement* that plants have for Zn but not for Cd. However, Cd is easily absorbed by plants and may therefore be expected to reflect relative Cd concentrations in the soils and groundwaters. Absolute concentrations differ among plant species because Cd can be captured by a variety of organic compounds in cell walls and therefore not all will be transported to the tree extremities. There is notable enrichment of Cd in samples from over Meguma Group sediments in the western part of the survey area.

Copper (Cu)

Data obtained by ICP-ES from the aqua regia leach are both precise and accurate. Copper plays a fundamental role in plant metabolism. It assists in respiration, photosynthesis, nitrogen fixation and valence changes, and it is present in many micro-components of plants (small and large molecules, chloroplasts, mitochondria etc.). As a consequence, the background concentration of Cu in ash of the twigs (median 164 ppm) is high compared to many trace elements.

The interpretation of Cu distribution patterns in tree tissues should be approached with caution, since laboratory studies report numerous antagonistic and synergistic interactions with both major and minor elements. These are reviewed briefly by Kabata-Pendias and Pendias (1984). However, despite the essentiality of Cu and the complex metabolic roles that it may play, substantial differences among the survey samples are more likely to reflect significant differences in the Cu content of the substrate than the relatively small differences attributable to micronutrient functions.

Gallium (Ga)

There are few data available on the biogeochemistry of Ga, and the accuracy of the data obtained by ICP-ES on the present samples is uncertain. However the precision is adequate, and some distinct regional patterns of enrichment are apparent - notably over the greywackes of the Goldenville Formation in the southwest where concentrations are up to four times higher than the median value of 4 ppm Ga.

Lithium (Li)

Lithium commonly follows Rb and Cs in nature. In balsam fir twigs it is less abundant than Rb but enriched with respect to Cs. It is not known to be essential to plant metabolism, and its high solubility (except where firmly bonded to clay minerals) causes Li enrichment in

soils and waters to be readily reflected in plant tissues. This is apparent in the East Kemptville area, and at several sites to the northwest.

Magnesium (Mg)

Magnesium is a macronutrient which plays several important roles in plant health, including photosynthesis and numerous enzymic reactions. From a biogeochemical prospecting perspective, major differences in Mg concentrations in plants can indicate significant differences in the underlying lithology, but smaller differences are not known to be of value in delineating zones of mineralization.

Manganese (Mn)

Manganese is highly enriched in balsam fir twigs. It is an essential element which is readily taken up by plants, especially where the acidity of the ground is high. In acidic environments there is a Mn/Fe antagonism, which is extended to elements with a broad affinity for Fe. Samples from the western part of the survey area are markedly enriched in Mn with locally over 13% Mn in ash.

Molybdenum (Mo)

Molybdenum in trace amounts is required by most plants for nitrogen fixation and nitrate reduction. Concentrations are usually <2 ppm Mo in conifer twigs, although over highly alkaline soils the trees are more readily able to absorb Mo and therefore slightly higher levels may be expected. No notable enrichment of Mo is apparent.

Nickel (Ni)

The presence of Ni may assist in the translocation of nitrogen in some plants, but its general essentiality is unproven. When in solution, Ni is readily taken up by plants, therefore it may be expected that the Ni content of the twigs is positively correlated with Ni concentrations in groundwaters. INAA has low sensitivity to Ni (detection limit of 50 ppm Ni in ash). In contrast, excellent precision and accuracy are obtained by ICP-ES down to the minimum level (6 ppm) recorded for this data set. There is a relative abundance of Ni in the western part of the study area over the Meguma Group sediments where concentrations reach 149 ppm Ni.

Phosphorus

Phosphorus plays a vital role in plant energy metabolism, and it is extremely important as a structural part of many organic compounds. Its uptake by trees may be antagonized by excess Ca which, from the maps showing distribution patterns of Ca and P, appears to take place in the balsam fir twigs. Similarly, high levels of P may influence the uptake of numerous trace metals, although this effect appears to be subordinate to the over-riding effect of the chemistry of the substrate.

Lead (Pb)

Despite the known toxic effects of Pb, it occurs naturally in all plants, and in small traces Pb may even be an essential element (Broyer et al., 1972). It is taken up mainly by root hairs and stored as a pyrophosphate in cell walls. The range of Pb concentrations is slightly high with respect to data sets for conifer twigs. Zones of relative enrichment occur in the northwest, at East Kemptville, and in the Shelburne area (maximum 325 ppm Pb).

Titanium (Ti)

The essentiality of Ti for plant growth is uncertain, but it may play a role in photosynthesis. The ICP-ES analysis is probably not 'total', although it is likely that most of the Ti in the ash goes into solution during the aqua regia digestion. There is a wide range in Ti content of the ash samples, with highest concentrations occurring in trees growing over the White Rock Formation in the west.

Vanadium (V)

Although V is present in all of the twig samples, its essentiality for plants other than green algae has not been proven. Soluble V is easily taken up by roots, and it may play a similar role to Mo in fixing nitrogen. The distribution of V is different from all other elements determined.

Other Elements

Each sample was analyzed for iridium and mercury. All Ir analyses showed concentrations of less than 2 ppb, suggesting a lack of platinum-group element enrichment in the area. All Hg analyses yielded less than 1 ppm, suggesting that there are no strong associations of Hg with mineralization. Although most Hg volatilizes during ashing of the twigs, it has been suggested that there is sometimes residual Hg in plant ash (in the form of a carbide) in the vicinities of some mineral deposits (Kovalevskii, 1986).

NOTES ON THE BIOGEOCHEMICAL DATA LISTINGS

(APPENDICES A and B)

Appendix A lists field data and all analytical data obtained for the balsam fir twig ash. Appendix B provides some simple statistical analyses of the data by treating the data set as a whole, and by dividing the data according to the underlying bedrock geology (according to stratigraphic formation for the sediments, or lithology for intrusions). Abbreviations used in the appendices are explained in Tables 9 and 10.

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Table 9: Abbreviations Used in Appendix A

RS	Replicate Status; an integer (1 or 2) that follows the Site ID and indicates two splits from the same sample.
Map Sheet	National topographic system (NTS): First three characters refer to 1:250,000 scale quadrangle; remaining two characters identify the 1:50,000 scale map sheet within the quadrangle.
Zone, Easting and Northing	The Universal Transverse Mercator (UTM) zone followed by easting and northing co-ordinates in metres.
Twig Min Age Twig Max Age	The minimum age of each length of twig collected. The maximum age of each length of twig collected.
Slope	0 = flat ground 1 = slight incline followed by downward compass direction (e.g. 1N = slight downward incline to the north) 2 = moderate incline 3 = steep incline
Forest Type	Type of vegetation cover and degree of surface water saturation.

Table 10: Abbreviations Used in Appendix B

Rock Type	Underlying bedrock lithology (derived from published geological maps): DCg - Devono-Carboniferous granite DCt - Devono-Carboniferous tonalite (Barrington Passage) OSw - Ordovician-Silurian White Rock Formation COh - Cambro-Ordovician Halifax Formation COg - Cambro-Ordovician Goldenville Formation
N dl Cum %	N = number of samples dl = determination limit Cum % - cumulative frequency (as a percentage)

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