

Chapter 27

Regional Geochemical Mapping

J.A.C. Fortescue

Geophysics/Geochemistry Section, Ontario Geological Survey

Abstract

Geochemical maps are now an essential component of the mineral resource appraisal process as it is applied by government agencies worldwide. For this reason, regional geochemical maps are prepared by the Ontario Geological Survey (OGS) for areas of the province considered to have particularly high mineral potential. Other components of OGS mineral resource appraisal activity include: 1) geological; 2) geophysical; 3) Quaternary geology; and 4) remote sensing maps prepared at a regional scale. A digital data base designed for use with a Geographical Information System (GIS) may employ all of these maps as components.

Part I of this chapter shows how regional geochemical maps are designed in relation to the other GIS components. Part II describes the theory behind the methodology used for the preparation of OGS regional geochemical maps. Examples of 3 OGS approaches to regional geochemical mapping are described in Part III of the chapter. Part IV outlines some of the research and development on which the different approaches were based. Part V includes: 1) a general discussion; 2) reference to some recent developments in geochemical mapping; and 3) some conclusions. The conclusions concern the future of OGS geochemical mapping, the need for further regional geochemical mapping research, and the possibility of the preparation of a geochemical map of Ontario.

PART I: OVERVIEW

An Introduction to Regional Geochemical Mapping in Ontario

In 1893, Willet Miller, a geology professor from Queen's University, completed what is usually considered to be the first successful geochemical prospecting in Ontario. Miller did so by locating economic corundum deposits in drift-covered areas of southeastern Ontario. According to Tyrrell (1926, p.104):

He [Miller] worked out a new method in the field of discovery. The rock exposures of corundum are not numerous in eastern Ontario. When he had discovered the direction in which the corundum-bearing rock seemed to be trending, he would travel southward, and then turn back north, watching for boulders of corundum bearing rock in the glacial drift. In other words, he came upstream against the glacial flow, and where he found drift boulders he was usually close to the source of supply.

Miller's corundum prospecting sounded a keynote for successful predictive mineral resource appraisal activity in Ontario. Prior to the 1960s, in the Ontario Geological Survey (OGS), this keynote was sounded almost exclusively by geological mapping (Groen 1978). Since 1960, geological mapping for mineral resource appraisal by the OGS has been augmented by: 1) geophysical mapping; 2) Quaternary geological mapping; 3) geochemical mapping; and most recently by 4) remote sensing (Groen 1978, 1987).

It was estimated recently (M. Cherry, Ontario Geological Survey, personal communication, 1990) that an area of 147 000 km² of Ontario has a high potential for mineral deposits. By 1990, this entire area had been mapped

geologically by the OGS at least once and 59% of the area had been mapped geophysically by the OGS. In 1990, regional geochemical mapping of the province was still in its infancy, and only 5.9% (or 5 000 km²) of the high mineral potential area had been mapped by this method. This relatively small area explains: 1) why this type of mapping is seldom mentioned elsewhere in this volume; and 2) the need to stress methodology and mapping results equally, in this introduction to the subject.

During the 1980s, mineral resource appraisal methodologies applied by government agencies passed through a revolution in technology worldwide. The revolution came about with the general introduction of the Geographic Information Systems (GIS) approach. This involves image processing of geographical and geoscience data simultaneously by computer (Fortescue 1990b; Plant et al. 1984; Ryghaug and Green 1988; Wright et al. 1988 and many others).

At the OGS, the gradual introduction of GIS methodologies (combining data sets from geological, geophysical and geochemical mapping) has struck a fresh keynote in the mineral resource appraisal process. In particular, this development has been accompanied by a rethinking of the philosophy for geochemical mapping in the province. Until the 1980s, the general aim of OGS geochemical surveys was to locate geochemical anomalies which could then be explained in terms of the presence of economic mineral deposits. Since 1980, regional geochemical mapping methodologies based on variations of standard methods on 1) basal till, 2) stream sediments and 3) lake sediments, have been developed by the OGS. These methodologies are designed to map geochemical province patterns in addition to geochemical anomalies.

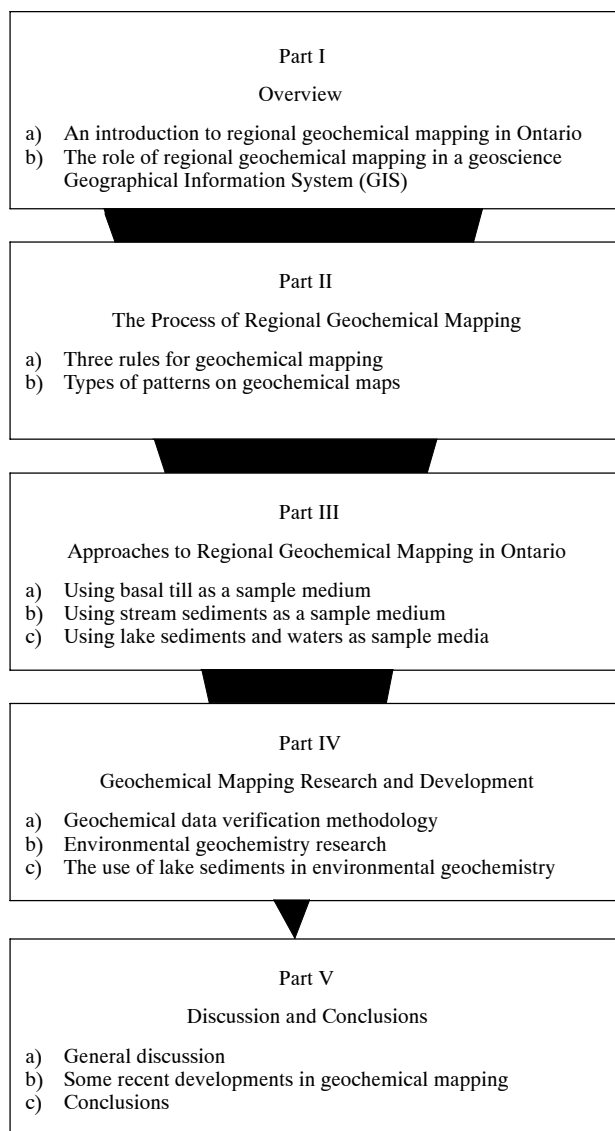


Figure 27.1. Flow diagram of the organization of the chapter.

A flow diagram (Figure 27.1) describes the organization of this chapter in 5 parts.

The Role of Regional Geochemical Mapping in a Geoscience Geographical Information System

The current series of OGS regional geochemical maps are designed for the use of prospectors, explorationists and users of a Geographic Information System (GIS). The role of these maps in a GIS environment is clarified by a general conceptual model (Figure 27.2). In this proposed model, the ideal sequencing of geoscience data collection for future projects would commence at the bottom of the diagram. Data collection would be accomplished in 3 steps: 1) the digital compilation of all geoscience map data for the area of interest at the start of the project; 2) the completion of new

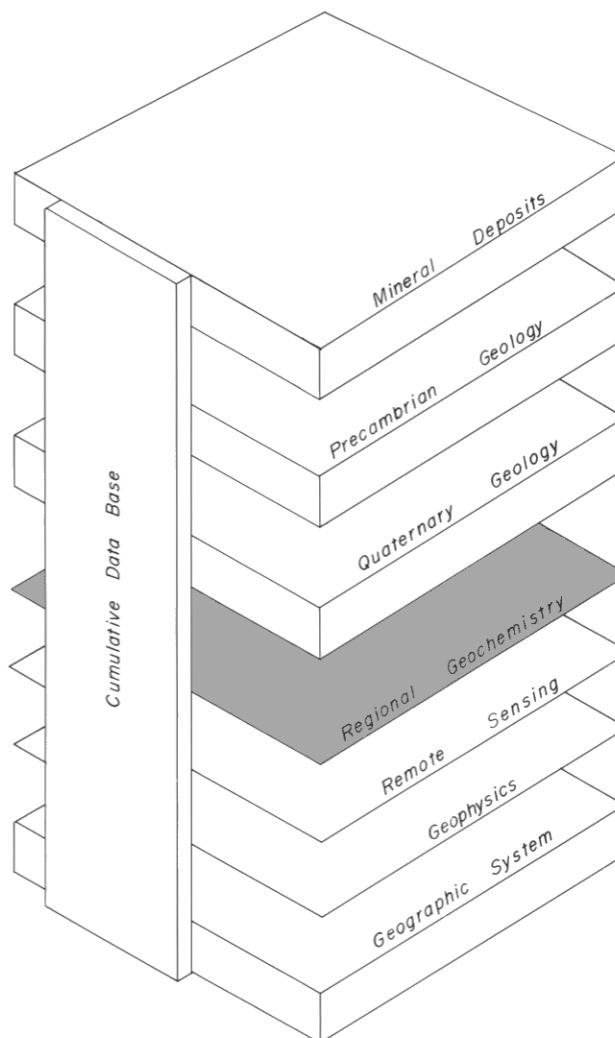


Figure 27.2. Block diagram showing relationships among map components of a hypothetical, Ontario Geological Survey regional level, mineral resource appraisal program (modified from Fortescue and Vida 1990a).

geophysical, geochemical and remote sensing maps of the area based on the digital data base established in Step 1; and 3) the preparation of new surficial, geological and metallogenic maps. The new maps prepared during step 2 would be released to the public soon after their preparation and be made available to OGS field geologists involved in step 3. Incidentally, the cost per km² of map coverage in step 3 is usually ten times greater than the map coverage in step 2.

Consideration of this model has affected the current OGS regional geochemical mapping program in several ways. For example: 1) the scientific tenor of the OGS regional geochemical maps should be comparable to other GIS-oriented regional geoscience data; 2) the time required to produce OGS geochemical maps should be less than, or equal to, that required for OGS geophysical maps; and 3) in order to ensure a uniform standard province-wide, the OGS regional geochemical mapping methodology must be fully standardized.

PART II: THE PROCESS OF REGIONAL GEOCHEMICAL MAPPING

Three Rules for Regional Geochemical Mapping

Modern geochemical mapping must follow 3 rules in order to be effective for mineral resource appraisal purposes.

1. The number and distribution of sample collection points must be uniform within the map area.
2. The sampling medium must be uniform throughout the map area.
3. The mapping methodology must be standardized.

Each of these rules will now be discussed in relation to the OGS regional geochemical mapping experience.

RULE 1: UNIFORM SAMPLE DENSITY

A modern geochemical map is based on sample points distributed uniformly across the mapped area; the number of sample points must be sufficient to describe the principal geochemical patterns in the area. Lake sediment regional geochemical mapping by the OGS relies on a uniform average sample density of 1 sample per km². The British Geological Survey (BGS) utilizes the same sample density (using stream sediments) for GIS-oriented regional geochemical mapping (Plant et al. 1990).

In Ontario, geochemical maps are currently produced at 2 sample densities with a third density under consideration (Table 27.1).

Reconnaissance Level Mapping

Since the mid-1970s, reconnaissance geochemical maps (prepared by the Geological Survey of Canada (GSC) under joint agreements with the OGS) have covered large areas of Ontario (Friske 1985). These maps are of general interest to the mineral exploration industry because low sample density, reconnaissance geochemical maps are now considered to be not detailed enough for use in a GIS, in areas of high mineral potential.

Regional Level Mapping

Regional level geochemical mapping was developed in Ontario largely as a result of the findings of a report on this subject (Fortescue et al. 1980). This report was critical of the use of traditional reconnaissance geochemical mapping for: 1) mapping areas of Ontario with high mineral potential; and 2) collecting base line data for environmental geochemistry.

Fortescue and Stahl (1987b) provided a comparison of the coverage of regional and reconnaissance geochemical mapping. The Wart Lake area is located in the Batchawana greenstone belt, some 50 km northeast of Sault Ste. Marie. The southern part of the Wart Lake area is relatively simple granitic terrane. Farther to the north, in the Batchawana

greenstone belt, the geology is more complex (Figure 27.3). Fortescue and Stahl (1987b) provided 2 maps of the geology of the Wart Lake area. The dots in Figure 27.3b indicate the reconnaissance level geochemical sample density, while the dots in Figure 27.3c indicate those for the regional level. The distribution of sample points is uniform in Figures 27.3b and 27.3c. On the regional map, the sample intensity is considerably greater. The increased sample intensity facilitates the recognition of geochemical patterns in areas of complex geology (see Figure 27.3c).

Low Density Sampling Mapping

In 1983, the preparation of a geochemical map of Ontario, based on reconnaissance level sampling, was considered and rejected as being impractical (Fortescue 1983b). The preparation of such a geochemical map is now considered feasible based on the recent Scandinavian experience

Table 27.1. Three types of geochemical mapping programs suitable for application in Ontario.

	Area (km ²) per sample
1. OGS Regional Geochemical Maps (lake sediments and lakewaters)	1
2. GSC-OGS Reconnaissance Geochemical Surveys (lake sediments and lakewaters)	14
3. OGS Low Density Geochemical Surveys (overbank samples and lakewaters)	500

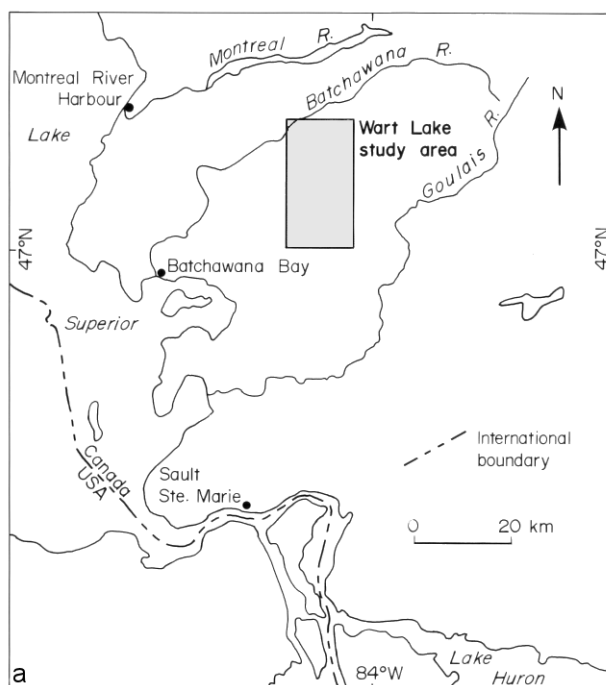


Figure 27.3a. Geological maps of the Wart Lake area showing lake sediment sample point locations: generalized map showing the Wart Lake study area (modified from Fortescue and Stahl 1987c).

described below. The map would be based on low density sampling which was recently developed in Norway (Ottesen et al. 1989) and Finland (Koljonen et al. 1989). Geochemical surveys of this type are based on a sample density of 1 sample per 500 km². Geochemical surveys of this type are based on: 1) overbank samples (Ottesen et al. 1989); 2) till samples (Koljonen et al. 1989); or 3) water samples (Eden 1990). A small-scale experiment involving overbank sampling in Ontario is described in the section entitled Geochemical Map of Ontario (Fortescue and Bolviken 1990).

RULE 2: UNIFORM SAMPLE MATERIAL

Effective geochemical surveys are always based on a sample medium which is common over the area selected for mapping. Unfortunately, there is no single sample medium

suitable for geochemical mapping of the entire province of Ontario at the regional level. Therefore, the OGS has developed a series of regional geochemical mapping methodologies (based on different sample media) for use in various regions of Ontario. In the 1980s, 3 approaches to regional geochemical mapping were developed. These approaches were based on: 1) basal till (for use in areas of deep overburden, e.g., in the Kirkland Lake area); 2) stream sediments (for use in the limestone terrains of southwestern Ontario); and 3) lake sediments (for use in the southern Canadian Shield where marl lakes are absent).

Within a given region, the general geology of the bed-rock and/or the nature of the Quaternary cover govern the choice of sample media for regional geochemical mapping. Figure 27.4 is a series of general conceptual landscape models drawn to illustrate this phenomenon. For example,

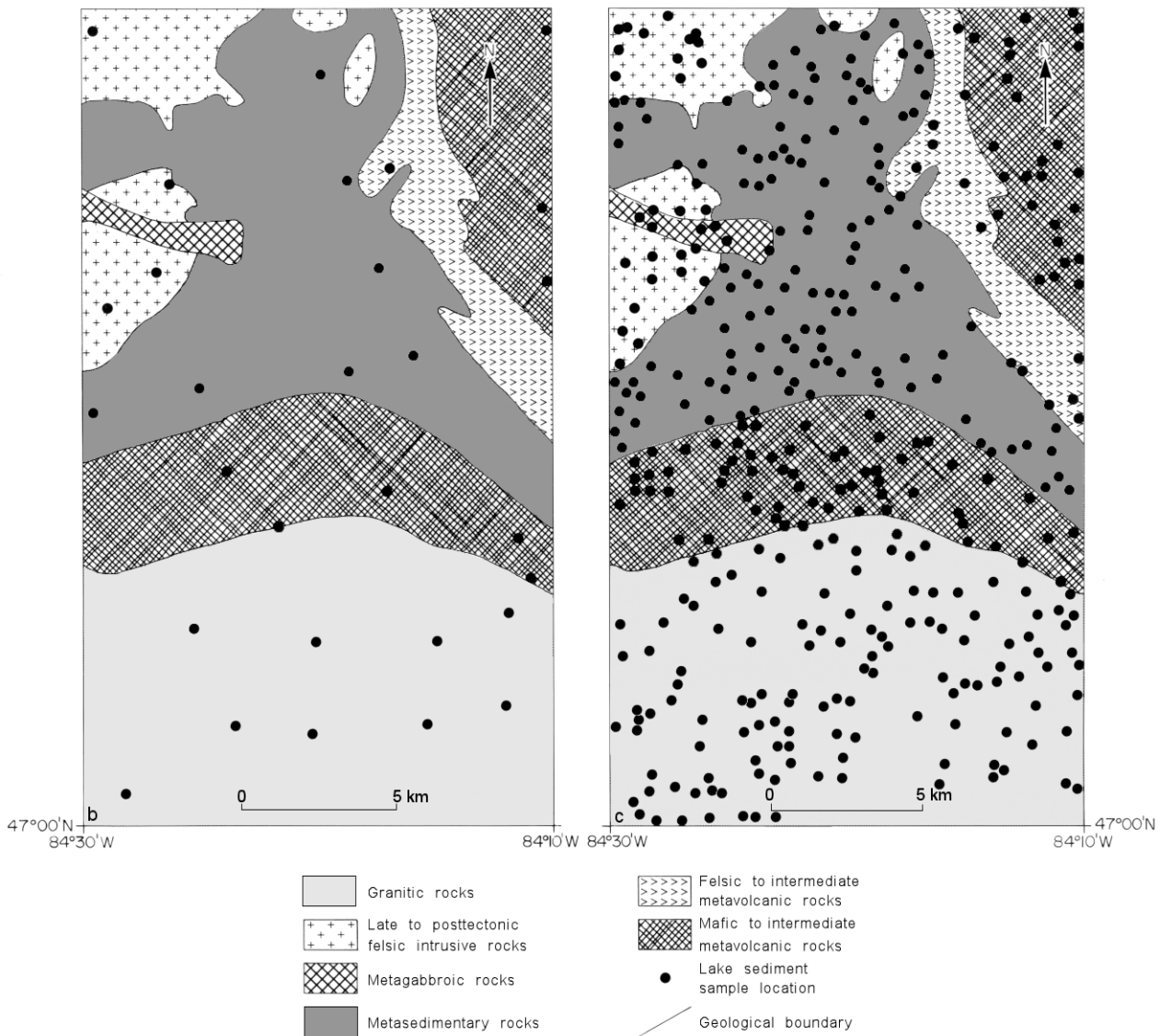


Figure 27.3b and c. Geological maps of the Wart Lake area showing lake sediment sample point locations: **b)** Geological Survey of Canada—Ontario Geological Survey reconnaissance level geochemical map; and **c)** Ontario Geological Survey regional level geochemical map (modified from Fortescue and Stahl 1987c).

geochemical mapping based on lake sediments and lakewaters is generally effective in landscapes with Precambrian bedrock and Quaternary cover shown as a, b, d and e on Figure 27.4. In contrast, geochemical mapping based on lake sediment is considered ineffective in areas where Precambrian bedrock is covered by a continuous layer of: 1) deep till (Figure 27.4c); 2) a complex overburden section (Figure 27.4f); 3) peat (Figure 27.4g); or 4) varved clay deposits (Figures 27.4h and 27.4i).

Basal Till

The use of basal till as a sample medium for regional geochemical mapping was investigated by the OGS between 1978 and 1982, during the Kirkland Lake Initiatives Program (KLIP) (Fortescue, Lourim et al. 1984; Fortescue and Gleeson 1984). In the KLIP map area, a continuous cover of deep, complex and varied overburden (see Figures 27.4c, 27.4e, 27.4f, 27.4g, 27.4h and 27.4i) overlies Precambrian bedrock. Samples of basal till were obtained from either pits dug by backhoe or by reverse circulation overburden drilling.

Stream Sediment

Stream sediment was the second sample medium tested by the OGS during the 1980s. In this case, regional

geochemical mapping was carried out in drift-covered Paleozoic carbonate terrains of southwestern Ontario (Fortescue 1983a, 1984a).

Lake Sediment

Modern geochemical mapping is designed to satisfy mineral resource appraisal and/or the need for base line information in environmental geochemistry. An advantage of the OGS lake sediment regional geochemical mapping methodology (and the overbank low density geochemical surveys) is the simultaneous collection of pre- and post-anthropogenic material from each sample site.

The lake sediment regional geochemical mapping technique, developed by the OGS, is based on chemical data obtained from pre-*Ambrosia* lake sediment core material. This sample medium is known to have been deposited over 100 years ago (Dickman and Fortescue 1984; Fortescue, Dickman et al. 1984; Fortescue 1984b, 1985b, 1988a). The same lake sediment core can also be used to collect post-*Ambrosia* material, which accumulated at the bottom of the lake for 5 or more decades, prior to sample collection.

For example, in 1986, in the vicinity of the Sturgeon River (some 50 km northeast (downwind) of the Sudbury smelters; Figure 27.5), 139 lake sediment cores were collected from a 10 by 75 km sampling strip (Fortescue and Stahl 1987a). Pre- and post-*Ambrosia* data for lead, nickel,

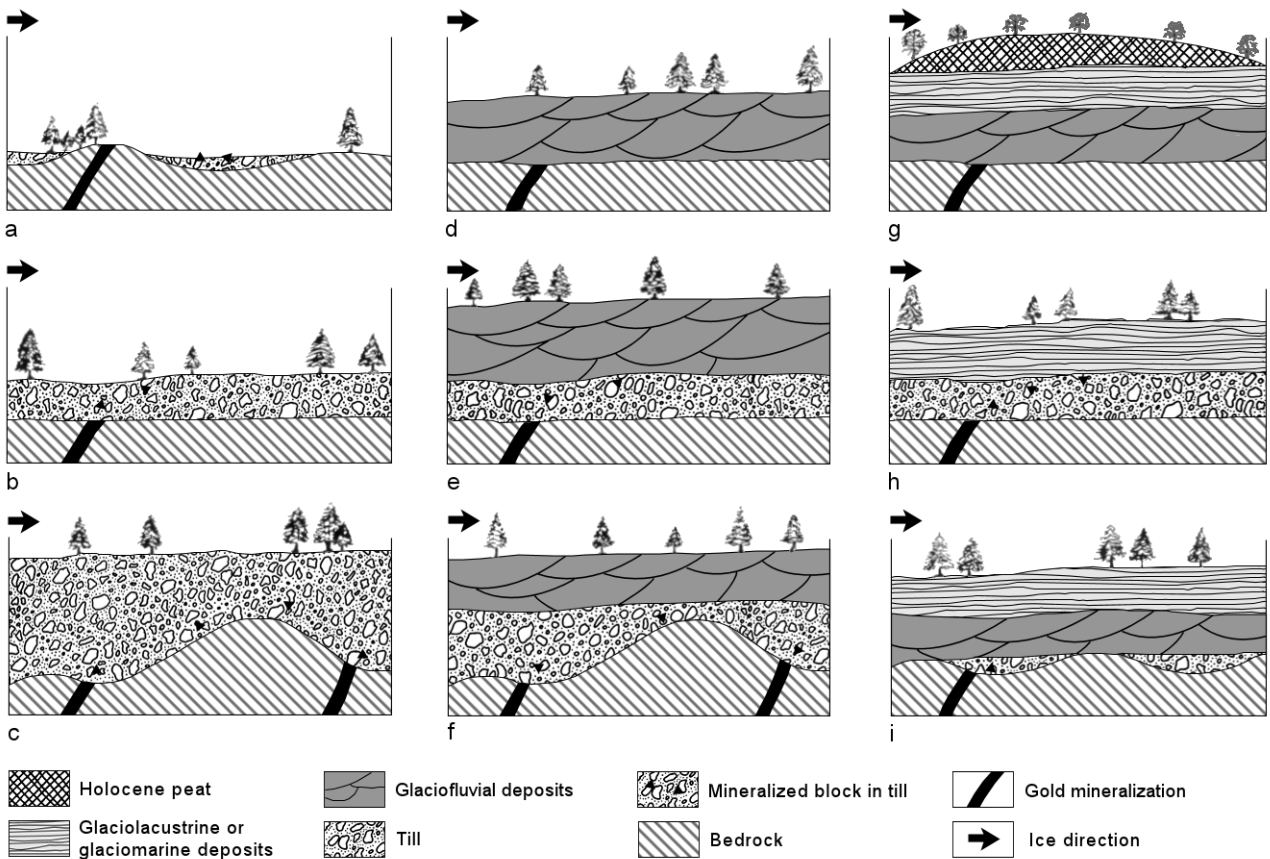


Figure 27.4. Cartoon sections of landscapes common in northern Ontario. The figure is designed as a guide to the choice of approaches to selection of sample media for regional geochemical mapping in the province (modified from Fortescue 1983c).

copper, strontium, lanthanum and uranium are plotted on Figure 27.5. These data show: 1) low levels for lead in the pre-*Ambrosia* material and enhanced levels in the post-*Ambrosia* material (due to atmospheric fallout from a non-point source; Figure 27.5a); 2) low levels of nickel and copper in the pre-*Ambrosia* material and enhanced levels in the post-*Ambrosia* material along a geochemical gradient away from the point source of atmospheric fallout in Sudbury (Figures 27.5b and 27.5c); 3) similar levels and patterns for strontium in pre- and post-*Ambrosia* material (Figure 27.5d); and 4) similar patterns for uranium in the pre- and post-*Ambrosia* material (Figure 27.5f). Figures 27.5d and 27.5e show patterns for strontium and lanthanum which are control elements not present at significant levels in atmospheric fallout.

Today, there is a need for the development of further regional geochemical mapping methodologies for use in areas of high mineral potential. These areas have: 1) continuous peat cover (see Figure 27.4g); 2) marl-rich lakes; and 3) complex Quaternary cover, which require a multimedia sampling approach (see Figures 27.4c to 27.4i).

Summary

Sample point location and age of sample material are of paramount importance in geochemical mapping. The choice

of sample medium is restricted by the landscape type in the area to be mapped. For example, in parts of Ontario where lakes and ponds are very common, lake sediment is the appropriate sample medium. In other areas with many streams and few lakes, stream sediment is the sample medium chosen for geochemical mapping. In either case, it is important that the medium is available over the entire map area and that the sample coverage is uniform.

Recently, the age of samples has become of considerable importance from the viewpoint of environmental geochemistry. The example from the Sturgeon River area showed how geochemical data obtained from dated lake sediments may provide important information for both mineral resource appraisal and environmental geochemistry.

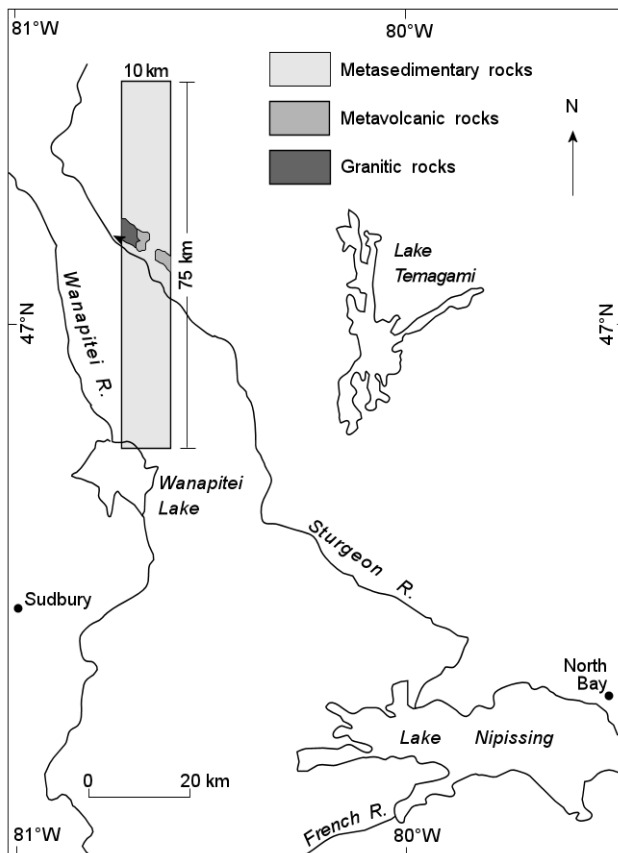


Figure 27.5. Location map shows geological setting of the Sturgeon Lake sampling strip.

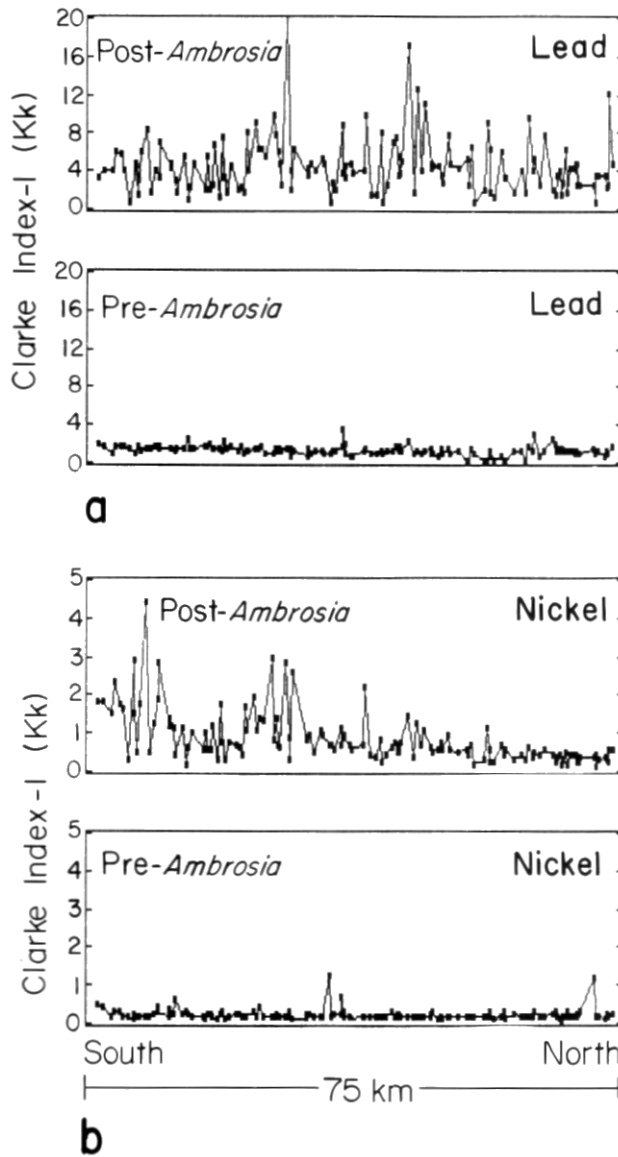


Figure 27.5a and b. Clarke-normalized element concentrations for post- and pre-*Ambrosia* data for 2 elements along the Sturgeon River sampling strip (modified from Fortescue and Stahl 1987a).

RULE 3: STANDARDIZED METHODOLOGY

Experience in geochemical mapping in several countries has demonstrated that strict standardization of methods is essential for the preparation of reliable geochemical maps (Fortescue 1990b). Standardized methods used during the preparation of the Hanes Lake regional geochemical map are indicated on the flow diagram in Figure 27.6 (Fortescue and Vida 1990b).

During the planning stage (Figure 27.6a), lake sediment sample sites are positioned (and pre-numbered) on a 1:50 000 scale topographic map of the area to be mapped (Figure 27.6b). The number sequence includes randomly spaced missing numbers used for quality control purposes

later on. Sample collection is carried out by 2 OGS staff working from the float of a helicopter (Figure 27.6c). They collect pre- (and post-) *Ambrosia* lake sediment core samples (Figure 27.6e) using the method described by Fortescue (1988b). A 1 L water sample is collected at all sample points (Figure 27.6d). At each sample site, the crew also note water colour, water depth, Secchi depth and other pertinent observations which may affect the analyses.

Using this method, 1 crew can sample 50 to 75 lake sites per day. At the base camp: 1) the pH of cooled water samples is measured within 24 hours of their collection; and 2) the sample bags are checked, sequenced and reference standards are inserted bearing the missing numbers (Figure 27.6f). At the end of a sampling program, the

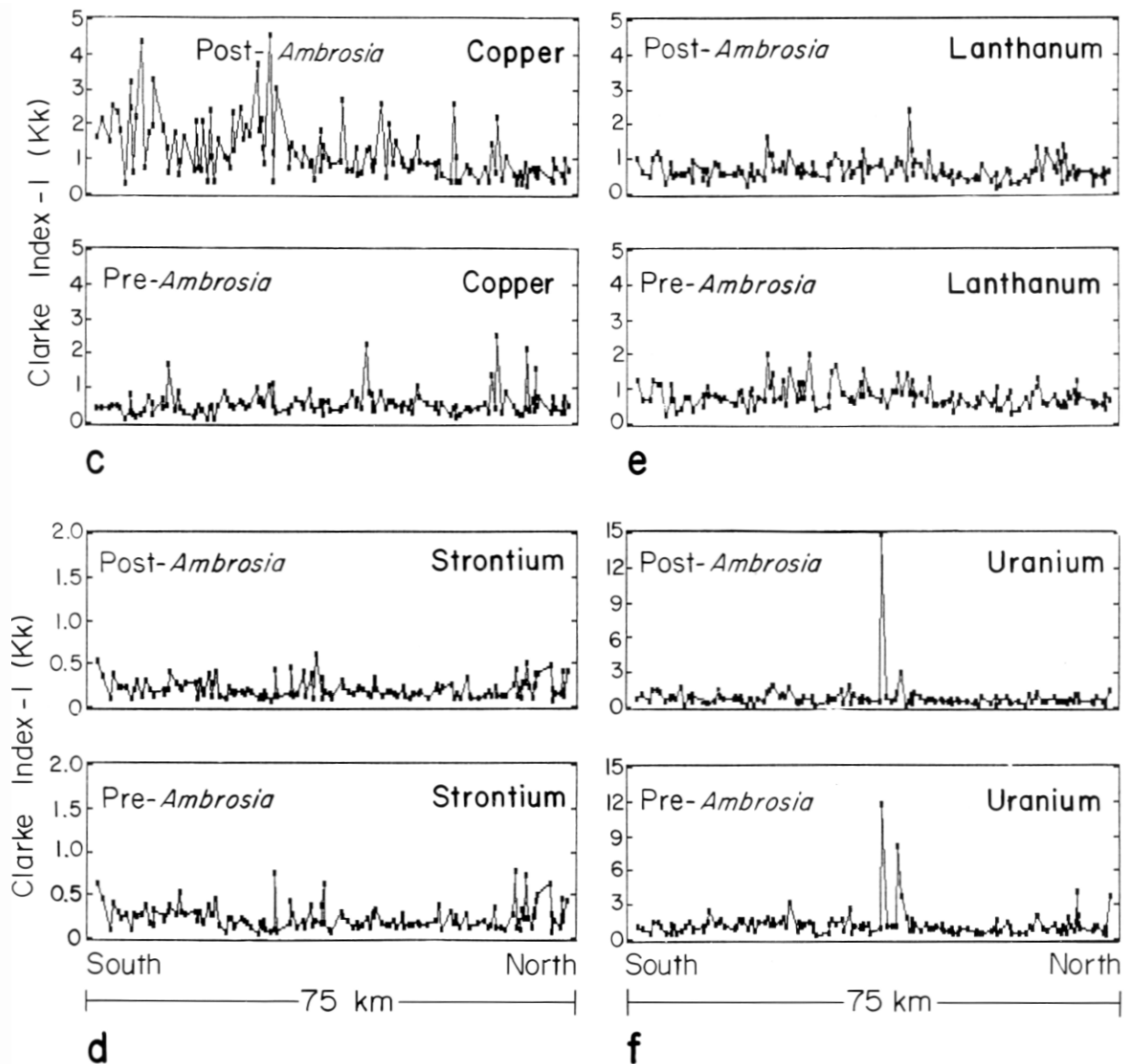
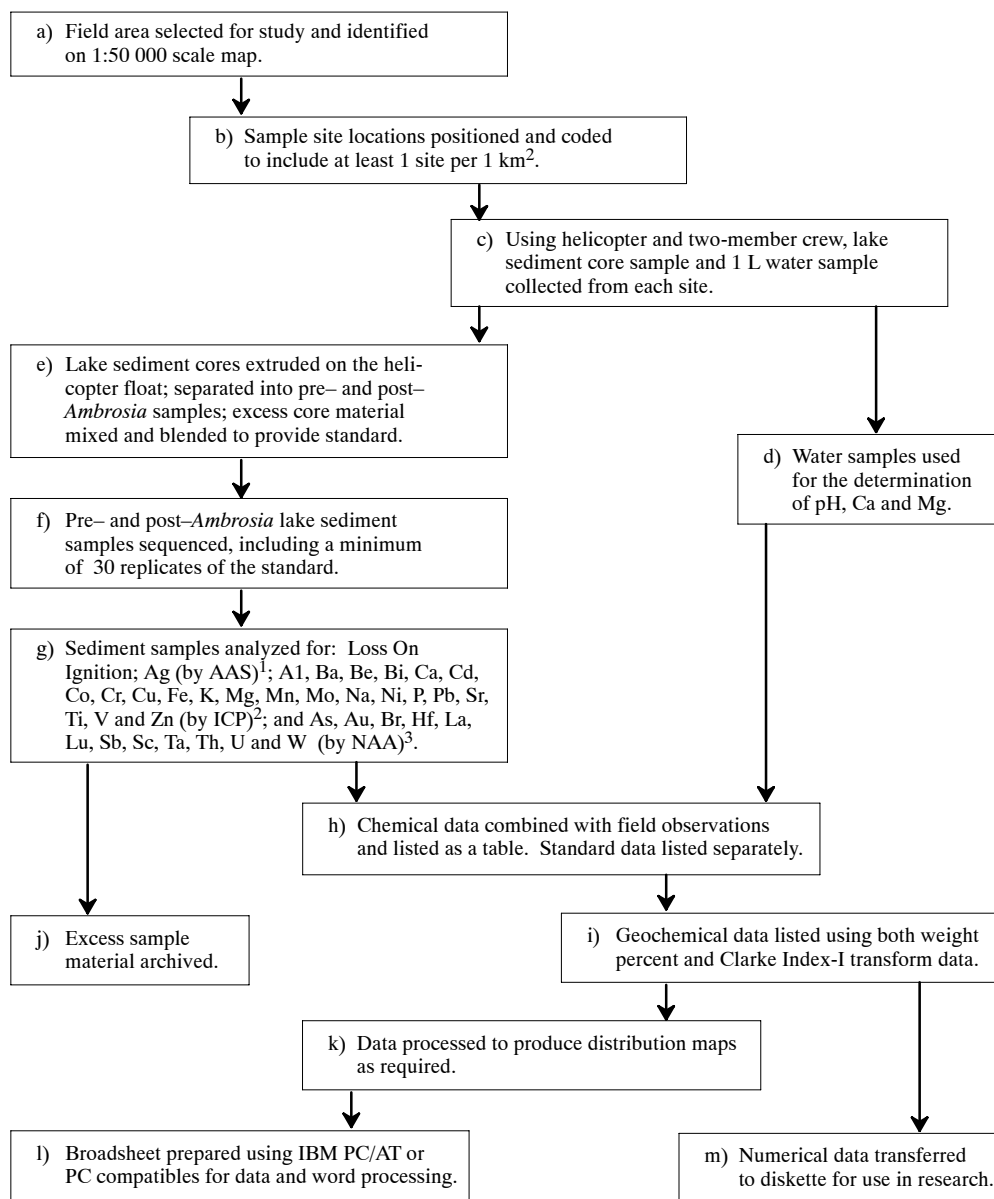


Figure 27.5c to f. Clarke-normalized element concentrations for post- and pre-*Ambrosia* data for 4 elements along the Sturgeon River sampling strip (modified from Fortescue and Stahl 1987a).



¹ Atomic Absorption Spectroscopy
² Inductively Coupled Plasma Mass Spectrometry
³ Neutron Activation Analysis

Figure 27.6. Flow diagram of the methodology used for Ontario Geological Survey regional geochemical mapping based on lake sediment and water geochemistry (*modified from Fortescue and Vida 1990b*).

Table 27.2. Summary of quality control data obtained from a reference standard replicated at random 44 times within a batch of Trout Lake pre-Ambrosia lake sediment samples.

Element	n	Mean (ppm)	Mean (Kk)	Minimum (Kk)	Maximum (Kk)	Range (Kk)	C.V.** (%)
LOI*	44	46.25	46.25	44.20	47.60	3.40	1.56
Sc	44	9.56	0.38	0.34	0.42	0.07	4.08
V	44	21.07	0.15	0.14	0.17	0.03	5.06
Al	44	1.45	0.17	0.14	0.20	0.06	6.84
Ti	44	0.08	0.12	0.09	0.14	0.05	7.10
Zn	44	75.75	1.00	0.79	1.18	0.39	7.44
Mn	44	152.07	0.14	0.12	0.17	0.05	7.58
Sr	44	71.59	0.19	0.16	0.23	0.07	7.75
Ba	44	132.05	0.34	0.28	0.41	0.13	7.76
P	44	371.14	0.33	0.27	0.40	0.13	8.30
Fe	44	0.85	0.14	0.11	0.16	0.05	8.31
K	44	0.31	0.17	0.13	0.20	0.07	8.34
La	44	103.02	2.98	2.46	3.79	1.33	8.72
Cu	44	56.59	0.83	0.66	1.10	0.44	8.98
Mg	44	0.21	0.08	0.06	0.10	0.04	9.45
Na	44	0.33	0.14	0.11	0.18	0.06	10.19
Co	44	5.89	0.20	0.17	0.24	0.07	11.12
Ca	44	0.79	0.17	0.14	0.25	0.11	11.22
U	44	8.60	3.74	2.48	4.83	2.35	11.65
Lu	44	0.39	0.73	0.19	1.11	0.93	20.81
Br	44	5.80	2.32	1.60	4.32	2.72	21.58
Cd	44	1.47	9.16	6.25	15.63	9.38	22.55
Th	44	13.28	1.64	0.74	2.41	1.67	24.54
Pb	44	17.82	1.37	0.62	3.85	3.23	33.18
Au	44	4.75	1.19	0.25	2.25	2.00	34.62
Mo	44	1.52	1.27	0.83	3.33	2.50	41.26
Ag	44	0.68	8.52	6.25	18.75	12.50	42.11
As	44	1.77	0.98	0.56	2.22	1.67	45.30
Ni	44	33.75	0.34	0.20	1.33	1.13	51.75
Cr	44	41.48	0.34	0.15	1.38	1.23	63.20
Sb	44	0.25	1.24	0.50	5.00	4.50	85.07
W	44	4.05	3.37	1.67	21.67	20.00	121.56
Hf	44	3.75	1.34	0.71	16.79	16.07	179.96
Be	44	0.50	0.25	0.25	0.25	0.00	0.00
Bi	44	2.00	243.90	243.90	243.90	0.00	0.00
Ta	44	2.00	1.18	1.18	1.18	0.00	0.00

n Number of samples

C.V. Coefficient of Variation

* The LOI data are listed in percent (%).

** Data for elements with a coefficient of variation below 15% are normally accepted for advanced statistical analysis, image processing or insertion into a geographical information system without question. Data for elements with a coefficient of variation greater than 15% should be carefully inspected prior to interpretation by these methods.

sequenced bags of wet sediment are delivered to a contractor.

The contractor's laboratory first dries and ring pulverizes the sediment prior to chemical analysis. Then Loss On Ignition (LOI) and concentrations of 35 elements are determined in parts of each sample (Figure 27.6g). Data from chemical analyses are transferred directly from the contractor's laboratories to the OGS via a modem (Figure 27.6h). Calcium and magnesium levels in water samples are determined in the OGS Geoscience Laboratories (Figure 27.6d).

During the winter, field and laboratory data are combined into a single data base (Figure 27.6h). The chemical

data for the quality control samples are then listed separately and analyzed statistically to determine the performance of the analytical methods (see Figure 27.6h). Data for an element are deemed acceptable for direct inputting to a GIS if the coefficient of variation (C.V.) of the quality control data is less than 16%. When the C.V. of an element in the quality control data is greater than 16%, caution is recommended if the data are to be included in a GIS.

As an example, data obtained from 44 replicates of a lake sediment standard sequenced randomly in a batch of 742 unknowns, are listed in Table 27.2. To facilitate inspection, data in Table 27.2 for 35 elements (and LOI) are ranked in order of increasing C.V. Table 27.2 shows that results for

Table 27.3. Clarke Index-I values (modified from Ranov and Yaroshevski 1972; Bowen 1979).

Element	Clarke (ppm)	Element	Clarke (ppm)
Oxygen	456000.0	Gadolinium	6.1
Silicon	273000.0	Dysprosium	5.0
Aluminum	83600.0	Erbium	3.5
Iron	62200.0	Ytterbium	3.1
Calcium	46600.0	Hafnium	2.8
Magnesium	27640.0	Cesium	2.6
Sodium	22700.0	Bromine	2.5
Potassium	18400.0	Uranium	2.3
Titanium	6320.0	Europium	2.1
Phosphorous	1120.0	Tin	2.1
Manganese	1060.0	Beryllium	2.0
Fluorine	544.0	Arsenic	1.8
Barium	390.0	Tantalum	1.7
Strontium	384.0	Germanium	1.5
Sulphur	340.0	Holmium	1.3
Carbon	180.0	Molybdenum	1.2
Zirconium	162.0	Tungsten	1.2
Vanadium	136.0	Terbium	1.2
Chlorine	126.0	Thallium	0.72
Chromium	122.0	Lutecium	0.54
Nickel	99.0	Thulium	0.50
Rubidium	78.0	Iodine	0.46
Zinc	76.0	Indium	0.24
Copper	68.0	Antimony	0.20
Cerium	66.0	Cadmium	0.16
Neodymium	40.0	Mercury	0.09
Lanthanum	35.0	Silver	0.08
Yttrium	31.0	Selenium	0.05
Cobalt	29.0	Palladium	0.02
Scandium	25.0	Bismuth*	0.0082
Niobium	20.0	Tellurium	0.0040
Nitrogen	19.0	Gold	0.0040
Gallium	19.0	Ruthenium	0.0010
Lithium	18.0	Rhenium	0.0007
Lead	13.0	Platinum	0.0005
Praseodymium	9.1	Rhodium	0.0002
Boron	9.0	Osmium	0.00002
Thorium	8.1	Iridium	0.000002
Samarium	7.0		

* Caution: The value for bismuth (Bi) has been found in the author's experience to be set too low (Fortescue 1985a).

LOI and 18 elements (Al, Ba, Ca, Co, Cu, Fe, K, La, Mg, Mn, Na, P, Sc, Sr, Ti, U, V and Zn) obey the performance rule described above. Eleven of the 17 other elements (Ag, As, Au, Cd, Cr, Mo, Ni, Pb, Sb, Th and W) are considered acceptable only if caution is exercised during the interpretation of their map patterns. Data for 6 other elements (Be, Bi, Br, Hf, Lu and Ta) are considered unreliable for geochemical mapping purposes except where exceptionally high values (i.e., geochemical anomalies) are reported (see Table 27.2).

Let us now return to the description of Figure 27.6. Geochemical data included in OGS regional geochemical maps are standardized using 2 units, one chemical and the other geochemical. The chemical unit of measurement is weight percent (e.g., ppb, ppm and wt %). The geochemical unit is the Clarke Index-I (Figure 27.6i; Fortescue 1985a). The Clarke Index-I transform converts chemical data (obtained from the contractor; Figure 27.6h) into geochemical data. This is accomplished by dividing the weight % data for an element by an estimate of the abundance of that

element in the earth's crust (Fortescue 1985a). The Clarke Index-I units (Kk), used by the OGS since 1980, are listed in parts per million (ppm) in Table 27.3. The use of Kk units simplifies the standardization of data tables, geochemical maps and diagrams included in hard copy releases of regional geochemical maps (Figure 27.6k). The use of Kk values also facilitates standardization of the marginal notes on these maps.

A data base on diskette(s) is available soon after the release of each regional geochemical map. The data base includes positional and geochemical data for the entire map in ASCII text or Lotus 1-2-3[®] format, suitable for immediate downloading into a GIS (Figure 27.6m).

Types of Patterns on Geochemical Maps

In theory, geochemical maps describe all important element patterns resulting from mineral deposits or anthropogenic activity in the area mapped. Element patterns on geochemical maps are identified in 2 ways: 1) visually

(by plotting, image processing and/or a GIS); and 2) mathematically (by using statistics).

Patterns on regional geochemical maps are either geochemical anomalies or geochemical provinces. On OGS regional geochemical maps, quotation marks around these terms indicate that the patterns were identified visually and the patterns have not been verified by resampling or reanalysis of the original samples.

GEOCHEMICAL ANOMALY PATTERNS

Govette (1983, p.30) defined a geochemical anomaly in exploration geochemistry as:

...an abnormally high or low content of an element or element combination, or an abnormal spatial distribution of an element or element combination in a particular sample type in a particular environment as measured by a particular analytical technique.

On an OGS geochemical map, a geochemical anomaly is an isolated high value (or a small cluster of high values) where element level(s) is (are) usually at least 3 times greater than in the surrounding sites.

A excellent example of a geochemical anomaly occurs on the OGS Trout Lake regional geochemical map (Fortescue and Vida 1989). The Trout Lake map area is located in the central part of the Batchawana greenstone belt, northeast of Sault Ste. Marie (Figures 27.7 and 27.8). The geochemical anomaly occurs in 3 small lakes in Desbiens Township (Figure 27.7a). The anomaly pattern for zinc is shown on Figure 27.8b and that for copper on Figure 27.8c. Figures 27.8b and 27.8c are sawtooth plots of all zinc and copper values from 98 lake sites in a 5 km (west-east) map strip located along the eastern boundary of the Trout Lake map sheet.

GEOCHEMICAL PROVINCES

Geochemical provinces are more common than anomaly patterns on geochemical maps. Levinson (1980, p.636) described geochemical province patterns as:

...large-scale crustal units characterized by common features of geological and geochemical evolution expressed in the chemical composition of the constituent geological complexes [formations], as well as in the endogenic and exogenic metalliferous and nonmetalliferous concentrations of the chemical elements.

On OGS regional geochemical maps, geochemical provinces are defined as areas of a geochemical map where the abundance of one (or more) elements is consistently higher, or lower, than in the surrounding area. In Ontario, geochemical provinces include linear and areal features which may involve one, or more elements. Also, areal geochemical provinces may include tens or hundreds of sample points.

Clarke Index-I transform data are standardized for plotting geochemical province and geochemical anomaly patterns on OGS regional geochemical maps. In the Trout Lake area, typical examples of geochemical provinces are found for uranium and arsenic. Mean Kk levels for uranium and arsenic in the entire Trout Lake area are 2.1 Kk (4.83 ppm) and 1.99 Kk (3.97 ppm), respectively. Geo-

chemical provinces for uranium (features labelled A and B on Figure 27.9b) include all values greater than 10 Kk which are indicated by large dots. Large dots denoting arsenic values greater than or equal to 7.0 Kk describe similar patterns (features labelled A and B on Figure 27.9c). The arsenic map also includes a number of isolated geochemical anomalies (features labelled C, D, E, F and G on Figure 27.9c).

SUMMARY

Two geochemical pattern types are common on OGS regional maps. These are geochemical provinces and geochemical anomalies. Marginal notes on OGS regional maps describe patterns considered to be important for mineral resource appraisal. Using the diskette provided with the hard copy map, other patterns in the 35 element geochemical data base may be examined by readers with access to a personal computer. The diskette may also be used for inputting the geochemical data into a GIS.

PART III: APPROACHES TO REGIONAL GEOCHEMICAL MAPPING IN ONTARIO

Using Basal Till as a Sample Medium

Lake or stream sediment regional geochemical mapping is not considered effective in areas covered with a continuous layer of deep and/or complex overburden (*see* Figures 27.4c, 27.4f to 27.4i). In these areas, the 3 rules of regional geochemical mapping previously described cannot be fully applied for 2 reasons.

1. It is impossible to sample the same geological formation across a region where a complex Quaternary section is combined with an uneven bedrock surface.
2. Drilling at a uniform sample density of 1 sample per km² is not practical because of the resources required.

A combination of these 2 constraints precludes the sampling of the same medium during regional geochemical mapping in areas of deep, continuous overburden.

Another problem is that deep overburden of the type found in landscapes c, f, g, h and i in Figure 27.4 is usually a product of mechanical (e.g., grinding) and physical weathering (e.g., frost wedging). Such material is usually unaffected by physical or chemical changes due to running water and/or the atmosphere. Physical weathering of this type almost always produces mixtures of locally and regionally derived material. This always complicates the interpretation of regional geochemical patterns based on material collected from the bedrock-overburden interface (e.g., basal till).

For example, a large percentage of locally derived material in a basal till weakens regional contributions and enhances local contributions to geochemical patterns and vice versa. Either way, from a regional viewpoint, the noise level of the geochemical data will be increased. Samples are subjected to a complex preparation procedure (summarized

in Figure 27.10) in order to circumvent this problem and to obtain more detailed information from individual overburden samples. This procedure provides several geochemical and mineralogical data sets on which regional geochemical maps can be based.

In the late 1970s, when the Kirkland Lake Initiatives Program (KLIP) was commenced, it was believed that regional geochemical mapping would be feasible in the area. The increased volume of geochemical map data obtained from the basal till samples was thought to offset the irregular distribution (due to poor access) of drill-hole sites.

At the end of the project, it was evident that this hypothesis was not tenable.

Sample preparation methodology (see Figure 27.10) was applied to 326 basal till samples (Fortescue and Gleeson 1984; Fortescue, Lourim et al. 1984). Each basal till sample produced: 1) 3 geochemical data sets obtained by analysis of different size fractions; 2) a gold grain count obtained by a visual examination; and 3) 4 sets of mineralogical data obtained from low power microscopic examinations of different subsamples (see Figure 27.10).

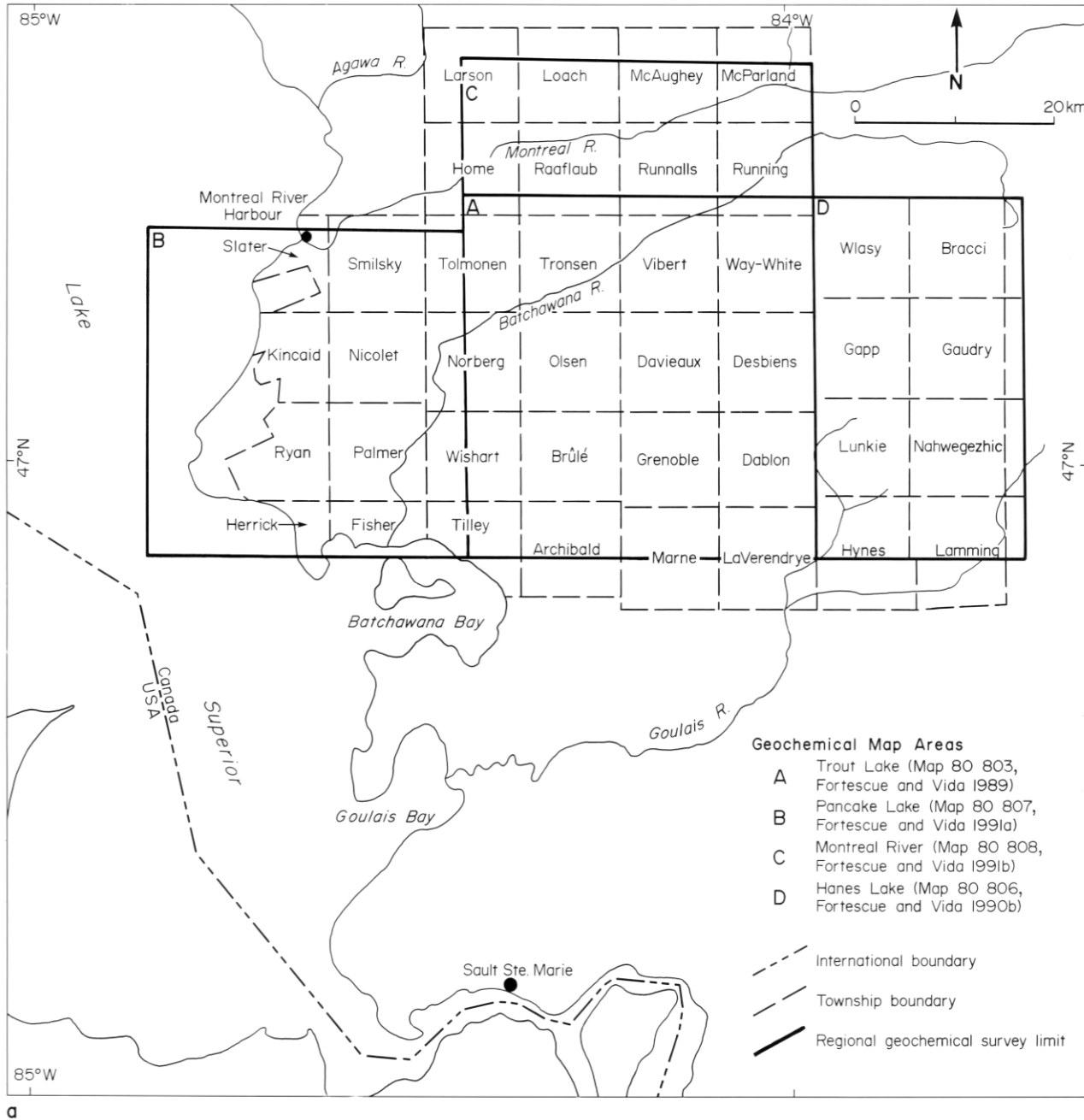


Figure 27.7a. Index map showing the location of Ontario Geological Survey regional geochemical maps of the Batchawana greenstone belt 1989–1991 (modified from Fortescue and Vida 1991b).

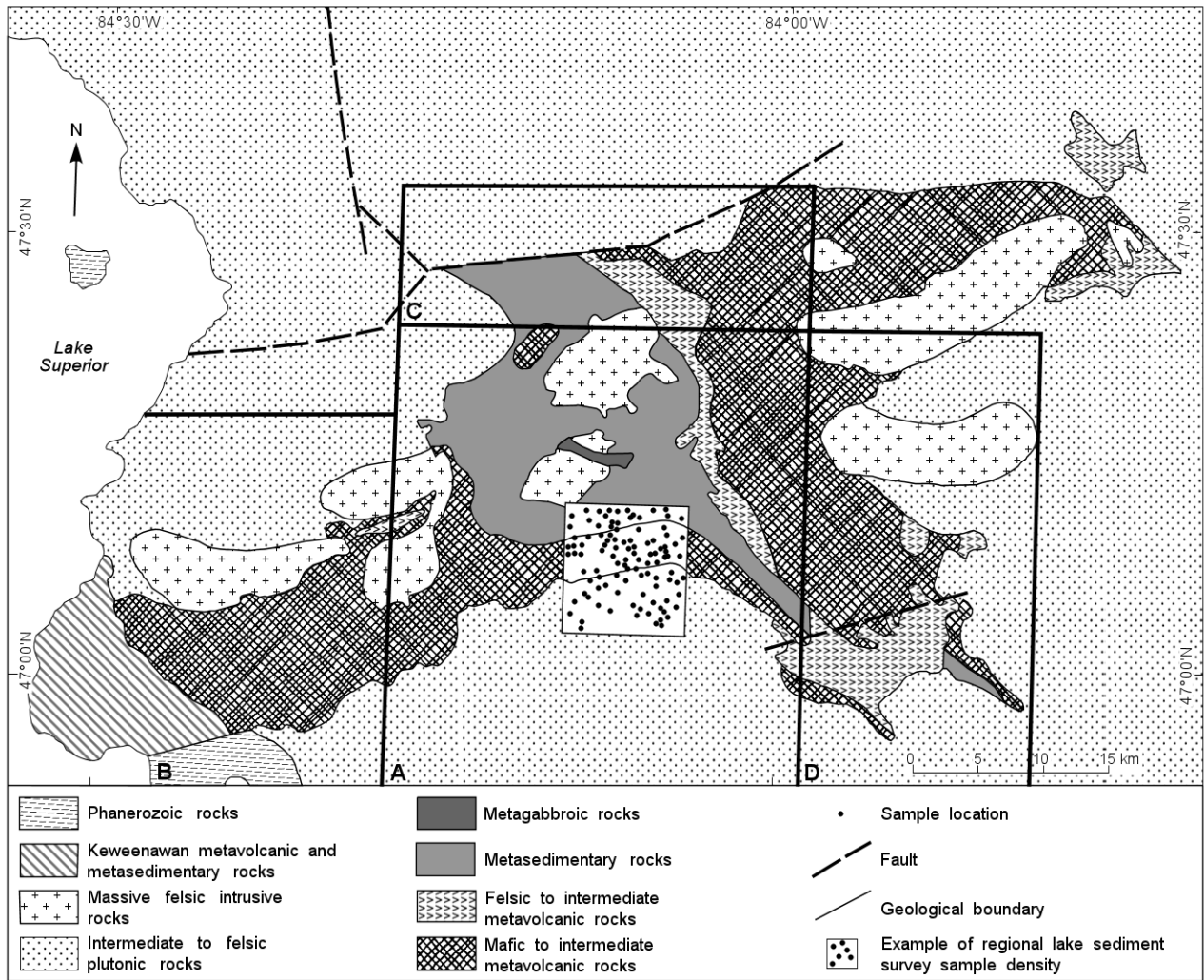
For reasons explained above, it was extremely difficult to interpret most of the patterns on the KLIP regional geochemical and mineralogical maps. Also, in 1983, little was known of the details of the Quaternary stratigraphy in the KLIP area. In spite of this, some of the KLIP regional geochemical and mineralogical map patterns proved to be useful in mineral exploration.

For example, before the KLIP was completed, bedrock kimberlite had seldom been reported from the survey area (Lee 1968). However, as a result of the KLIP, kimberlite indicator minerals were found in many of the basal till samples.

The KLIP index map (Figure 27.11a) includes the limits of the area mapped, and the locations of drill holes and backhoe pits from which 326 basal till samples were collected (Fortescue, Lourim et al. 1984). During the project, a total of 243 geochemical and mineralogical maps of the area were prepared (Fortescue, Lourim et al. 1984). These included maps for kimberlite indicator minerals

(spinel, chrome diopside and pyrope garnet; Figures 27.11b, 27.11c and 27.11d). A total of 120 spinels of 3 different colours were observed in basal till samples (see Figure 27.11b). Distribution maps for 69 black spinels, 26 pink spinels and 25 clear spinels showed no simple geochemical province pattern. Chrome diopside was found in 87 of the basal till samples. The provincial distribution for this mineral is similar to that for spinel, except that chrome diopside occurs more commonly to the southeast of the area (see Figures 27.11b and 27.11c). Unlike the patterns for spinel and chrome diopside, 83 of the 87 pyrope garnet occurrences are in the southern part of the map area (see Figure 27.11d).

In retrospect, the pyrope garnet pattern turned out to be of considerable importance. In the mid-1980s, 5 kimberlite pipes were found under deep overburden in Morrisette, Arnold and Clifford townships (see Figure 27.11d). If it is assumed that the sampled basal till was deposited by ice moving towards the southeast, the distribution of the pyrope



b

Figure 27.7b. Generalized geological map of the Batchawana greenstone belt. Note the density of sample locations in comparison to the size of the study area.

garnet can be related directly to the kimberlite pipes as all but 4 of the samples containing pyrope garnet were collected southeast of the pipes. Diamonds of various sizes have been reported from all of the kimberlite pipes (W.C. Fipke, Dia Met Minerals Ltd., personal communication, 1990).

COMMENTS

Regional geochemical mapping using basal till samples obtained from boreholes now appears impractical due to: 1) complex Quaternary stratigraphy in many areas of deep overburden; 2) the problem of drill site access in remote areas; and 3) the expense of deep overburden sampling at a uniform density of 1 sample per km². Detailed geochemical mapping can be an important component of the OGS mineral resource appraisal process if overburden drilling is both carried out in areas of exceedingly high mineral potential and based on detailed Quaternary stratigraphy of the overburden sections. A recent study by Bajc (1988) clearly supports this assertion.

Using Stream Sediments as a Sample Medium

In 1981, the OGS completed the Southwestern Ontario Regional Geochemical Survey in an area of 25 000 km² extending from the Niagara River to Lake Huron (Figure 27.12a). The project involved the collection of over 4000 stream sediment samples in which concentrations of 28 elements were determined.

The Southwestern Ontario Geochemical Survey area was chosen on the basis of geological considerations for a test of stream sediment regional geochemical mapping methodology. The area is underlain by Paleozoic sedimentary strata which strike northwest (Figure 27.12b). The last ice movement across the area was towards the southwest (Hewitt 1972). Quaternary deposits in the survey area are of 3 types: 1) tills and moraines in the western part of the area; 2) glaciofluvial sands and gravels in the centre of the area; and 3) lake sediments in the eastern part of the area (Figure 27.12c).

The Southwestern Ontario Geochemical Survey mapping project was designed to fulfill the requirements of the 3 regional geochemical mapping principles discussed above. The overall aim of the survey was to provide a regional geochemical data base which could be utilized for mineral resource appraisal and base line environmental geochemistry.

The first principle of geochemical mapping was satisfied in the Southwestern Ontario Geochemical Survey area as follows: 1) the entire area to be mapped was divided into 10 by 10 km squares (micromodules); 2) each micromodule was further divided into four 5 by 5 km squares (micromodule quarters); and 3) 5 stream sediment sample points were located within each micromodule quarter. Limits of micromodules, micromodule quarters and sample sites were plotted on 1:50 000 topographic base maps that were later used for field sampling. All stream sediment collection sites were positioned at least 50 m upstream from

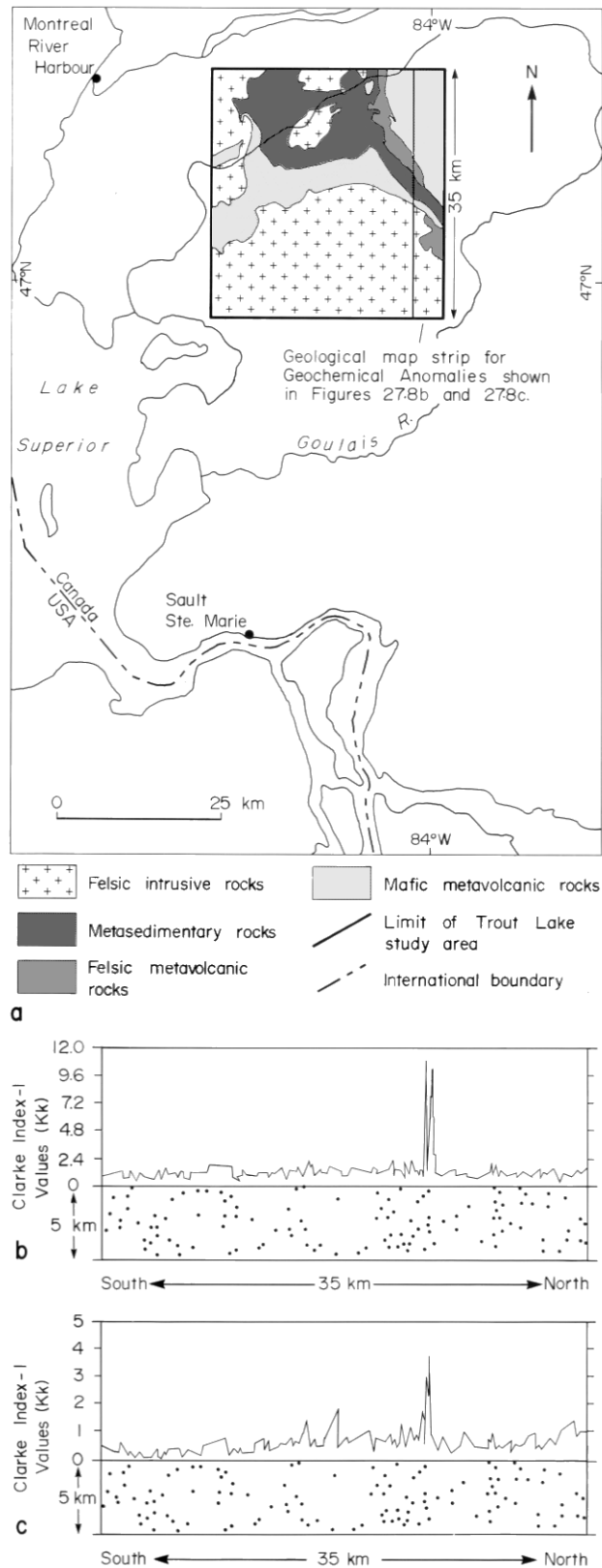


Figure 27.8. a) Generalized map showing the location and geology of the Trout Lake study area. b) Geochemical section of a zinc anomaly in the Trout Lake area. c) Geochemical section of a copper anomaly in the Trout Lake area. For parts b and c, the bottom panel of each section represents the geological map strip located at the eastern edge of the Trout Lake study area. The dots represent sample locations (modified from Fortescue and Vida 1989).

road bridges. Prior to this mapping project, a sample density of 1 sample per 5 km² was considered adequate for regional geochemical mapping in southwestern Ontario.

Constraints of the second principle of regional geochemical mapping were met by collecting samples of active

stream sediment. This material is found over the entire Southwestern Ontario Geochemical Survey area. When the survey was planned, it was expected that fine-blown eolian mineral matter, derived from arable fields adjacent to streams, might blur the geochemical map patterns. It was discovered that this blurring effect was insignificant during the preliminary interpretation of patterns in the geochemical data. Stream sediment samples were dried, crushed and passed through an 80 mesh (180 micron) sieve before chemical analysis.

The third principle of regional geochemical mapping was obeyed by standardization of all the steps in the preparation of the Southwestern Ontario Geochemical Survey maps. Data for levels of 28 elements (including Al, Ag, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Sr, Th, Ti and Zn) were obtained from each of the 4000 samples collected during the survey. The project also included analyses of several hundred standard samples inserted within the unknowns for quality control purposes. At the time of writing, none of the geochemical patterns in the Southwestern Ontario Geochemical Survey data had been verified either by resampling or reanalysis of the original samples.

THE SOUTHWESTERN ONTARIO GEOCHEMICAL SURVEY MAPS

Major geochemical anomaly and geochemical province patterns in the data sets for 20 selected elements were presented and described on 2 broadsheets (Fortescue 1983a, 1984a).

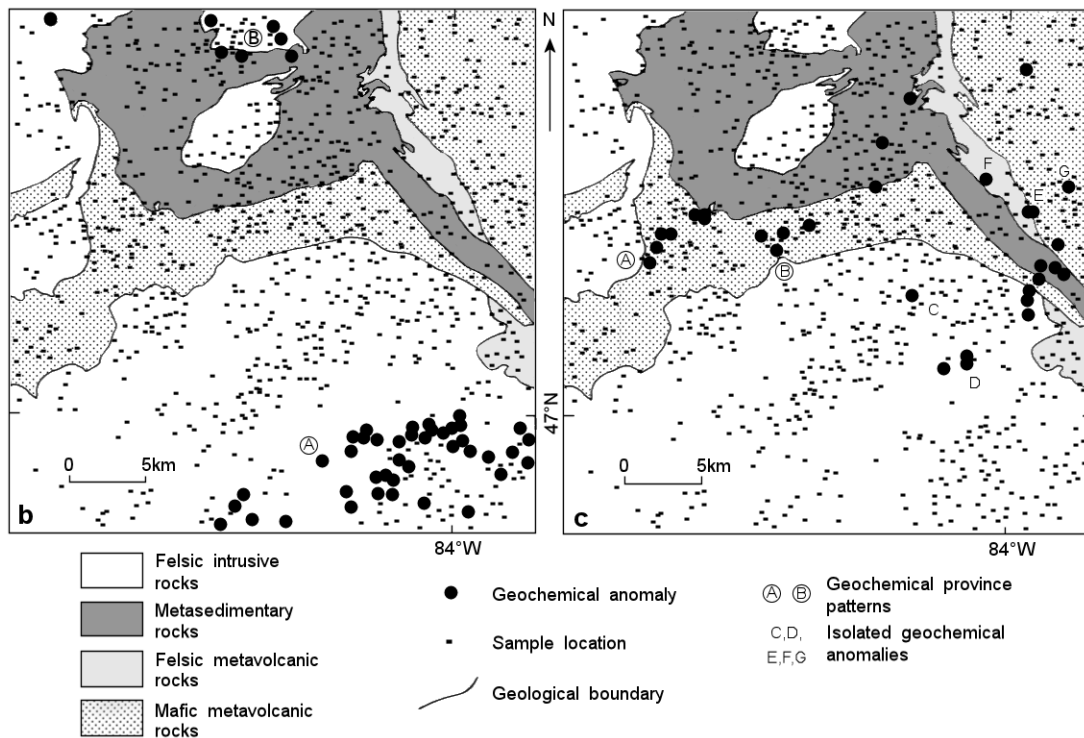
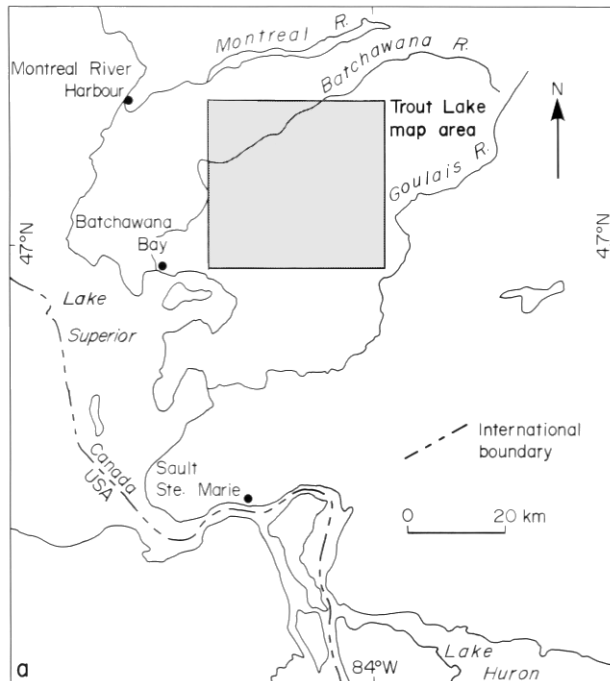
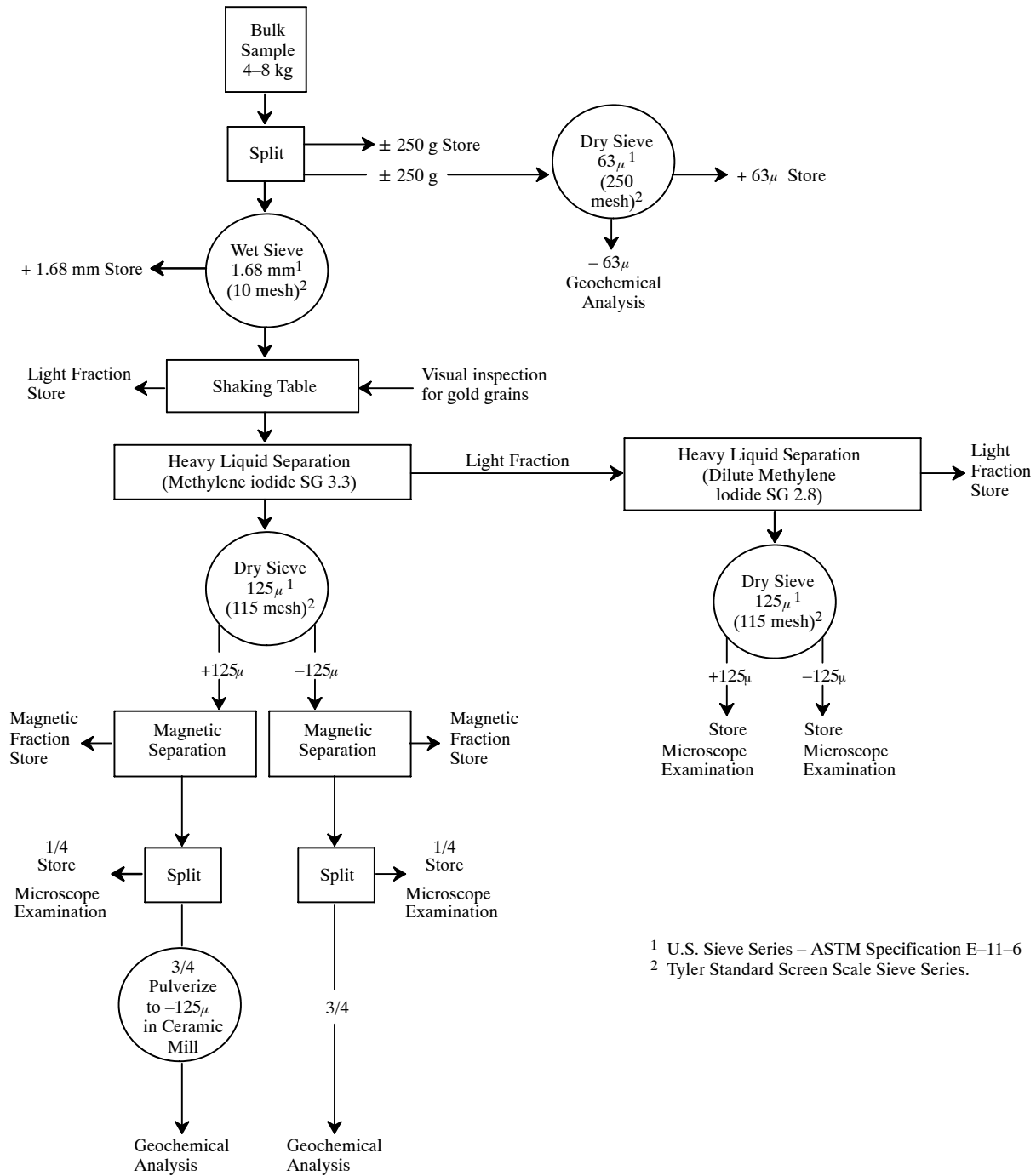


Figure 27.9. a) Generalized map showing the location of the Trout Lake study area. Geochemical province patterns for: b) uranium; and c) arsenic, as related to the general geology and sample locations in the Trout Lake study area (modified from Fortescue and Vida 1989). Geochemical provinces are denoted by Clarke Index-I values greater than or equal to 10 Kk for uranium and 7.0 Kk for arsenic.



¹ U.S. Sieve Series – ASTM Specification E-11-6
² Tyler Standard Screen Scale Sieve Series.

Figure 27.10. Flow diagram of sample preparation for geochemical and mineralogical analysis of the Kirkland Lake Initiatives Program (KLIP) basal till samples (modified from Fortescue and Gleeson 1984).

Figure 27.12 includes maps of the Southwestern Ontario Geochemical Survey area showing: a) geography; b) bedrock geology; c) Quaternary geology; d) the micromodule grid (with points plotted at the centre of each micromodule); and e) the micromodule-quarter grid (with points plotted at the centre of each micromodule quarter).

The Southwestern Ontario Geochemical Survey geochemical anomaly and province patterns were displayed using micromodule (i.e., 20 sample) composite values on the 1983 broadsheet (Fortescue 1983a). Using the procedure described above, parts per million (ppm) values for each element were transformed into Clarke Index-I units (Kk). The resulting Kk value data sets for all 20 elements were classified using the same Kk frequency distribution cell limits. Values for an element in each cell of the frequency distribution were plotted as large dots on a copy of the micromodule grid map (Figure 27.12d). The resulting frequency distribution cell maps for an element were then arranged in a column with the lowest Kk value map at the bottom and the highest Kk value map at the top. The columns were then ranked in order of increasing median Kk value to produce a scan sheet (Figure 27.13). The ranking procedure facilitates visual comparisons among the element Kk level map patterns. Surprisingly, it is easy to identify many geochemical map patterns on Figure 27.13 such as: 1) geochemical gradient; 2) geochemical anomaly; and 3) geochemical province patterns. The reader should refer to Figure 27.13 for a description of these patterns.

The second Southwestern Ontario Geochemical Survey broadsheet (Fortescue 1984a) included regional geochemical map patterns similar to those just described, but based on micromodule-quarter composites (e.g., mean values for 5 samples). A scan sheet format was not used to display geochemical patterns in the 1984 broadsheet. Instead, regional geochemical patterns involving both micromodule and micromodule-quarter plots were combined on the same map (e.g., zinc in Figure 27.14).

Geochemical Patterns

The median level for the 727 micromodule quarters in the Southwestern Ontario Geochemical Survey map area is around 1.25 Kk (100 ppm) Zn. Eleven of these samples were found to have Zn levels greater than 10 Kk (760 ppm) and an additional 5 samples were found to have levels between 5 and 9.9 Kk (380 and 759 ppm; see Figure 27.14). When all samples with Zn levels greater than or equal to 5 Kk are plotted, high values form a geochemical province pattern in the north-central part of the map area (see Figure 27.13, pattern 2; Figure 27.14). This province pattern for zinc covers an area of approximately 400 km² and is probably due to small amounts of zinc in the bedrock which have been concentrated locally in swampy areas.

An interesting geochemical anomaly pattern for lithium, which is so far unexplained, occurs in the Niagara Peninsula (Figure 27.15). The Southwestern Ontario Geochemical Survey median value for Li is between 0.75 and 1.0 Kk (13.50 and 18.00 ppm). The Li geochemical province includes 61 samples with levels

greater than or equal to 2.50 Kk (45.00 ppm; see Figure 27.15). Three geochemical maps are used to describe the lithium geochemical province (see Figures 27.15a, 27.15b and 27.15c). They include data for lithium in micromodule and micromodule-quarter composites in the area. The accompanying table in Figures 27.15a, 27.15b and 27.15c shows the frequency distribution of lithium Clarke Index-I codes. It includes 6 sample points with Li values greater than or equal to 3 Kk (54 ppm). Four of these points appear as a weak linear anomaly in the western part of the area, whereas the other 2 points occur near the Buffalo–Niagara Falls industrial complex (see Figure 27.15a). Figures 27.15b and 27.15c include plots of Li levels greater than or equal to 2.75 Kk (49.5 ppm) and 2.50 Kk (45 ppm), respectively. Figure 27.15c also includes the pattern for all Li values greater than or equal to 2.0 Kk (36 ppm), because these are associated with the stronger Li map patterns just described.

In summary, a lithium geochemical province pattern was found in the stream sediment composite data collected during the Southwestern Ontario Geochemical Survey project in the Niagara Peninsula. This geochemical province is a weak northeast-trending linear anomaly. At the time of writing in early 1991, the pattern had not been explained. The pattern is coincident with aeromagnetic linear anomaly features (see Map 2587, map case).

Geochemical province patterns for potassium, aluminum and beryllium (Figures 27.16a, 27.16b and 27.16c) are associated with glacial lake sediment cover of the Niagara Peninsula (see Figure 27.12c). High levels of argillaceous minerals in the lake sediments probably account for geochemical province patterns for potassium and aluminum in the area (see Figures 27.16a and 27.16b). The beryllium geochemical province is probably due to this element having almost the same ionic potential as aluminum, causing the 2 elements to behave similarly during the formation of secondary phyllosilicates (Goldschmidt 1954).

SUMMARY

Even though they are based on composite samples, the Southwestern Ontario Geochemical Survey maps show both geochemical anomaly and geochemical province patterns. Although the composite of the regional geochemical data was carried out for practical reasons, it was concluded that important geochemical map patterns can still be delineated using micromodules and micromodule-quarter composites. More important, the survey demonstrated that it is feasible to produce valid geochemical maps based on composite samples. If the samples are composited prior to chemical analysis, then geochemical maps can be made rapidly and cheaply, using very few chemical analyses.

Using Lake Sediments and Waters as Sample Media

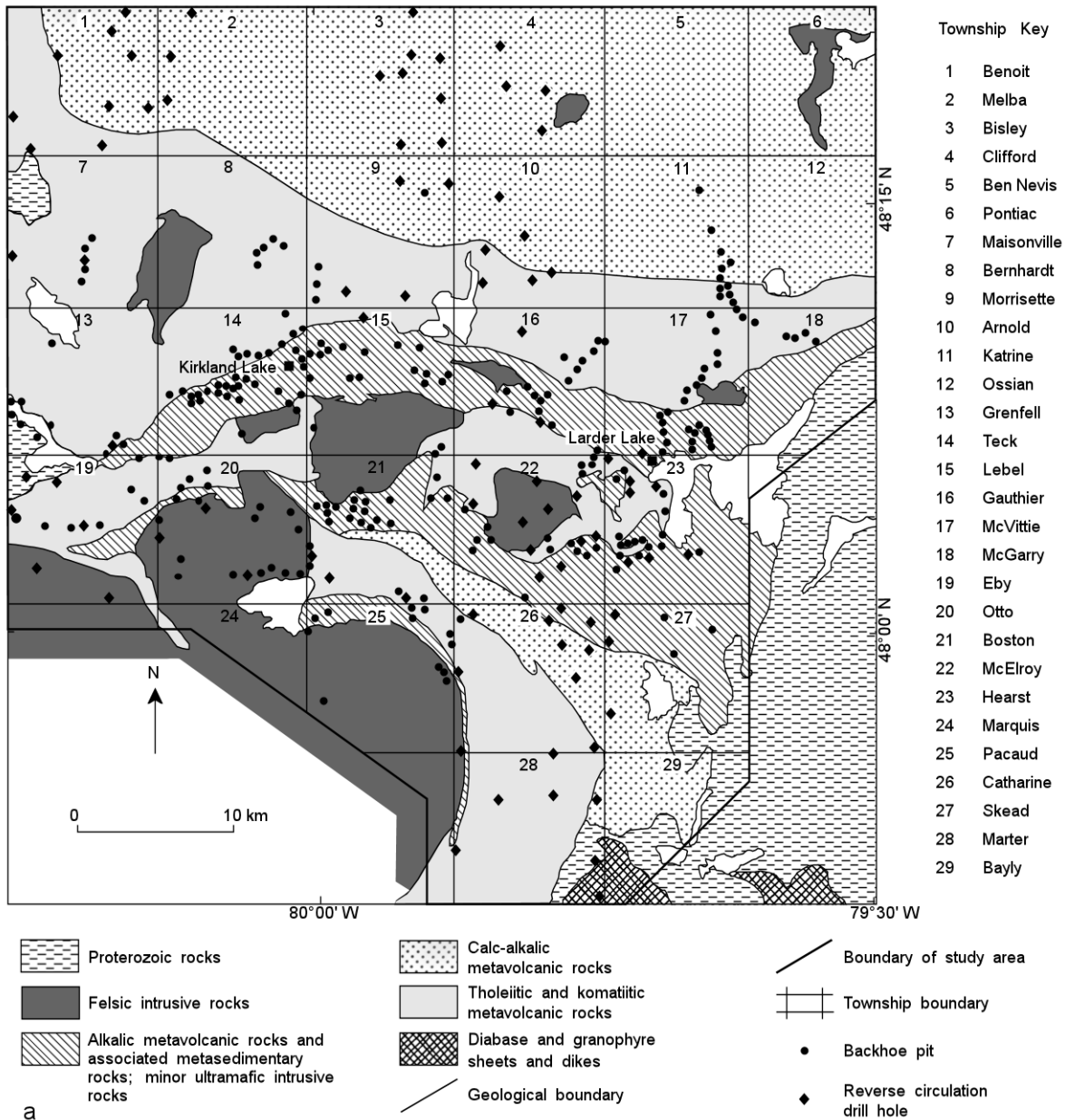
By 1991, 5 regional geochemical maps had been released by the OGS based on pre–*Ambrosia* lake sediment (Fortescue

and Vida 1989, 1990a, 1990b, 1991a, 1991b). Four of these maps are located in the Batchawana greenstone belt (see Figure 27.7) and one in the Michipicoten greenstone belt (Figure 27.17).

Examples of zinc, copper, uranium and arsenic geochemical patterns from the Trout Lake map were described above in the section entitled Geochemical Patterns (Fortescue and Vida 1989). This section is concerned with other pattern types important for interpreting modern regional geochemical maps.

LINEAR GEOCHEMICAL PROVINCES

Figures 27.18a through 27.18g present geochemical-geological map strips (G-GMS) displaying gold data for 946 Trout Lake area pre-Ambrosia samples. In Figure 27.18, the 5 km wide G-GMS are oriented from south to north (left to right). The western margin of the Trout Lake map area is included in Figure 27.18a and the eastern margin in Figure 27.18g. The mean level for gold in the entire Trout Lake area is 0.71 Kk (2.81 ppb). The gold linear geochemical province of interest is highlighted by arrows on



Figures 27.18b–e. This linear feature parallels the strike of the greenstone belt for 20 km and includes 4 gold values ranging from 2 to 2.5 Kk (8 to 10 ppb). The gold pattern in lake sediment is associated with a small, but persistent, iron formation in the greenstone underlying lake catchment areas. This iron formation has been reported to have low gold values throughout its length (G. Bennett, Resident Geologist's office, Sault Ste. Marie, Mines and Minerals Division, personal communication, 1989). It is noteworthy that the OGS regional geochemical mapping methodology is sensitive enough to trace this relatively weak gold pattern over a distance of 20 km. Two single sample point geochemical anomalies for gold also occur in Figure 27.18. Anomaly A (64 ppb Au) is in Figure 27.18f; Anomaly B (21 ppb Au) is indicated in Figure 27.18c. At the time of

writing, these results had not been verified by further analysis.

The gold linear geochemical province just described was concordant with the strike of the greenstone belt. This contrasts with a weak, 3 sample point discordant thorium linear geochemical province, which was also found in the Trout Lake map data (Figures 27.19e, 27.19f and 27.19g). In this case, Th values of 2.72 Kk (18 ppm), 1.73 Kk (14 ppm) and 1.52 Kk (12 ppm) form the 15 km long linear province where the background level for Th is 0.39 Kk (3.2 ppm). This thorium geochemical linear province is assumed to be due to a structural feature which cuts across the regional strike of the greenstone belt.

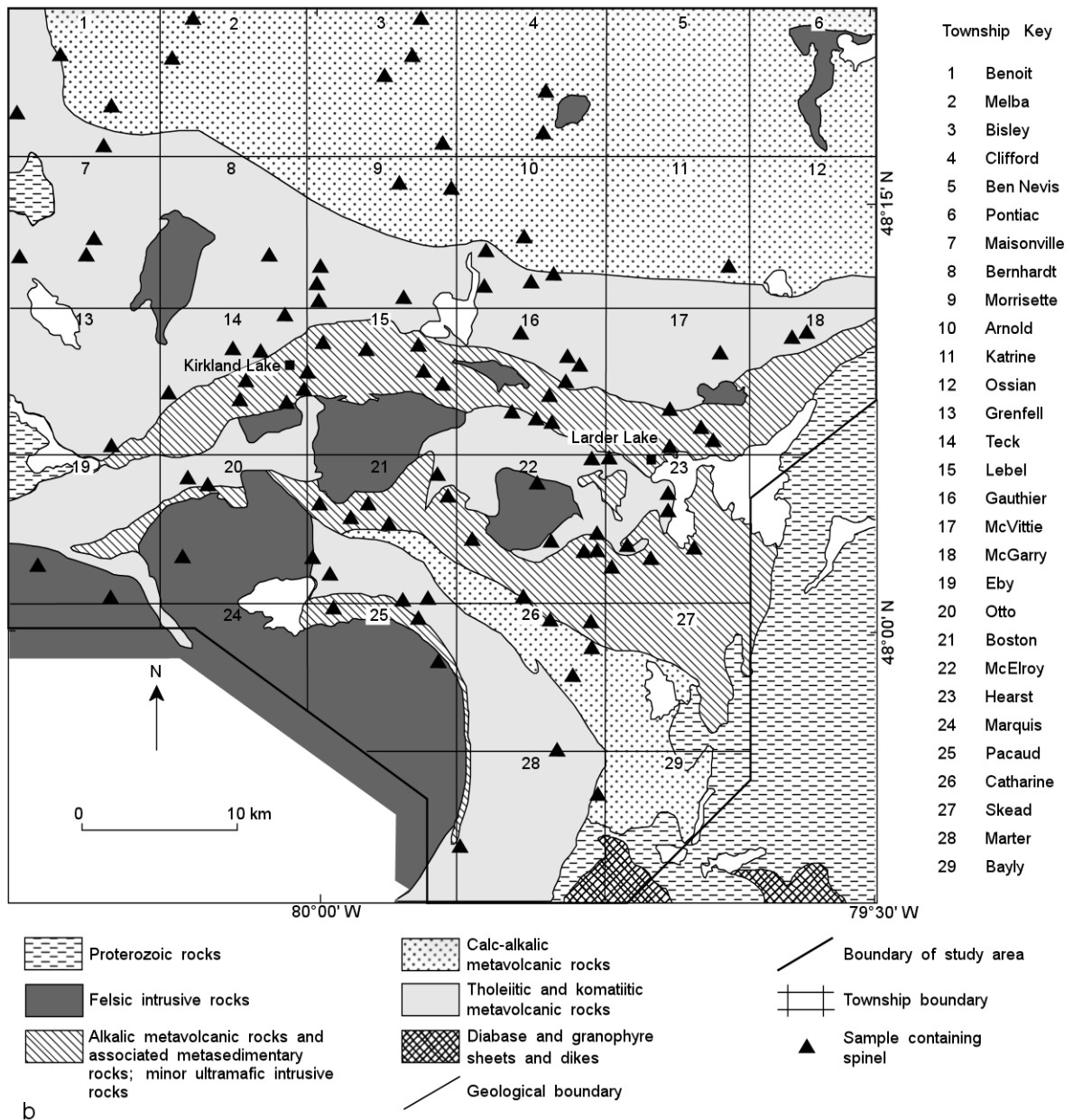


Figure 27.11b. Geological maps of the Kirkland Lake Initiatives Program study area displaying locations of till samples containing spinel (modified from Fortescue and Gleeson 1984).

AREA GEOCHEMICAL PROVINCE PATTERNS

Several examples of regional area geochemical province patterns have already been described (e.g., Figures 27.9a, 27.9b, 27.13, 27.14, 27.15 and 27.16). A good example of a combined geochemical province–geochemical anomaly pattern occurs in the molybdenum data from the Hanes Lake map area (Figure 27.20; Fortescue and Vida 1990b). The mean Mo level in the Hanes Lake area is 1.5 Kk (1.85 ppm). The Mo geochemical province is delineated by values greater than or equal to 5 Kk (6.0 ppm) in an area of complex geology (Figure 27.20b). Two Mo anomalies with values of 34 Kk (41 ppm) and 29 Kk (35 ppm), respectively, occur

within this geochemical province. At the time the Hanes Lake geochemical map was released, neither the molybdenum province nor the anomalies had been staked.

Area geochemical province patterns are not always due to bedrock geology. For example, a geochemical province for pH and for calcium in lakewater occurs in the west-central part of the Hanes Lake map (Figure 27.21; Fortescue and Vida 1990b). This geochemical province is associated with an area of calcareous ground moraine and outwash plain (see Figure 27.21). It is interesting that a geochemical province for arsenic (Figure 27.22b) is coincident with the pH and calcium patterns just described. The G-GMS geochemical province patterns for arsenic (Figure 27.22c, parts

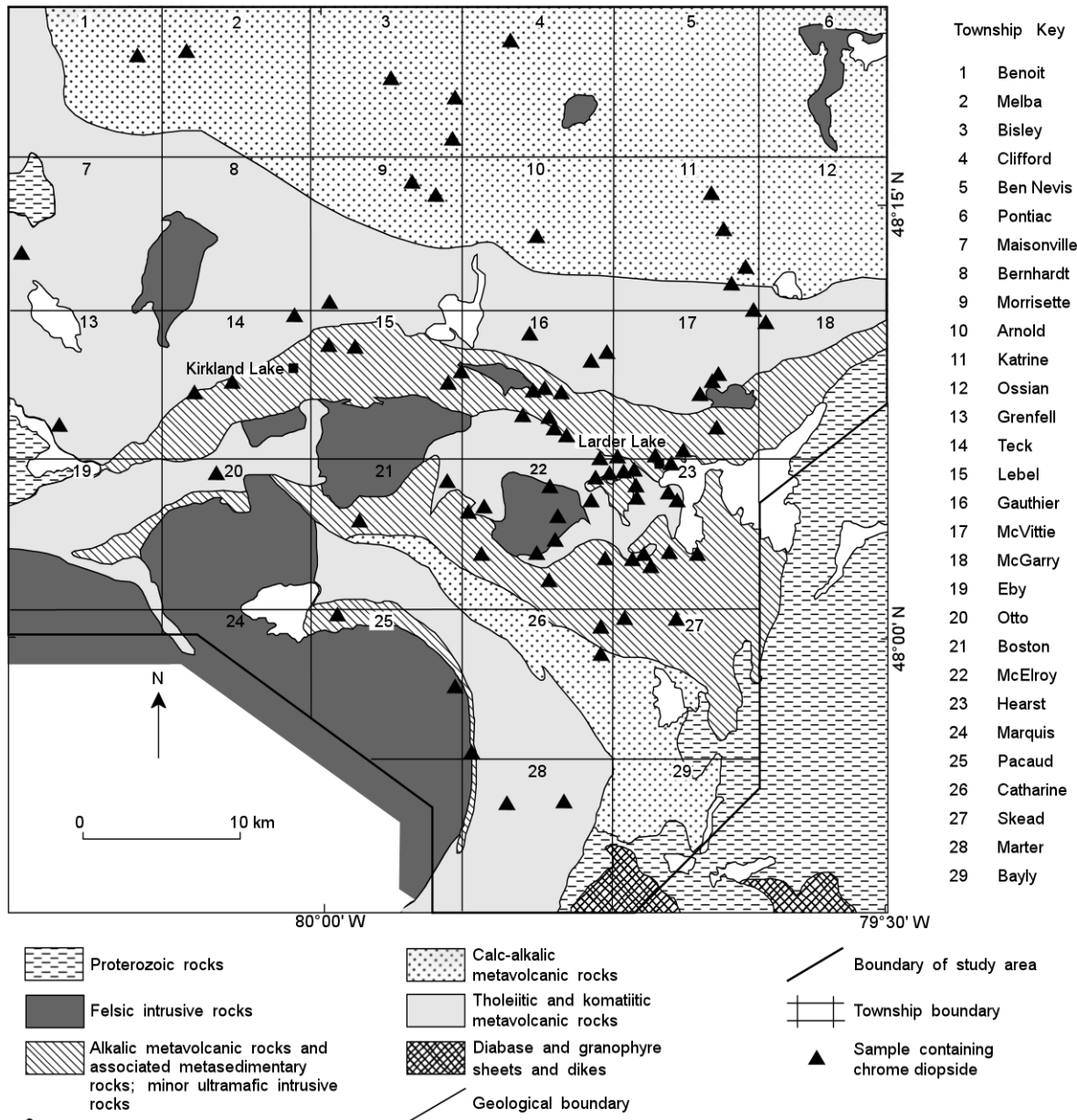


Figure 27.11c. Geological maps of the Kirkland Lake Initiatives Program study area displaying locations of till samples containing chrome diopside (modified from Fortescue and Gleeson 1984).

C and D and parts B and C) show a strong geochemical gradient from north to south. Variation in the thickness of the ground moraine may account for this gradient. Also, the arsenic G-GMS includes a single anomalous value of 53 Kk (96 ppm) in Figure 27.22c, parts B and D, which has not yet been verified or explained.

associated with similar patterns in OGS remote sensing and metallogeny data.

PART IV: GEOCHEMICAL MAPPING RESEARCH AND DEVELOPMENT

Geochemical Data Verification Methodology

COMMENTS

These examples of regional geochemical provinces, and many others like them, provide an introduction to pattern recognition in geochemical mapping. As more interpretive experience of this type is gained, it should be possible to predict the presence of some of these geochemical province patterns. As more experience is gained with GIS, it is probable that geochemical province patterns will be

Ideally, all geochemical anomalies and some geochemical province patterns should be verified by resampling soon after discovery. Unfortunately, this is not possible unless the program is serviced by a Mobile Laboratory Unit (MLU; see The Dedication of a Chemical Laboratory to Ontario

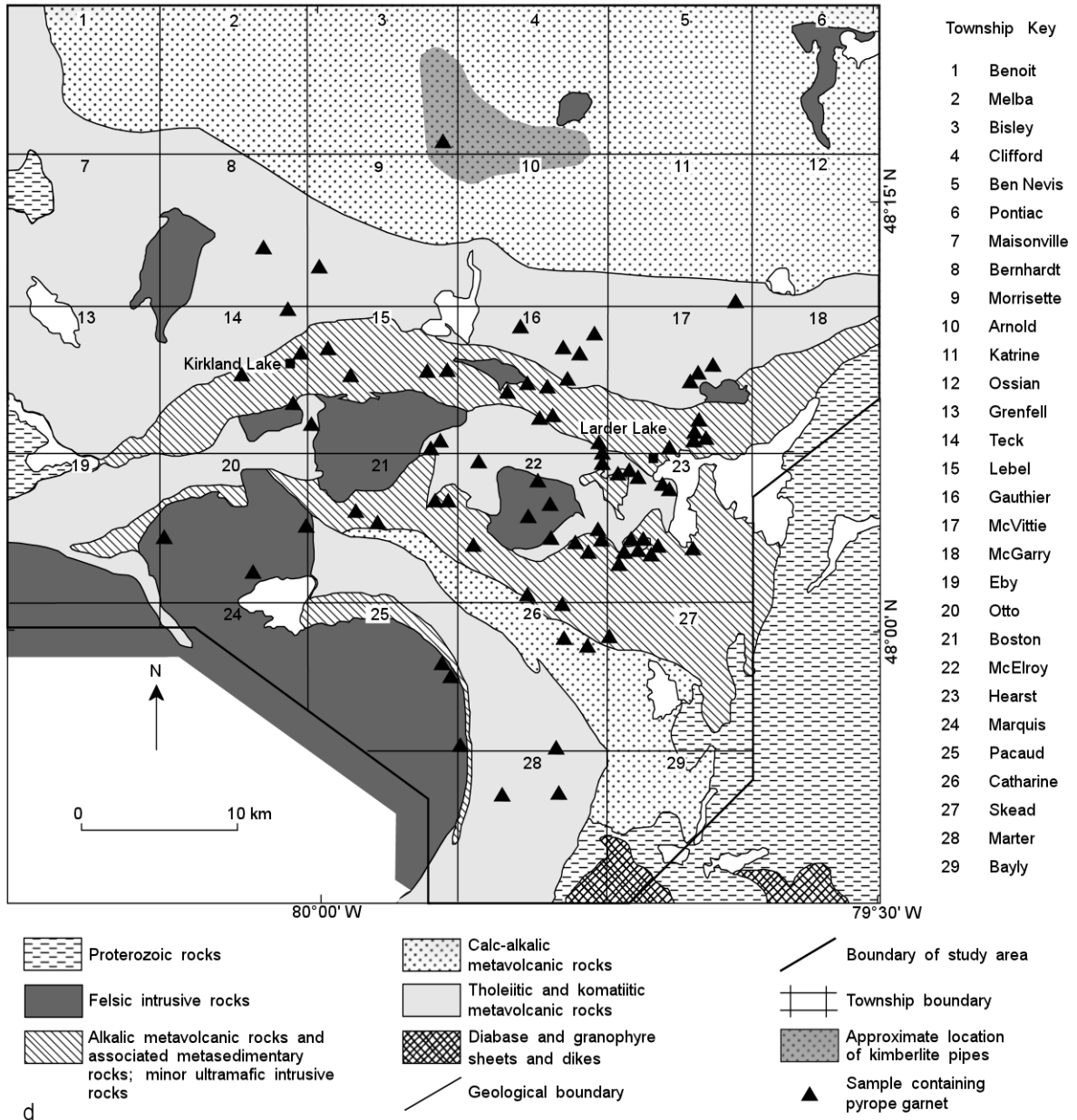


Figure 27.11d. Geological maps of the Kirkland Lake Initiatives Program study area displaying locations of kimberlite pipes and locations of till samples containing pyrope garnet (modified from Fortescue and Gleeson 1984).

Geological Survey Mapping). Instead, the OGS has focussed attention on the development of resampling methods for verification of pre-*Ambrosia* lake sediment core anomaly data. The 4 approaches to the solution of this problem that have been examined are: 1) duplicate chemical analyses of the original pre-*Ambrosia* material; 2) chemical analysis of both pre- and post-*Ambrosia* samples from anomalous cores; 3) replicated sampling of pre-*Ambrosia* material from lakes of interest; and 4) the collection of a long lake sediment core from a sample point of interest (Fortescue 1988b).

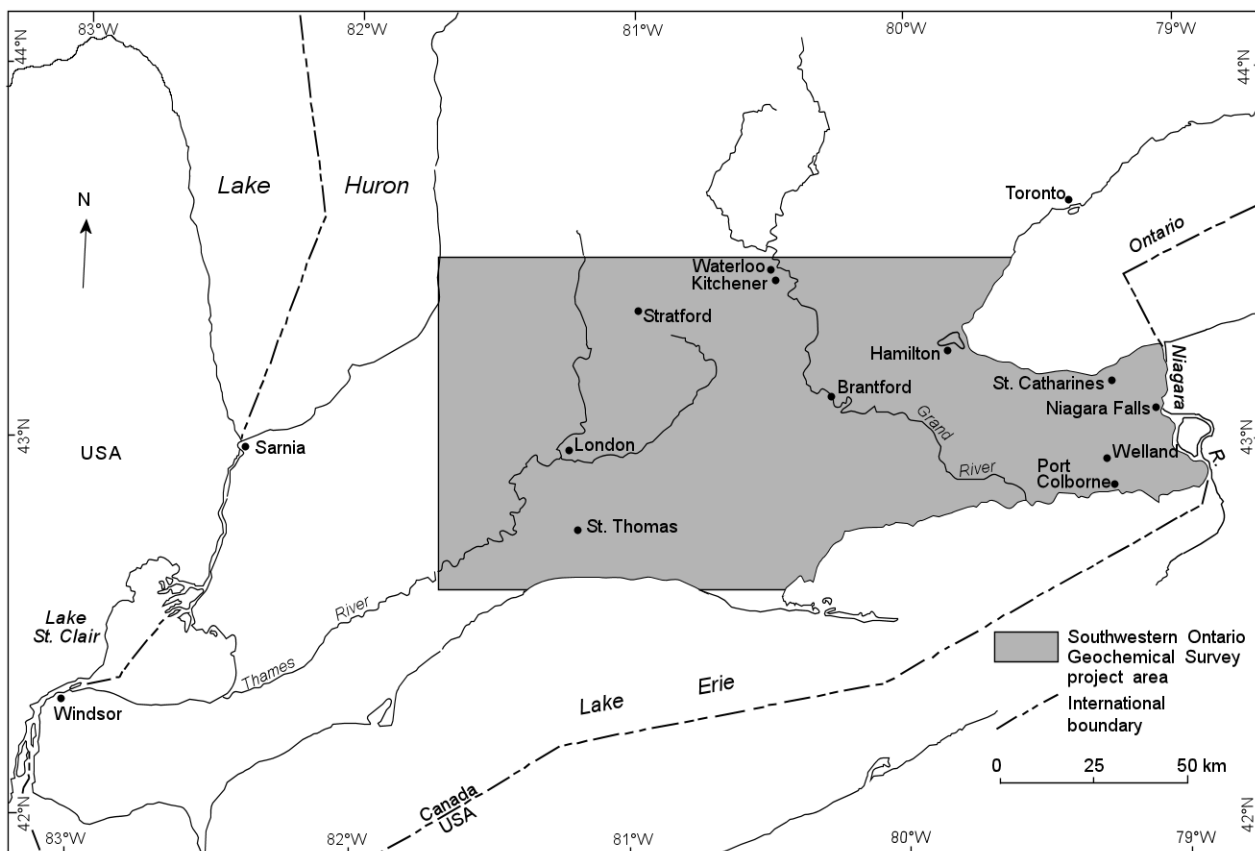
Because of the excellent reliability of modern chemical analyses, approach 1 listed above is not usually necessary. For example, in recent OGS experience involving the preparation of 5 regional geochemical maps, only 2 minor analytical errors were found, both of which were easy to identify since they involved only a small number of elements.

An example of approach 2 along a 75 km geochemical sampling strip is illustrated on Figure 27.5. In this case, the pre- and post-*Ambrosia* patterns for strontium and uranium were very similar and unaffected by atmospheric fallout (see Figures 27.5d and 27.5f). The patterns for lead and nickel in the same samples (see Figures 27.5a and 27.5b) are dissimilar due to anthropogenic fallout from the atmosphere during the post-*Ambrosia* period. Consequently, this

approach to anomaly verification in lake sediment cores cannot be used for all elements.

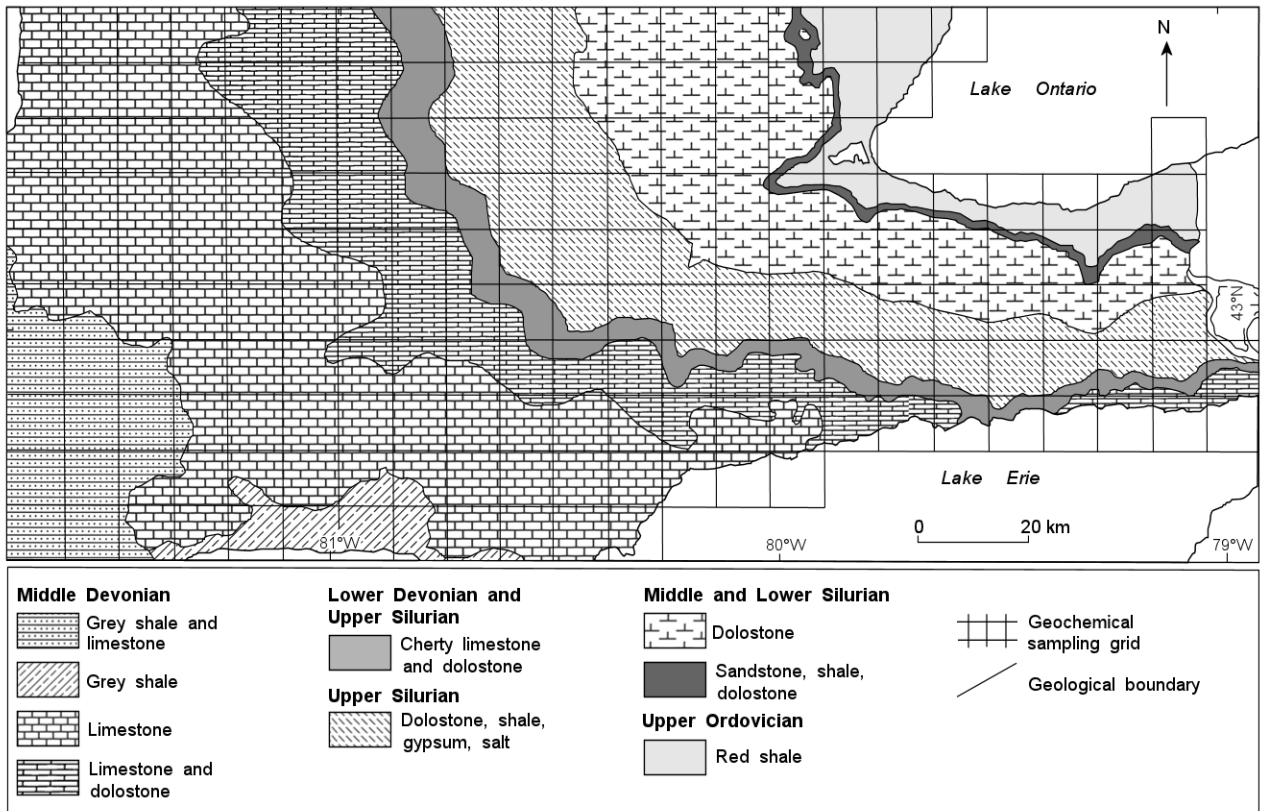
An example of approach 3 is the resampling of the pre-*Ambrosia* material to verify the zinc and copper anomaly shown in Figures 27.8b and 27.8c. Geochemical results obtained from 1988 and 1989 samplings from the 3 lakes of interest (see Figure 27.8) are included in Table 27.4. The data in Table 27.4 include: 1) levels for a global datum signature (GDS) based on the median Kk values for 32 elements, in 3000 pre-*Ambrosia* lake sediment samples (Fortescue and Vida, in prep.); 2) a list of Kk values for 32 elements in the 1988 sampling of lake sites EG599, EG603 and EG617; and 3) a list of Kk values for a 1989 sampling of lake sites EG599 (X1054), EG603 (X1055) and EG617 (X1056). Values for 5 important elements (Zn, Cu, As, Fe and Mn) are underlined on Table 27.4.

The contrast for the Zn geochemical anomaly is between 5.7 and 12.9, with a GDS value of 1.00 Kk (see Table 27.4). The contrasts for the Cu geochemical anomaly ranged between 1.8 and 4.1 with a GDS level of 0.49 Kk (see Table 27.4). Arsenic is another element associated with this geochemical anomaly (see Table 27.4). In the 1989 sampling, in 2 of the 3 samples of interest, the As values were close to the GDS value of 1.11 Kk. In the 1988 sampling, all 3 samples were found to be anomalous for As, with a contrast between 2.8 and 7.8 (see Table 27.4).

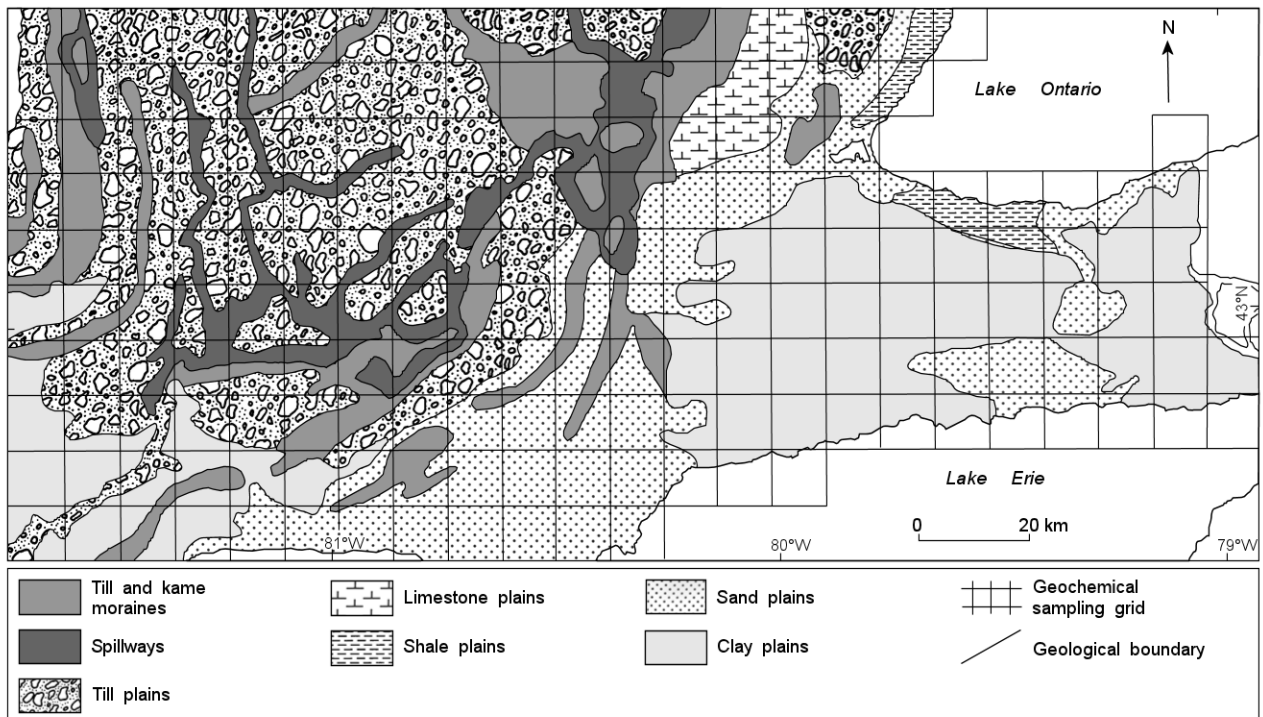


a

Figure 27.12a. The Southwestern Ontario Geochemical Survey project area: location map (modified from Fortescue 1983a, 1984a).



b



c

Figure 27.12b and c. The Southwestern Ontario Geochemical Survey project area: **b)** bedrock geology map; and **c)** Quaternary geology map (*modified from Fortescue 1983a, 1984a*).

At 2 of the 3 anomalous sample sites (EG603 and EG617), iron and manganese values were replicated well, at approximately half of their GDS value of 0.12 Kk (see Table 27.4). In the 2 samples from the headwater lake (EG599), values averaged 1.4 times the GDS value for iron and 1.9 times the GDS value for manganese. This suggests that the source of the geochemical anomaly may be gossan in the lake or catchment area of sample EG599. The data on Table 27.4 illustrates the importance of verification by

resampling of pre-*Ambrosia* lake sediment and also illustrates how additional geochemical information can be obtained from this procedure.

Approach 4 is the most effective and sure method for verification of pre-*Ambrosia* geochemical data. This method involves the collection of long lake sediment cores. In central Ontario, the organic layer sampled by long lake sediment cores has accumulated during a 9000-year period

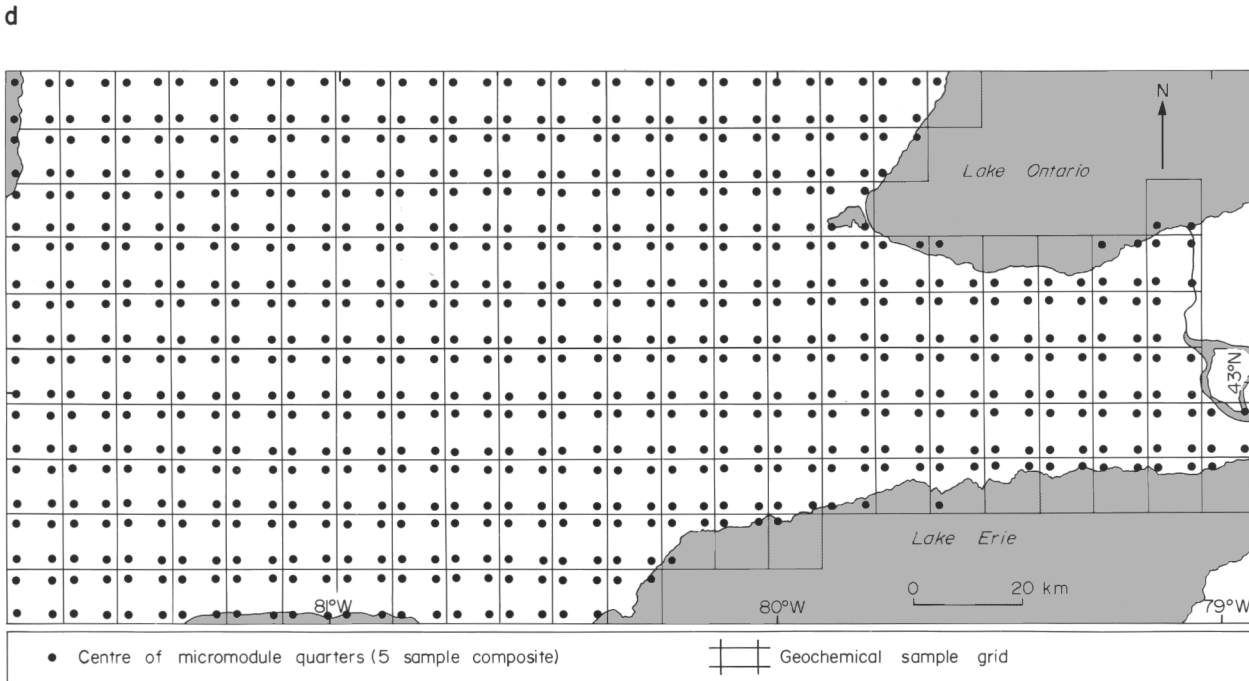
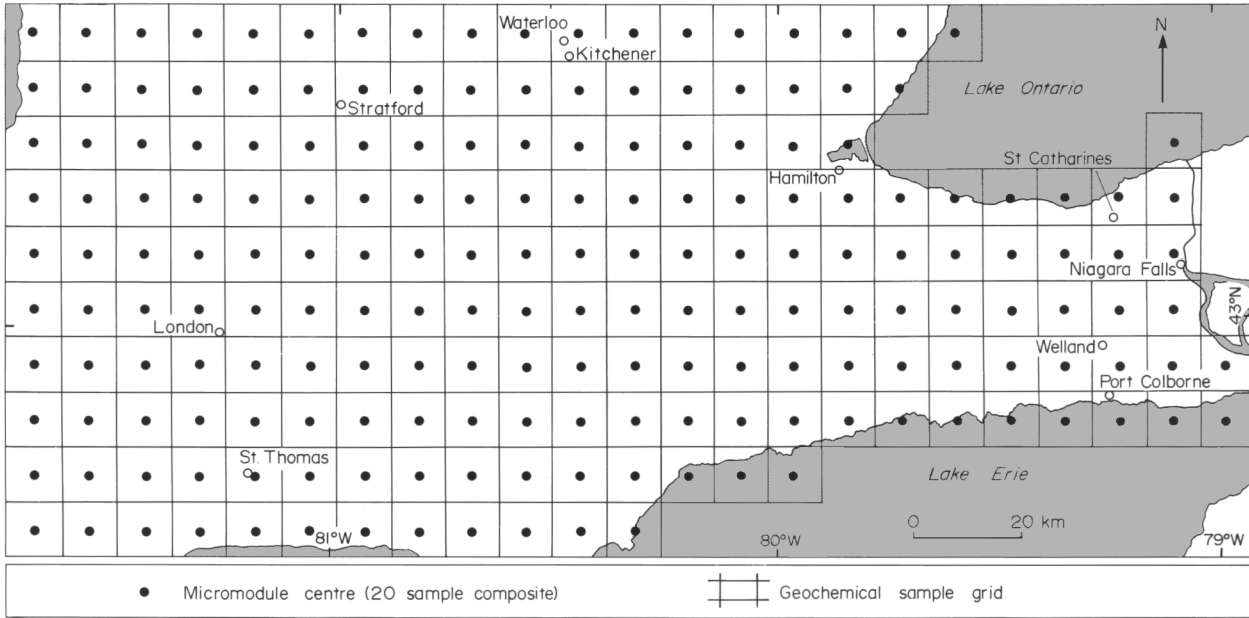
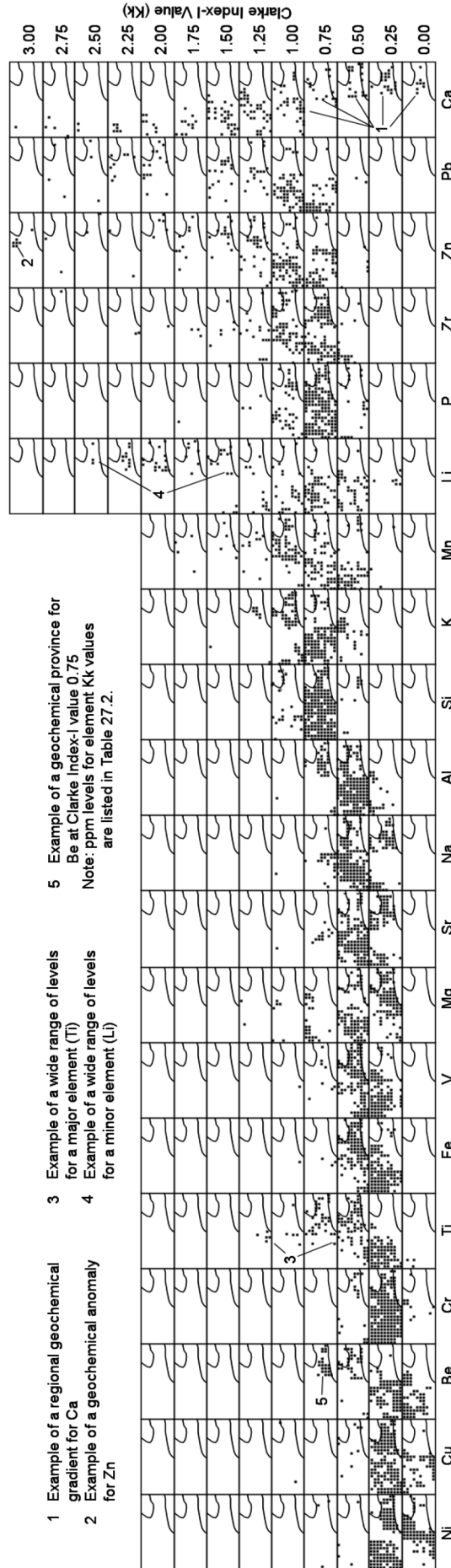


Figure 27.12d and e. The Southwestern Ontario Geochemical Survey project area: **d)** map overprinted with the micromodule (20 sample) composite boundaries; and **e)** map overprinted with micromodule quarter (5 sample) composite boundaries. One micromodule consists of an area of 10 by 10 km and one micromodule quarter consists of an area of 5 by 5 km. For a more detailed explanation see text (modified from Fortescue 1983a, 1984a).



- 1 Example of a regional geochemical gradient for Ca
- 2 Example of a geochemical anomaly for Zn
- 3 Example of a wide range of levels for a major element (Ti)
- 4 Example of a wide range of levels for a minor element (Li)
- 5 Example of a geochemical province for Be at Clarke Index-I value 0.75
Note: ppm levels for element Kk values are listed in Table 27.2.

Figure 27.13. Composite scan sheet summarizing regional geochemical patterns for 20 elements in over 4000 samples included in the Southwestern Ontario Geochemical Survey project (modified from Fortescue 1983a).

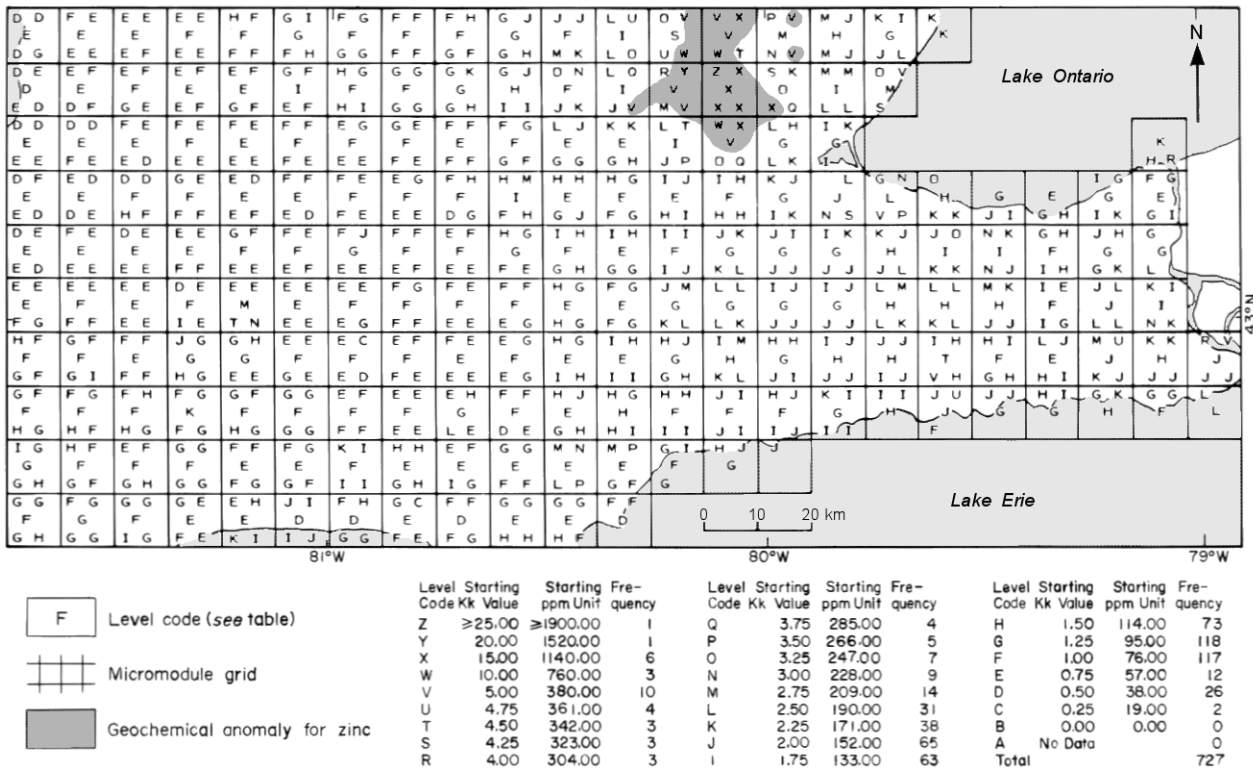


Figure 27.14. Map showing a regional geochemical anomaly for zinc in the Southwestern Ontario Geochemical Survey area. The accompanying table shows frequency distribution of zinc Clarke Index-I codes used in the preparation of the map (modified from Fortescue 1984a).

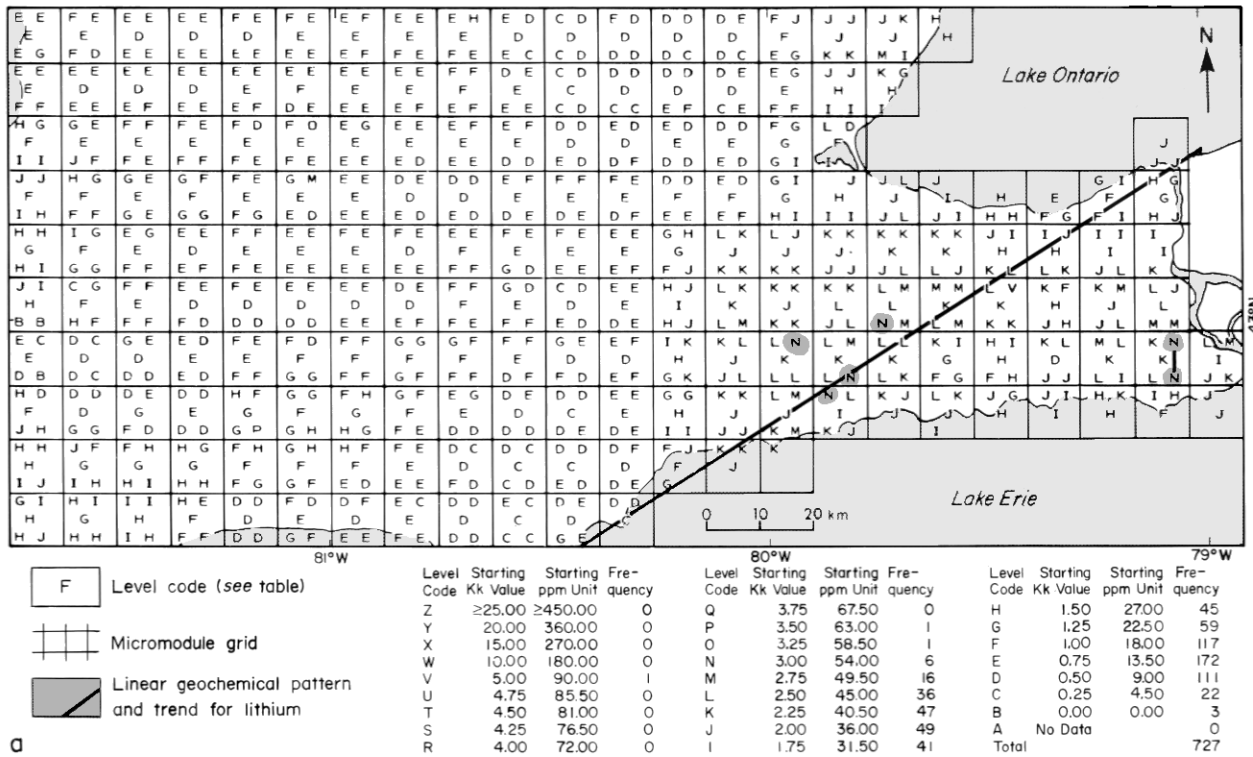


Figure 27.15a. The first in a series of 3 geochemical maps showing linear geochemical patterns and a geochemical province for lithium discovered in the Niagara Peninsula. Each map is accompanied by a table showing the frequency distribution of lithium Clarke Index-I codes (modified from Fortescue 1984a).

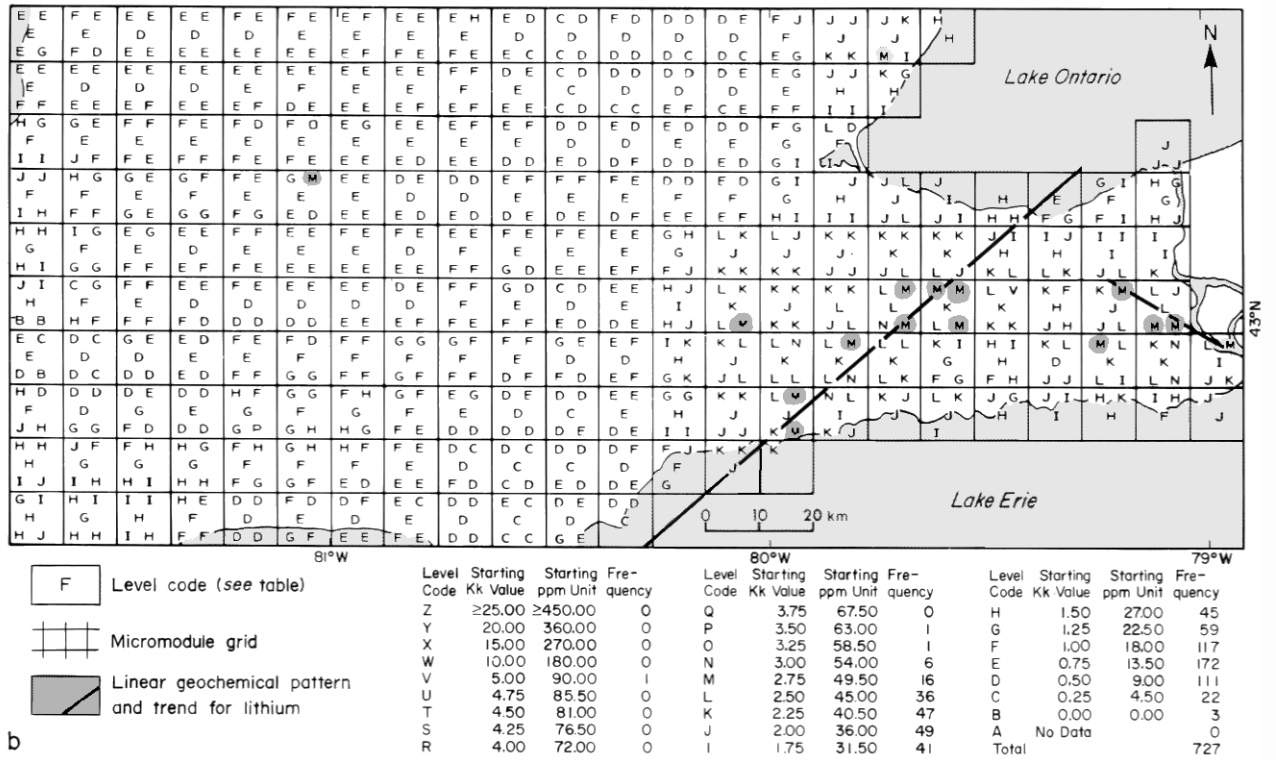


Figure 27.15b. The second in a series of 3 geochemical maps showing linear geochemical patterns and a geochemical province for lithium discovered in the Niagara Peninsula. Each map is accompanied by a table showing the frequency distribution of lithium Clarke Index-I codes (modified from Fortescue 1984a).

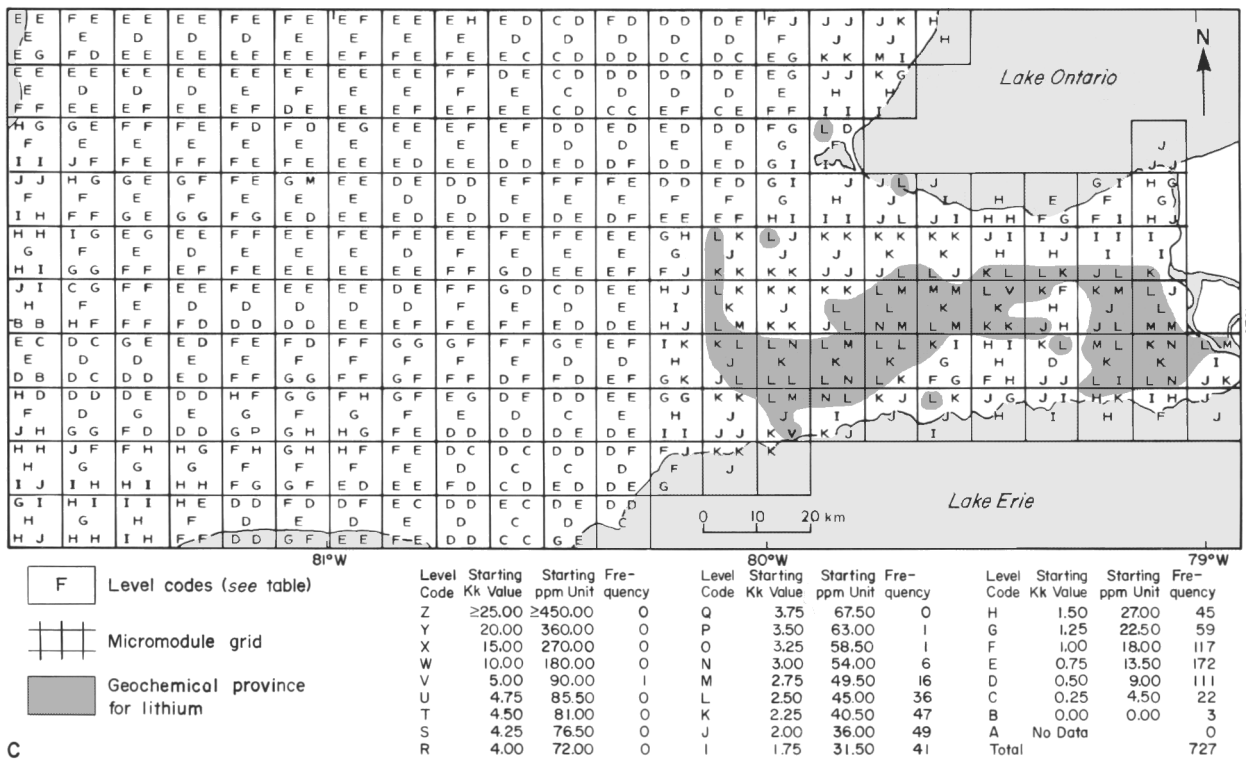
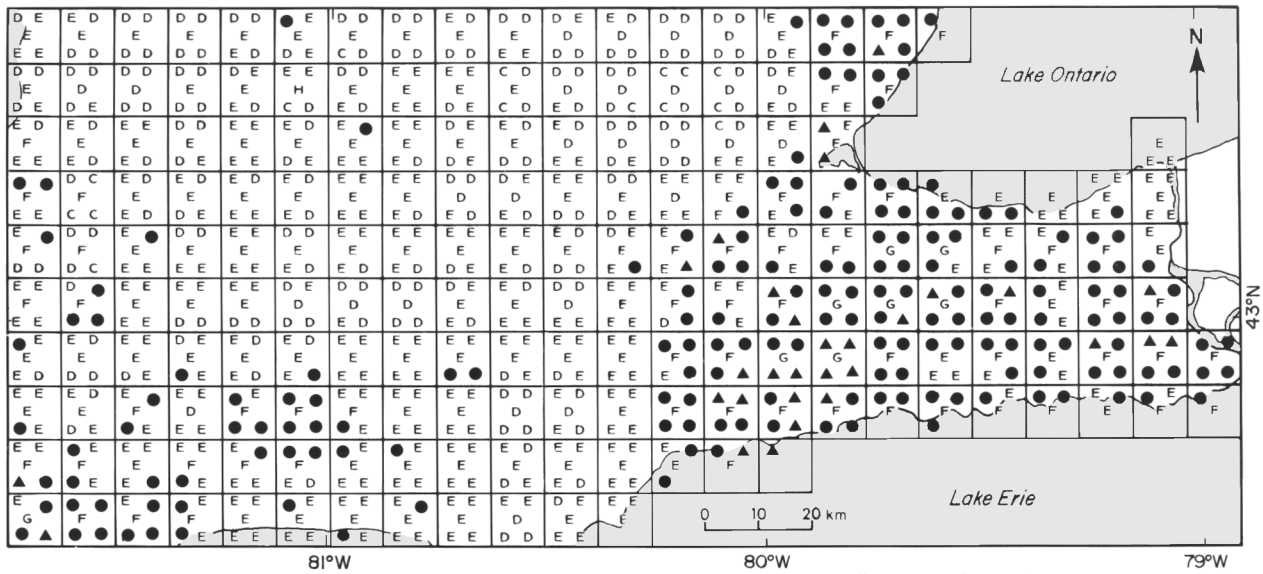


Figure 27.15c. The third in a series of 3 geochemical maps showing linear geochemical patterns and a geochemical province for lithium discovered in the Niagara Peninsula. The map is accompanied by a table showing the frequency distribution of lithium Clarke Index-I codes (modified from Fortescue 1984a).



F Level code (see table)

Micromodule grid

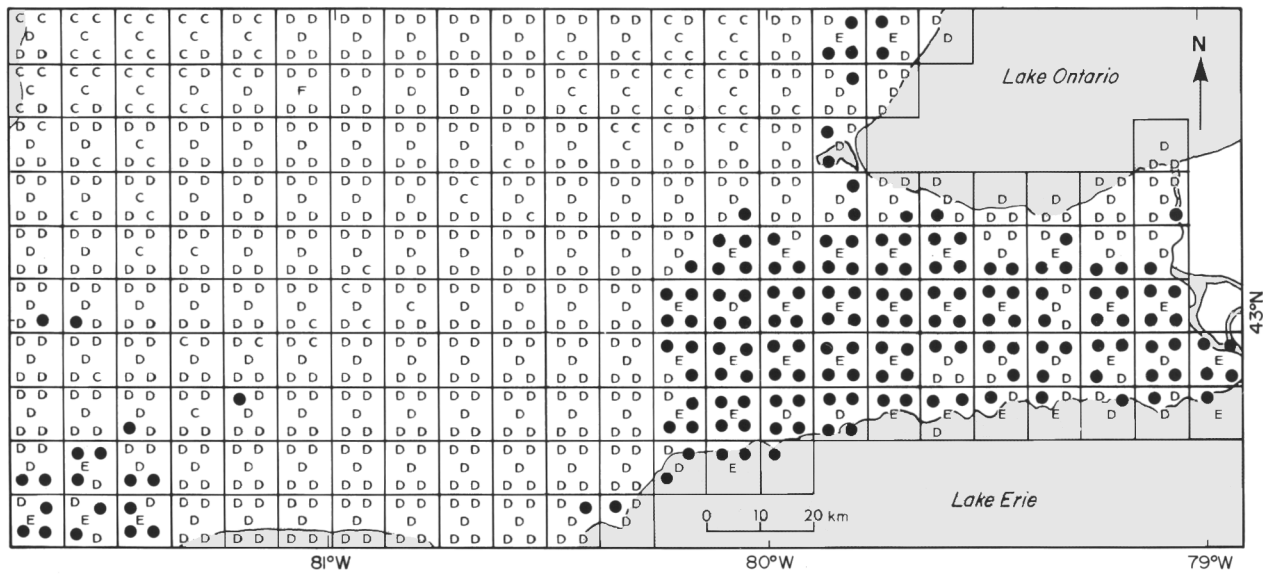
Geochemical anomaly for level code F

Geochemical anomaly for level code G

Frequency distribution of potassium

Level Code	Starting Kk Value	Starting ppm Unit	Frequency	Phase II Symbols
H	1.50	27 600.00	0	
G	1.25	23 000.00	30	▲
F	1.00	18 400.00	184	●
E	0.75	13 800.00	312	
D	0.50	9 200.00	186	
C	0.25	4 600.00	15	
B	0.00	0.00	0	
A	No Data		0	
Total			727	

a



F Level code (see table)

Micromodule grid

Geochemical anomaly (level codes F, E)

Frequency distribution of aluminum

Level Code	Starting Kk Value	Starting ppm Unit	Frequency	Phase II Symbols
H	1.50	125 400.00	0	
G	1.25	104 500.00	0	
F	1.00	83 600.00	2	●
E	0.75	62 700.00	166	●
D	0.50	41 800.00	489	
C	0.25	20 900.00	70	
B	0.00	0.00	0	
A	No Data		0	
Total			727	

b

Figure 27.16a and b. Geochemical maps of the entire Southwestern Ontario Geochemical Survey area showing geochemical province patterns for: a) potassium (K); and b) aluminum (Al). Each map is accompanied by a table showing the frequency distribution of Clarke Index-I values for each element (modified from Fortescue 1984a).

(Saarnisto 1975). These cores, which are usually from 3 to 5 m long, extend from the bottom of a lake through the entire layer of organic sediment into the underlying mineral matter.

For example, Fortescue and Vida (1990a) described a cluster of 5 anomalous copper values in pre-*Ambrosia* short core samples from the Herman Lake regional geochemical survey (Figure 27.23). These cores were collected during the summer of 1987. In March 1988, using the vibrocoring drilling technique described by Fortescue (1988b), a long lake sediment core was taken at one of these points (core 24J is indicated by an arrow on Figure 27.23).

Table 27.5 lists, in full, the data for lanthanum, copper, molybdenum, gold and arsenic in long core 24J. The 1987 copper geochemical anomaly is verified by this data. Also, the 5 high copper values actually extend to the bottom of the organic layer. The copper anomaly does not continue into the underlying mineral matter. This suggests that the source of the geochemical anomaly is not in the immediate vicinity of the drill hole. Table 27.5 also shows enhanced values for molybdenum, gold and arsenic in the lower organic part of the core. Like all long cores examined so far, core 24J has a marked enrichment of copper near the base of the organic layer. This is probably associated with an increase in *Betula*

pollen (Fortescue 1986). At the time of writing, the lanthanum pattern in core 24J had not been explained.

SUMMARY

Long cores are certainly the most effective of the 4 approaches to pre-*Ambrosia* lake sediment data verification. Long cores verify the location of geochemical anomalies and provide information on the duration of element input into sediments at a drill site.

Environmental Geochemistry Research

Between 1980 and 1987, the OGS supported a small research program in environmental geochemistry (Fortescue et al. 1981; Fortescue, Dickman et al. 1984; Fortescue 1984b, 1986; Fortescue and Stahl 1987a, 1987b). Initially, the aim of the program was to investigate the relationships between geochemical mapping and effects of the acid rain in the Wawa area. Experience gained from this environmental geochemistry research contributed substantially to the development of the lake sediment regional geochemical mapping methodology (see Figure 27.6). For this reason, some additional results of the environmental research are summarized here.

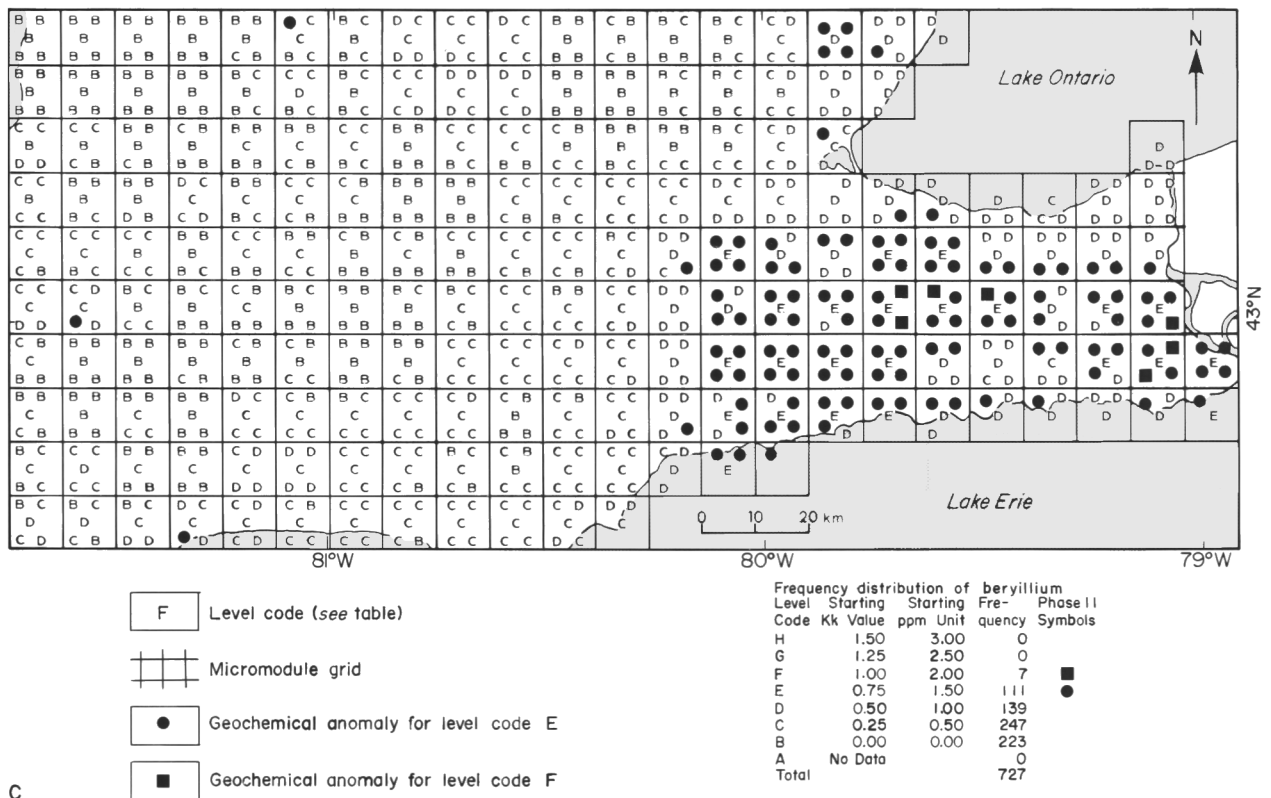


Figure 27.16c. Geochemical maps of the entire Southwestern Ontario Geochemical Survey area showing geochemical province patterns for beryllium (Be). The map is accompanied by a table showing the frequency distribution of Clarke Index-I values for each element (modified from Fortescue 1984a).

WATER GEOCHEMISTRY ALONG A pH GRADIENT NEAR WAWA

The first experiment in the environmental program was a comparative study of the water geochemistry in a series of 20 lakes. The lakes were located at ~5 km intervals along a sampling strip, 100 (northeast-southwest) by 10 km (northwest-southeast), positioned west of Wawa and the Herman Lake map area (see Figure 27.17). The sampling strip was selected on the basis of pH data obtained from a prior reconnaissance level geochemical survey completed in 1978 (OGS-GSC 1979). The sampling strip was chosen to include 20 lakes within a pH range from 4.5 to 8.0 (Figure 27.24; Fortescue et al. 1981; Fortescue 1984b).

It was concluded from this study that: 1) the pattern of pH variation in the 20 lakes was almost identical from year to year (Fortescue 1984b); and 2) the pH of the 20 lakes was governed by a combination of the geochemistry of the bed-rock and Quaternary deposits in their catchment areas.

Both results are important from the viewpoint of regional geochemical mapping. The former, because it indicated pH patterns on adjacent geochemical map sheets (compiled during a multiyear geochemical mapping program) would be realistic; and the latter, because it indicated that in the Wawa area, the geological setting of lakes would likely overprint lakewater pH patterns that were due to acid rain.

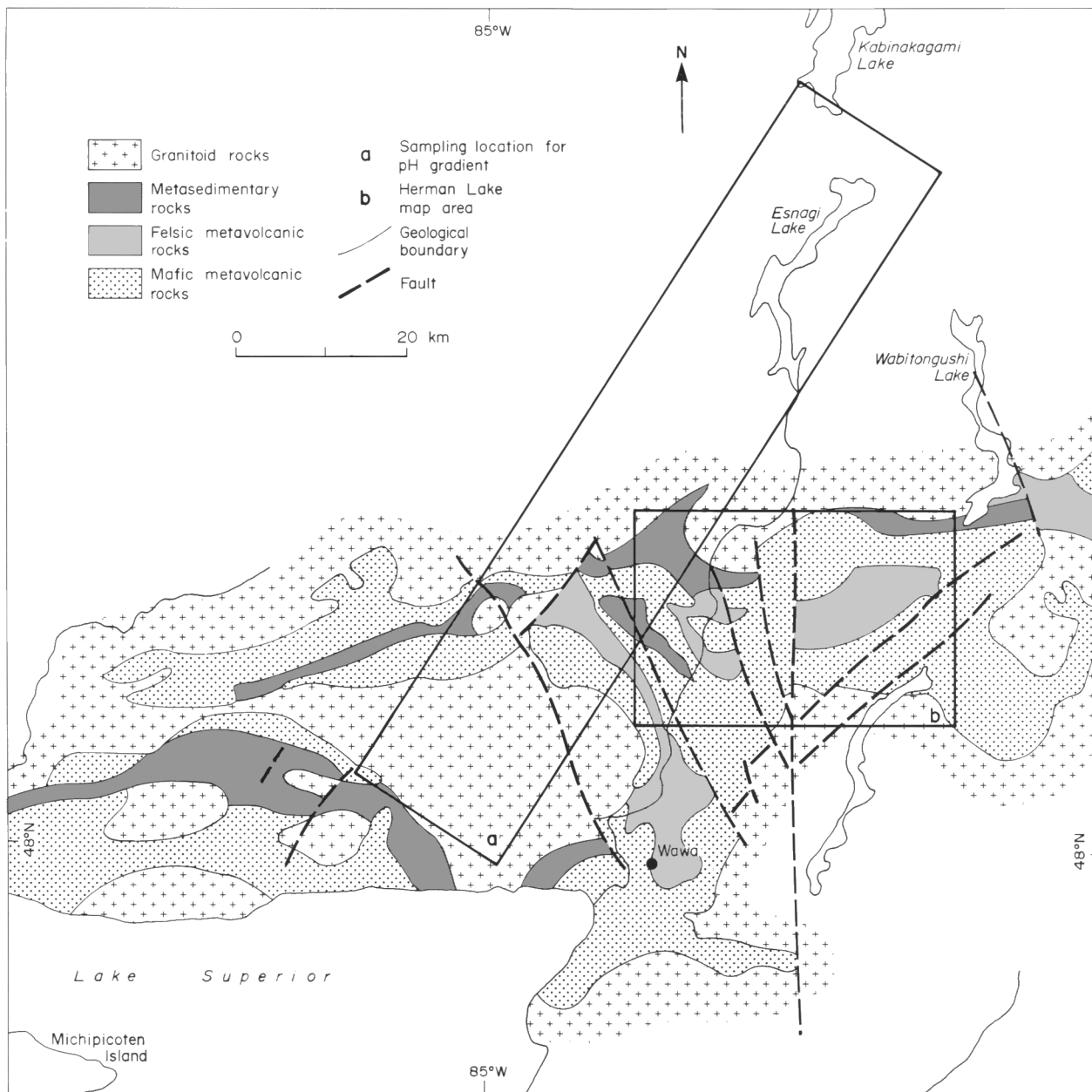
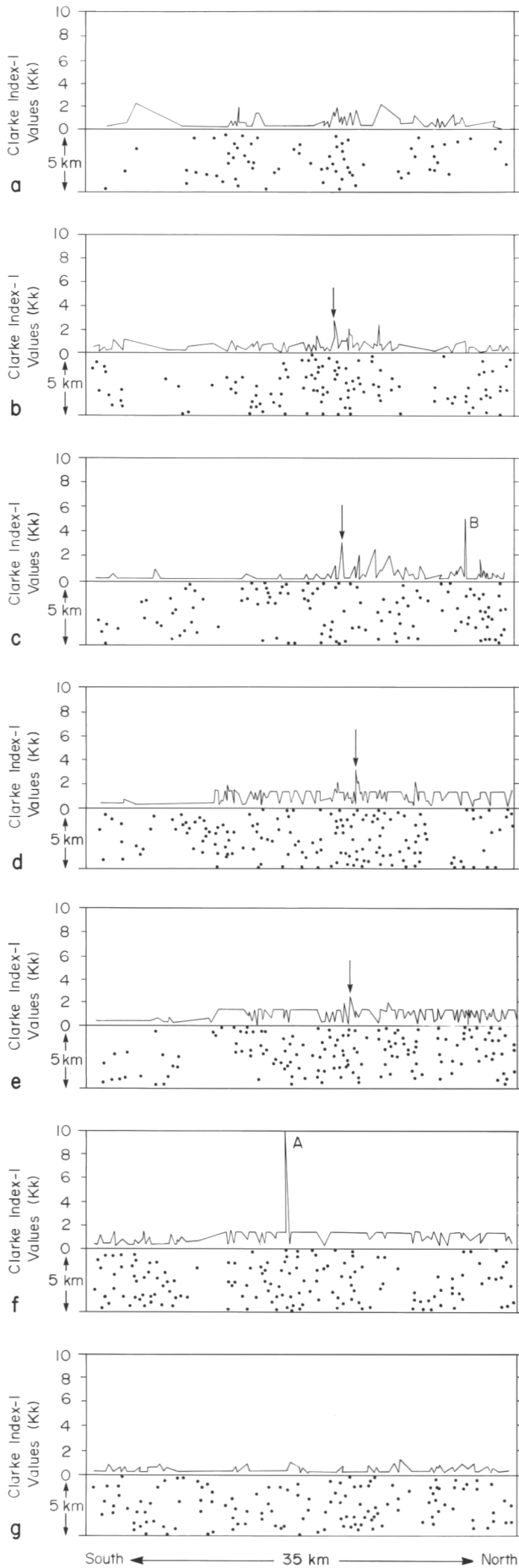


Figure 27.17. Generalized geological map of the Michipicoten greenstone belt near Wawa showing: **a**) the location of the pH gradient selected for the acid rain research; and **b**) the extent of the Herman Lake regional geochemical map area (modified from Fortescue and Vida 1990a).



DETERMINATION OF THE pH HISTORY OF WAWA AREA LAKES

The limnologist in the OGS interdisciplinary environmental geochemistry research team was Professor Dickman, of the Department of Biological Sciences at Brock University, St. Catharines, Ontario. During the acid rain research project, Dickman and his student researchers developed a standardized approach for the description of pH history of Wawa area lakes for the past 100 years (Dickman and Fortescue 1984, 1991; Fortescue, Dickman et al. 1984).

The standardized method was based on the detailed study of diatom remains in 1 cm sections of lake sediment cores 20 to 25 cm long. To estimate the pH of a particular core section, pH-sensitive diatoms were identified and population statistics obtained and combined; the result was then related to a working curve. The working curve was based on similar measurements of diatom floras taken from the bottom of lakes of known pH. Examples of graphs for the “diatom inferred pH” history of lakes during the past 100 years (based on this methodology) are provided for the Wawa area (Fortescue 1984b) and the Sudbury area (Dickman and Fortescue 1984).

This research showed that lakes and ponds in central Ontario may become acid due to: 1) a natural accumulation of humic acids; 2) forest fires in catchments (which change the pH of waters for a relatively short time); 3) chemical fallout from nearby smelters; and 4) non-point smelter fallout of acid rain derived from a distant source. It was noted that acid rain has the most drastic effect on nutrient-poor lakes which are usually located in catchments underlain by quartzites (Dickman and Fortescue 1984).

This research aided the development of regional geochemical mapping in several important ways: 1) it led to the development of a simple, rapid and reliable lake sediment core sampler (Fortescue 1988a); 2) it provided detailed information on the depth of the *Ambrosia* pollen rise in central Ontario lakes, leading to the standardization of pre-*Ambrosia* sediment as a sample medium for geochemical mapping; 3) it was shown that subsequent to the deposition of the sediment, no significant vertical movement of elements occurs in organic lake sediments, indicating that pre-*Ambrosia* material could be used with confidence to map pre-anthropogenic geochemical patterns; and 4) it was shown (Fortescue, Dickman et al. 1984; Fortescue 1988a) that in spite of bioturbation by small organisms, a lake sediment core can be dated using: a) pollen (e.g., the *Ambrosia* rise); and b) radio-isotopes (^{210}Pb , ^{137}Cs etc.).

SUMMARY

The acid rain environmental geochemistry program made substantial contributions towards the choice of

Figure 27.18. Geochemical section diagrams showing a linear geochemical province for gold in the Trout Lake regional geochemical map area. Unexplained isolated high gold values also occur at A and B. The black dots at the base of each section represent sample site locations. See Figure 27.8 for a map showing the location and general geology of the Trout Lake study area (modified from Fortescue and Vida 1989).

pre-*Ambrosia* lake sediment as a medium for regional geochemical mapping by the OGS.

The Use of Lake Sediments in Environmental Geochemistry

Simultaneous pre- and post-*Ambrosia* sampling during geochemical mapping is feasible using the lake sediment core sampling technique just discussed. If the 2 samples (i.e., pre- and post-*Ambrosia*) from each lake sediment core are analyzed separately, using identical methodologies (see Figure 27.6), the resulting element maps provide information on pre- and post-anthropogenic geochemical patterns similar to those described previously (see Figure 27.5).

The Herman Lake regional geochemical map area (Fortescue and Vida 1990a) is located in the Michipicoten greenstone belt some 40 km northeast of Wawa (see Figure 27.17). The Herman Lake regional geochemical map is a 1000 km² area, located 40 km downwind from the Wawa sintering plant—a point source of chemical fallout.

During the Herman Lake geochemical survey, 742 pre-*Ambrosia*, and 1 post-*Ambrosia* lake sediment cores were collected. Both sets of lake sediment samples were analyzed for 35 elements using the methodology summarized in Figure 27.6. The resulting geochemical data were used to prepare pre- and post-*Ambrosia* based regional geochemical maps for: 1) manganese and copper (control elements); 2) lead (non-point source pollution); 3) arsenic and antimony (point source pollution from the Wawa sintering plant); and 4) gold (element associated with prospecting and mining activity). These are shown in Figure 27.25 (Fortescue and Vida, in prep.).

Each of these geochemical maps includes: 1) an outline of the bedrock geology of the area; 2) lake sediment sample sites (small dots); and 3) lake sediment sample sites with values greater than or equal to an arbitrary threshold selected to display an anthropogenic pattern (large dots).

Briefly, the copper and manganese patterns were similar for both maps in each set. The pattern for the post-*Ambrosia* lead map (see Figure 27.25c) clearly shows an increased lead level due to atmospheric fallout from a non-point source. Post-*Ambrosia* patterns for arsenic and antimony are due to anthropogenic fallout of these elements from a point source (i.e., the Wawa sintering plant). Note that both these pre-*Ambrosia* element patterns include a geochemical province along the southern margin of the map. The post-*Ambrosia* pattern for gold shows 2 types of anthropogenic patterns (A and B) both associated with mining activity (see Figure 27.25f). The high post-*Ambrosia* gold values in the top right centre of the map (area A) are due to

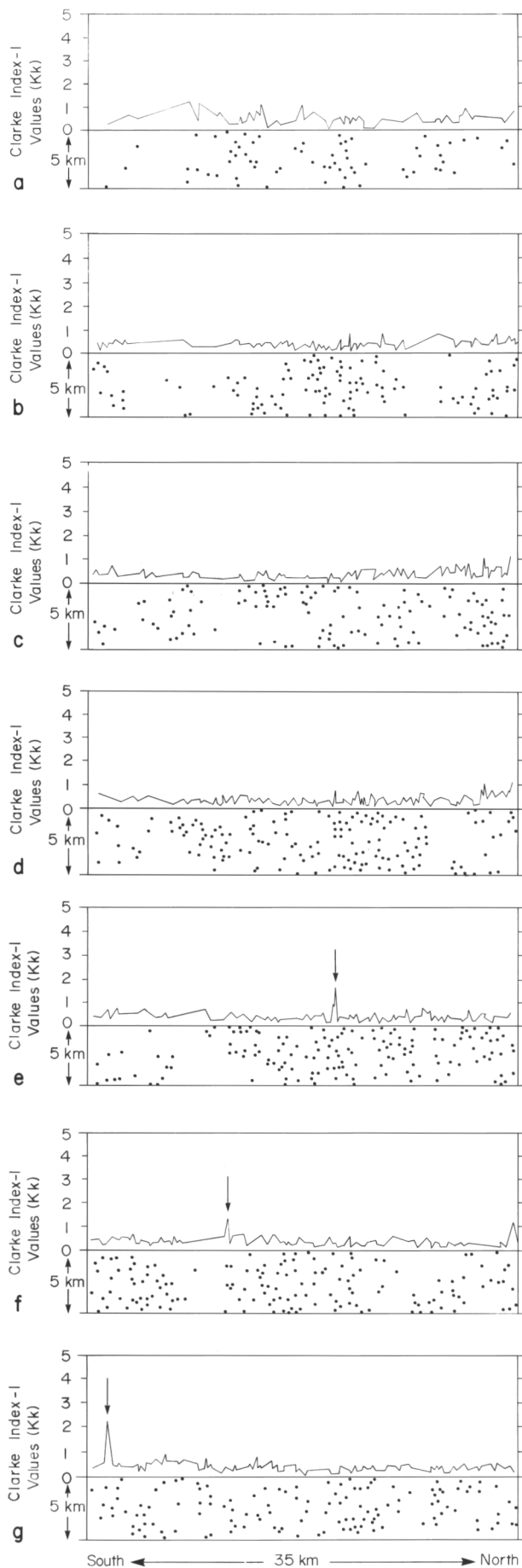


Figure 27.19. Geochemical section diagrams showing a linear geochemical province for thorium in the Trout Lake regional geochemical map area. The black dots at the base of each section represent sample site locations. See Figure 27.8 for a map showing the location and general geology of the Trout Lake study area (modified from Fortescue and Vida 1989).

surface disturbance of the landscape during recent prospecting activity. The area marked B is the site of an abandoned gold mine where tailings have contaminated lakes with small amounts of gold.

SUMMARY

A regional geochemical mapping methodology based on separate pre- and post-*Ambrosia* based maps was demonstrated for the first time in the Wawa area. The map pairs are of interest in modern environmental geochemistry because they map: 1) effects of anthropogenic fallout; 2) contamination of the environment by mining activity; and 3) pre-anthropogenic patterns of interest in mineral resource appraisal and, possibly, forest nutrition.

PART V: DISCUSSION AND CONCLUSIONS

General Discussion

Part I of this chapter introduced regional geochemical mapping and its role in the mineral resource appraisal process. This was followed by a description of how the geochemical data can be incorporated into a

geoscience-oriented Geographic Information System. Part I also stressed the role played by regional geochemical mapping in the current Ontario Geological Survey approach to mineral resource appraisal of Ontario.

At the time of writing, the OGS regional geochemical mapping program is still being developed. For example, it is expected that the number of elements determined in each sample will rise from 35 to around 60 elements in the near future (Table 27.6). As experience is gained with the interpretation of geochemical map patterns for the new elements, the importance of the geochemical mapping component in an Ontario Geological Survey Geographic Information System should increase rapidly. When a similar situation occurred in the British Geological Survey some years ago, it led the British Geological Survey to officially recognize that geological, geophysical and geochemical maps are of equal importance in the mineral resource appraisal process (Jane Plant, British Geological Survey, personal communication, 1989).

Part II of this chapter described the process of regional geochemical mapping on the basis of 3 rules which currently guide the planning and interpretation of OGS regional geochemical maps. Examples taken from the OGS experience were used to illustrate the application of each rule. Major types of geochemical patterns currently

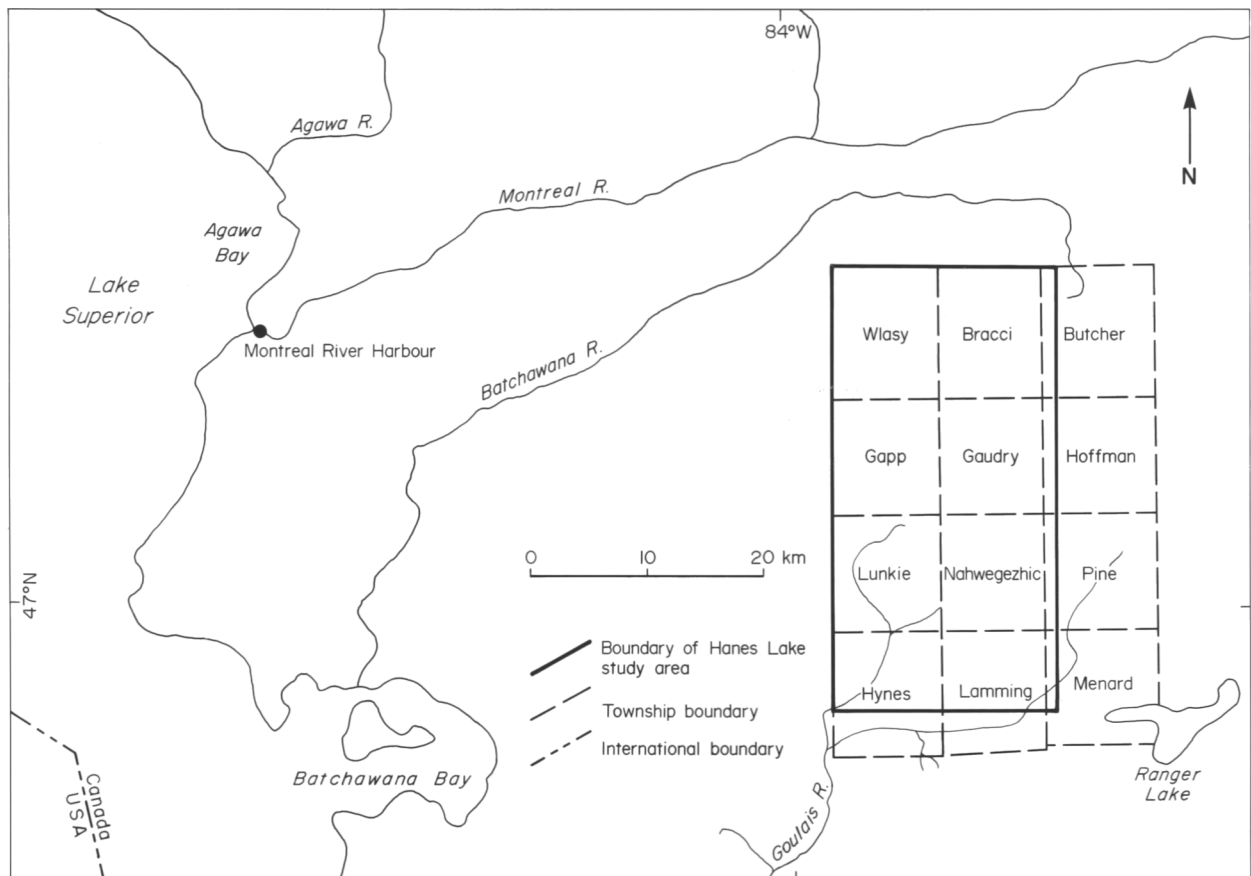
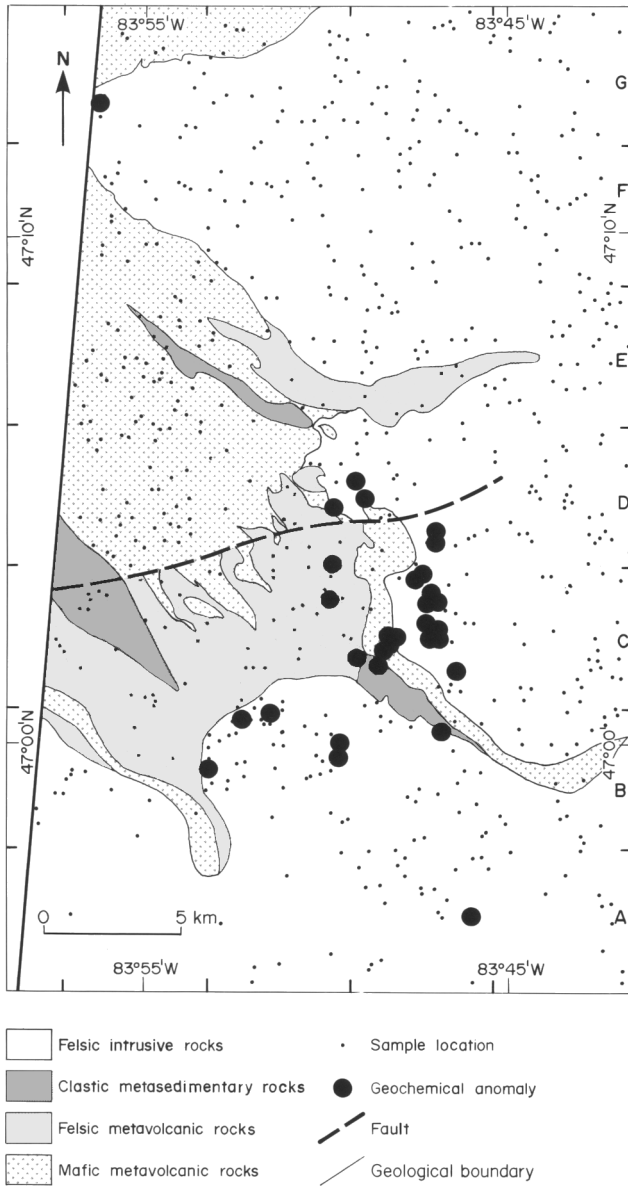


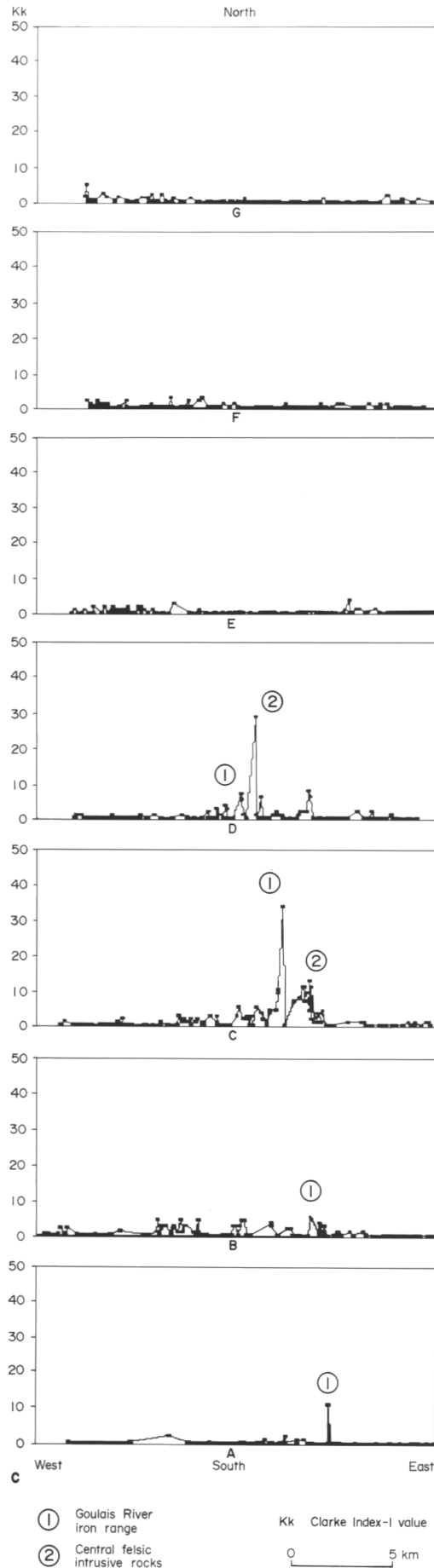
Figure 27.20a. Map showing the location of the Hanes Lake map area (modified from Fortescue and Vida 1990b).



b

Figure 27.20b. Map showing the location of geochemical sample sites and anomalies with respect to general geology of the Hanes Lake area. Geochemical anomalies represent Clarke Index-I values greater than or equal to 5.0 Kk for molybdenum (*modified from Fortescue and Vida 1990b*).

Figure 27.20c. Geochemical section diagrams showing combined molybdenum geochemical anomaly and province patterns in the Hanes Lake area. The sections are lettered to correspond with the appropriate area of the map in part b (*modified from Fortescue and Vida 1990b*).



c

identified on OGS regional geochemical maps were also described in this part of the chapter.

In Part III, results from the 3 approaches to regional geochemical mapping developed by the OGS during the 1980s were described. The first approach used basal till as a sample medium. This approach was developed between 1978 and 1982 in the KLIP (i.e., Kirkland Lake) area where there is deep, complex and continuous overburden. It was concluded that, although this approach was effective for geochemical mapping at the local scale, it was too impractical at the regional scale because of: 1) the complexity of Quaternary stratigraphy; 2) the unevenness of the bedrock surface; and 3) the difficulty (and high cost) of drill access in remote areas.

During the Southwestern Ontario Geochemical Survey program (1981 to 1983), successful regional geochemical maps of southwestern Ontario based on stream sediment

were prepared. Important geochemical patterns in the survey data were described using composited data derived from 5 by 5 km or 10 by 10 km areas. This procedure produced strong and clear geochemical province and anomaly patterns for each of the 20 elements included in this survey. Most of these patterns could be explained in relation to the geology of the area and some by anthropogenic activity.

Since 1986, OGS geochemical mapping based on lake sediment core and water sampling has been successfully developed for use in areas of the Canadian Shield. This approach to regional geochemical mapping has proven to be a reliable, effective and economical component of the OGS mineral resource appraisal process.

Unfortunately, regional geochemical mapping based on stream or lake sediments cannot be completed in all of the areas where high mineral potential occurs in the province. For this reason, additional approaches to regional

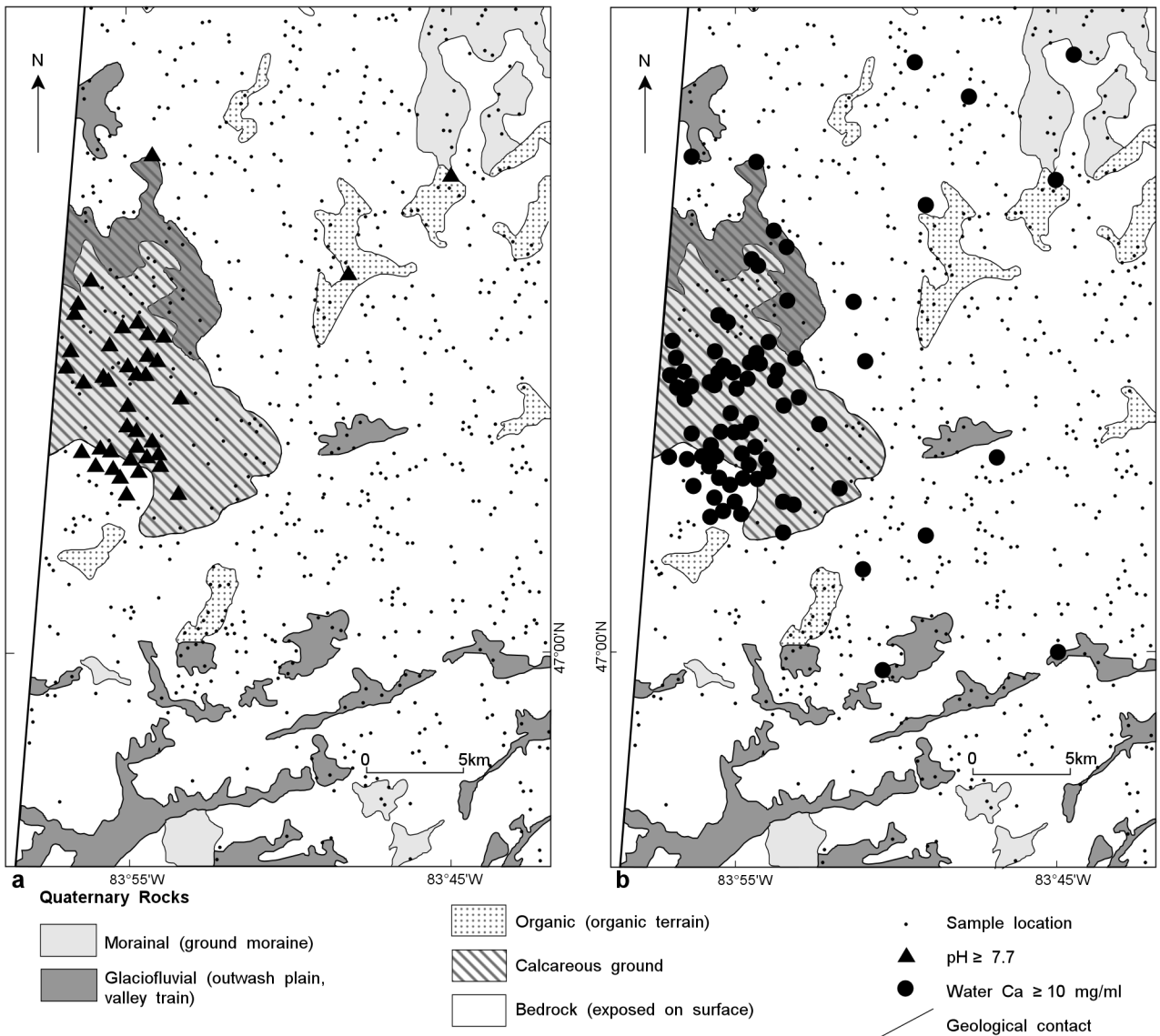


Figure 27.21. Quaternary geological maps of the Hanes Lake area showing: **a)** water pH values equal to or above 7.7, shown by large triangles; and **b)** water Ca values equal, or greater than 10 mg/ml, shown by large dots (*modified from Fortescue and Vida 1990b*).

geochemical mapping designed for 1) organic terrain, 2) areas of marl lakes and 3) areas of complex terrain (which need multimedia sampling), require development in the near future.

In general, the results of regional geochemical surveys presented in this chapter provide an introduction to the current state of the art in this type of mapping. It was not possible to include in this chapter examples of the presentation of regional geochemical map data using a GIS.

Part IV described 4 approaches to geochemical data verification methodologies and their viability. Some OGS environmental geochemistry research was then reviewed. Results show how it has aided in the development of modern regional geochemical mapping. This part ended with a discussion of the use of lake sediments in environmental geochemistry. Pre- and post-anthropogenic geochemical maps of the Herman Lake area (near Wawa) were chosen as an example of this trend. Because of the increased awareness of the importance of environmental geochemistry in Canada, this aspect of geochemical mapping is likely to increase in importance in the near future.

Some Recent Developments in Geochemical Mapping

To conclude this chapter, it is appropriate to refer to a few of the new developments in geochemical mapping worldwide.

THE GEOCHEMICAL SCOPE OF REGIONAL MAPPING

A total of 35 elements are currently included in OGS regional geochemical mapping (Fortescue and Vida 1989, 1990a, 1990b, 1991a, 1991b). Until recently, there was no international consensus among geochemists on the number of elements required for inclusion in geochemical maps. In 1990, this changed when Darnley (1990) and Xuejing (1990) stressed the importance of including 60 to 70 elements in global geochemical mapping. Many of the additional elements, for example, the Rare Earth Elements (REE), are now considered to be essential for mineral resource appraisal purposes, while other elements, such as iodine and selenium, are required for environmental geochemistry (see Table 27.6).

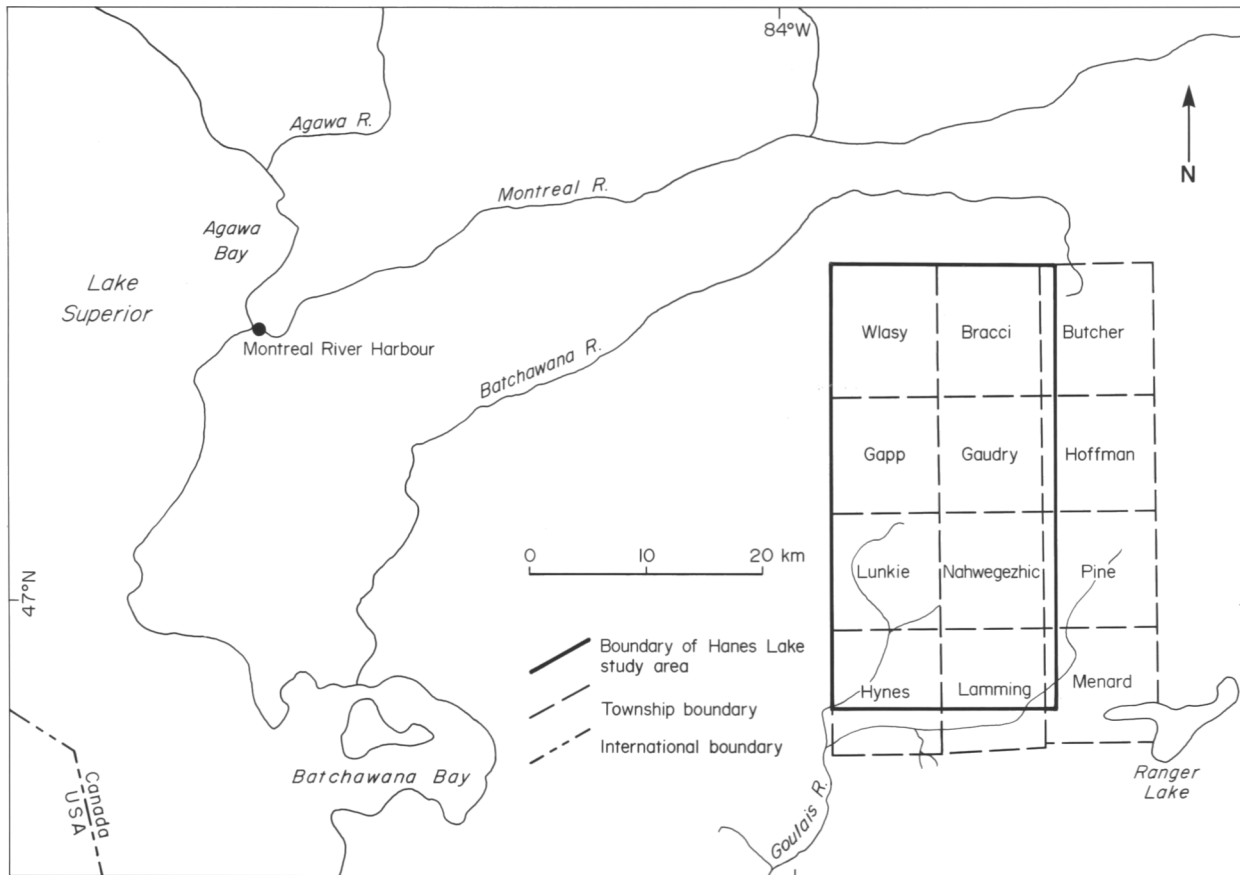
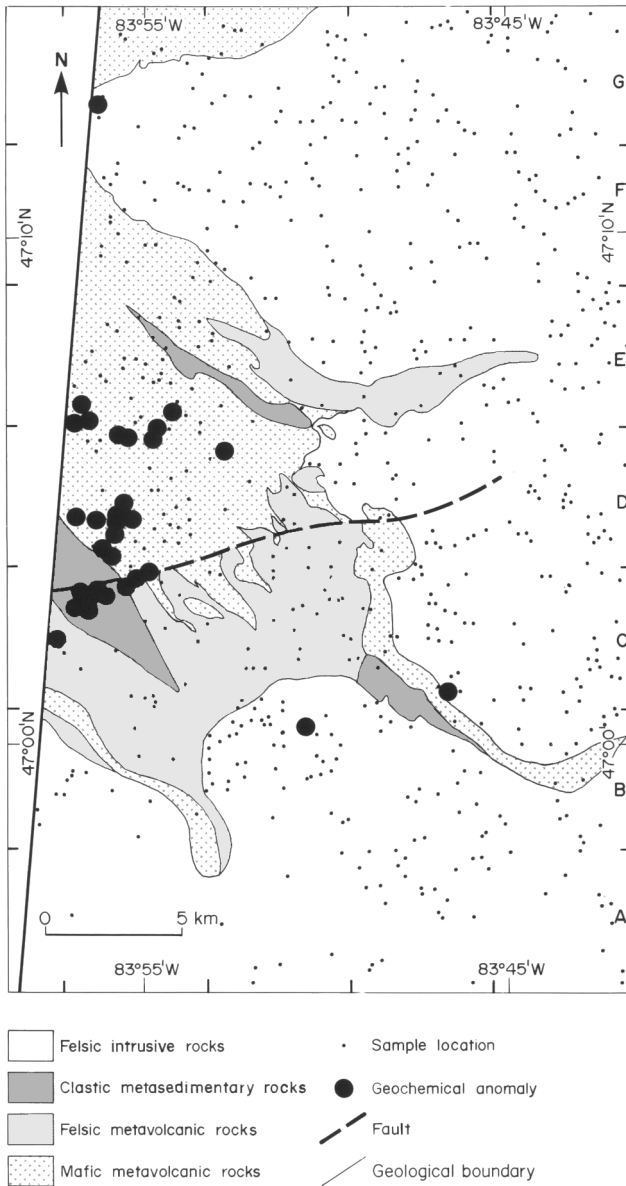


Figure 27.22a. Map showing the location of the Hanes Lake study area. (modified from Fortescue and Vida 1990b).



b

Figure 27.22b. Map showing the location of geochemical sample sites and anomalies with respect to general geology of the Hanes Lake map area. Geochemical anomalies represent Clarke Index-I values greater than or equal to 2.0 Kk for arsenic (*modified from Fortescue and Vida 1990b*).

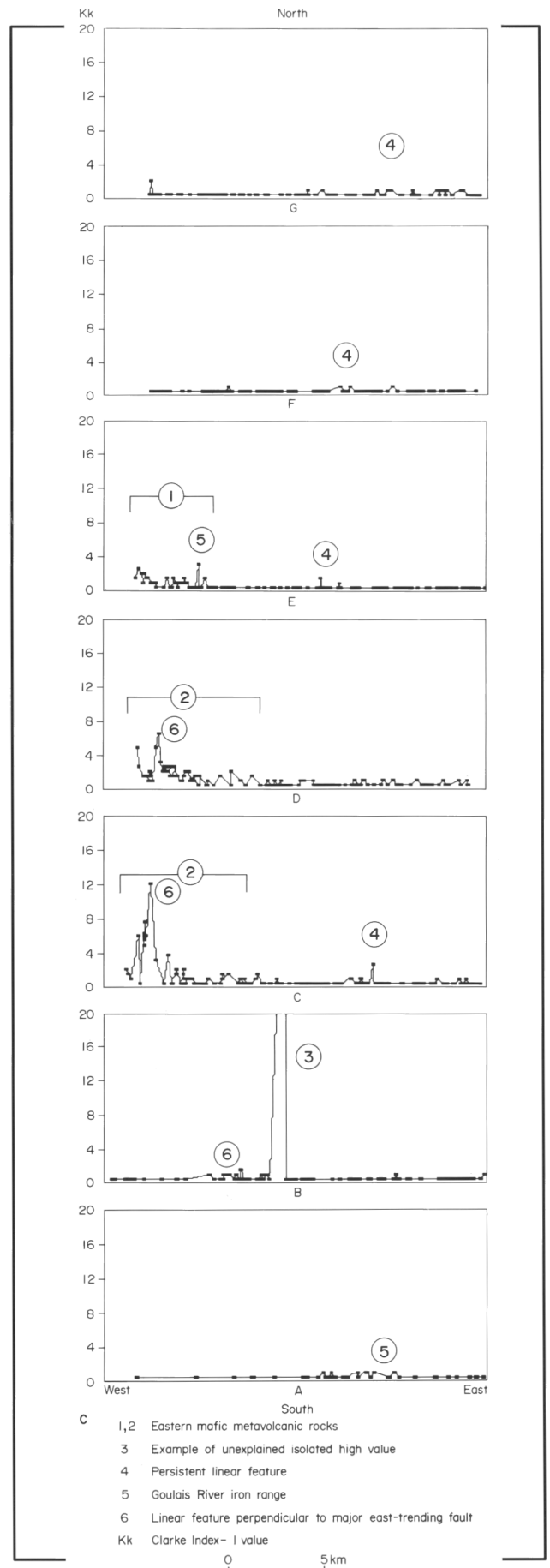


Figure 27.22c. Geochemical section diagrams showing a geochemical province pattern for arsenic in the Hanes Lake area. The sections are lettered to correspond with the appropriate area of the map in part b (*modified from Fortescue and Vida 1990b*).

Table 27.4. Geochemical data obtained from field verification of a pre-Ambrosia geochemical anomaly in the Trout Lake geochemical map area.

Element	Order	Datum _n	Datum _k (GDS)	EG599 1988	X1054 1989	EG603 1988	X1055 1989	EG617 1988	X1056 1989
Mg	1	3000	0.07	0.03	0.03	0.03	0.03	0.04	0.04
Ti	2	3000	0.11	0.03	0.05	0.05	0.05	0.05	0.06
Mn	3	3000	0.12	0.25	0.21	0.05	0.05	0.04	0.04
Fe	4	3000	0.12	0.19	0.15	0.06	0.07	0.07	0.08
Na	5	3000	0.13	0.04	0.03	0.04	0.04	0.07	0.05
K	6	3000	0.15	0.05	0.07	0.06	0.08	0.08	0.09
Sr	7	3000	0.15	0.05	0.05	0.04	0.05	0.07	0.07
Ni	8	3000	0.16	0.24	0.20	0.33	0.36	0.39	0.39
Ca	9	3000	0.18	0.19	0.21	0.18	0.21	0.17	0.17
V	10	3000	0.18	0.18	0.16	0.08	0.09	0.09	0.09
Sc	11	3000	0.20	0.16	0.15	0.16	0.15	0.24	0.20
Co	12	3000	0.21	0.31	0.24	0.28	0.24	0.28	0.24
Cr	13	3000	0.22	0.11	0.07	0.11	0.08	0.15	0.12
Be	14	3000	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Al	15	3000	0.29	0.14	0.14	0.10	0.10	0.13	0.13
Lu	16	3000	0.37	0.19	0.19	0.19	0.19	0.37	0.37
Th	17	3000	0.37	0.25	0.20	0.25	0.23	0.25	0.36
Ba	18	3000	0.38	0.13	0.15	0.13	0.15	0.18	0.18
Cu	19	3000	0.49	1.85	2.01	1.88	2.07	3.76	4.13
Au	20	3000	0.50	0.25	0.25	0.25	0.25	0.25	0.25
Pb	21	3000	0.62	0.31	0.31	0.15	0.31	0.31	0.31
La	22	3000	0.69	0.38	0.20	0.29	0.17	0.55	0.35
Hf	23	3000	0.71	0.71	0.36	0.71	0.36	0.71	0.36
P	24	3000	0.72	1.16	1.13	0.35	0.42	0.29	0.28
U	25	2999	0.74	0.30	0.26	0.22	0.13	0.52	0.48
Mo	26	3000	0.83	0.83	0.83	0.83	0.83	1.67	0.83
Zn	27	3000	1.00	5.71	6.18	11.07	12.87	10.22	10.32
Sb	28	3000	1.00	1.00	1.00	1.00	0.50	1.00	0.50
As	29	3000	1.11	7.78	3.89	2.78	1.11	5.00	1.67
Ta	30	3000	1.18	1.18	0.59	1.18	0.59	1.18	0.59
W	31	3000	1.67	1.67	4.17	1.67	1.67	1.67	1.67
Br	32	3000	8.40	32.80	26.60	12.80	11.88	11.20	9.12

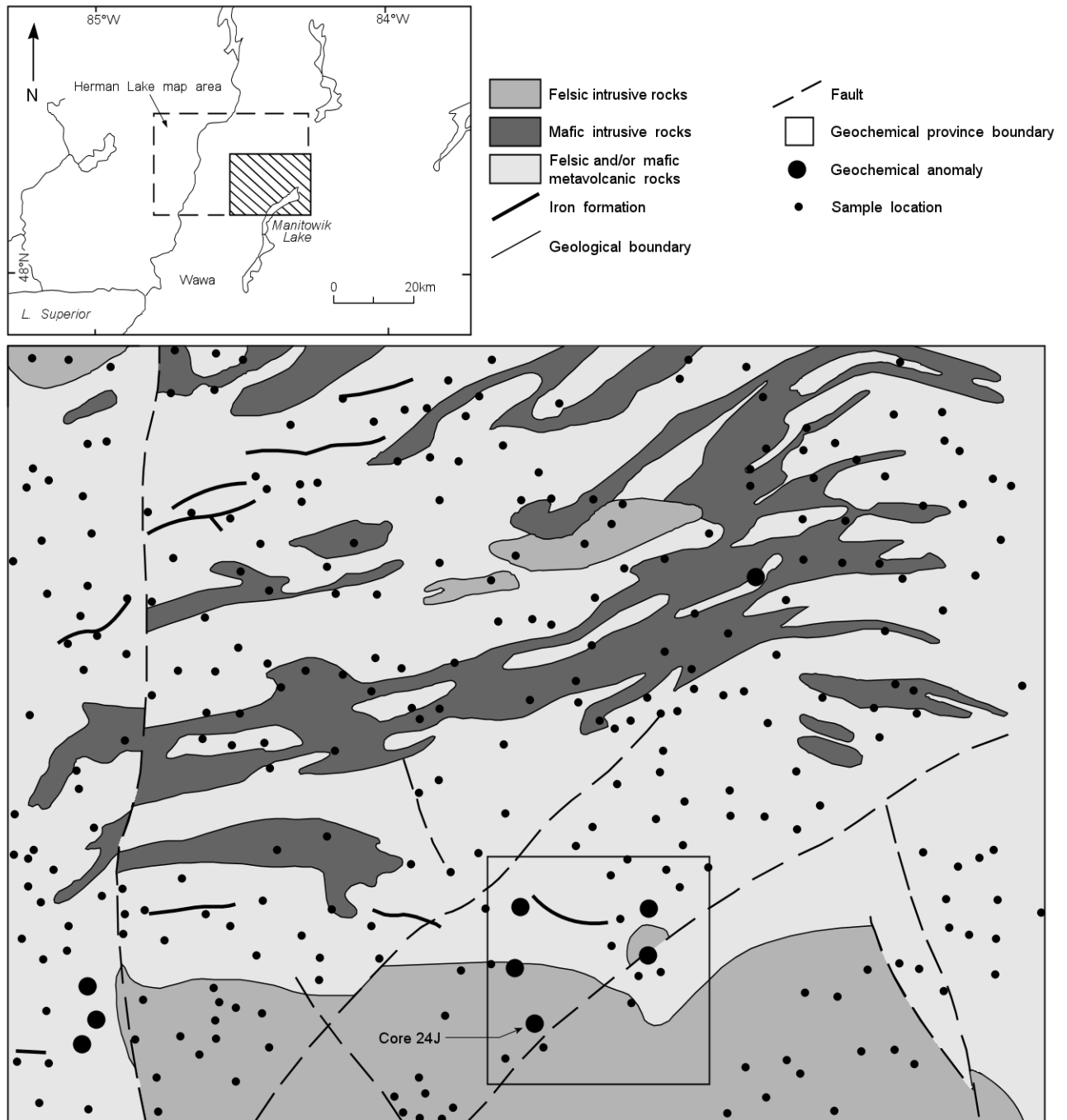


Figure 27.23. Map of part of the Herman Lake geochemical map area showing a geochemical province pattern for copper and the location of a pre-*Ambrosia* geochemical anomaly for copper which was verified by long-core drilling. Geochemical anomalies are represented by Clarke Index-I values greater than or equal to 2.0 for copper (modified from Fortescue and Vida 1990a).

Examples of organizations that are setting the new trend in geochemical mapping include: 1) the British Geological Survey, which listed 61 elements (excluding the REE) determined in groundwaters (Edmunds et al. 1989); 2) the Western European Geological Surveys (WEGS) planned for 70 elements to be routinely determined in 9000 overbank samples during a low density geochemical mapping project (Demetriades et al. 1990); and 3) the

International Geochemical Mapping Project scientists who require a minimum of 65 elements in global-scale geochemical mapping (Darnley and Garrett 1990).

Elements included in future geochemical mapping are usually divided into 5 groups (see Table 27.6). If it is practical, the OGS geochemical maps prepared in the future should include all elements listed in groups 1 to 4 of the table.

Table 27.5. Geochemical data obtained from verification of a pre-Ambrosia geochemical anomaly by long core drilling of a sample site in the Herman Lake area (modified from Fortescue 1988b).

Depth (inches)	LOI (%)	La (ppm)	Cu (ppm)	Mo (ppm)	Au (ppm)	As (ppm)
6	nss	74	196	4	<5	2
12	38.6	74	192	3	5	2
18	39.8	90	244	4	<5	2
24	42.8	97	272	4	<5	1
30	43.2	100	280	5	<5	1
36	42.6	100	284	5	<5	1
42	45.2	110	374	10	<5	1
48	36.8	106	412	19	<5	<1
54	42.2	94	474	25	<5	1
60	44.4	83	598	39	7	2
66	27.2	49	397	32	<5	2
72	34.6	54	521	40	<5	3
78	49.6	64	926	65	5	3
84	44.6	66	1335	46	11	5
90	55.0	58	1810	115	11	6
96*	20.4	30	673	64	5	4
102	1.4	16	66	13	<5	1
108	0.4	15	36	2	<5	2
114	0.2	12	53	1	<5	3
120	1.0	12	95	5	<5	1

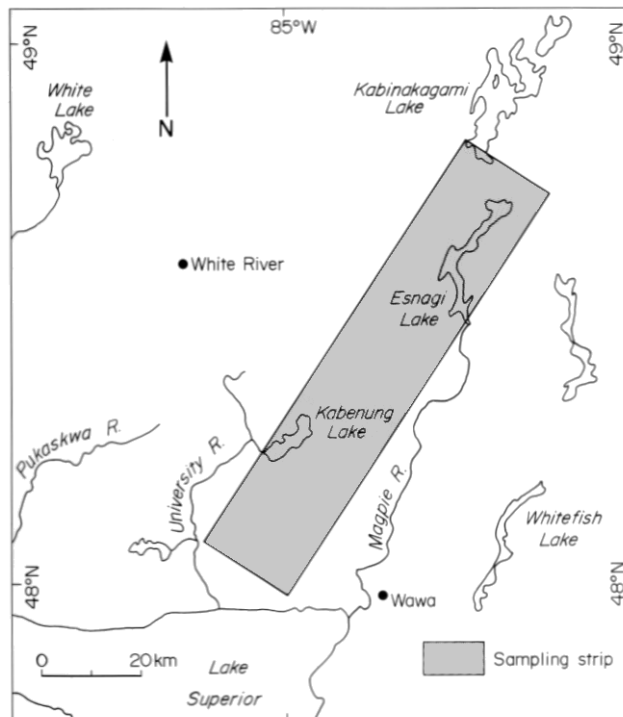
* Transition from organic to mineral matter.

LOI Loss on Ignition

nss Not sufficient sample

Table 27.6. Groups of elements included in regional geochemical mapping.

1. Major Elements (10):	Si, Al, Fe, Mg, Ca, Na, K, Mn, Ti and P
2. Minor Elements (20):	Cu, Pb, Zn, Ga, Cr, Ni, Co, V, Sr, Ba, Sc, Y, La, Nb, (S), (Cl), Th, Rb, U and Zr
3. Trace Elements (20):	As, Sb, Bi, Hg, Cd, Au, Ag, Se, Sn, W, Mo, B, F, Li, Be, Tl, In, Ge, Te and Ta
4. Rare Earth Elements (14):	Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu
5. Platinum Group Elements (6):	Pt, Pd, Ir, Rh, Ru and Os



a

Figure 27.24a. Map showing the location of the Wawa sampling strip (modified from Fortescue et al. 1981).

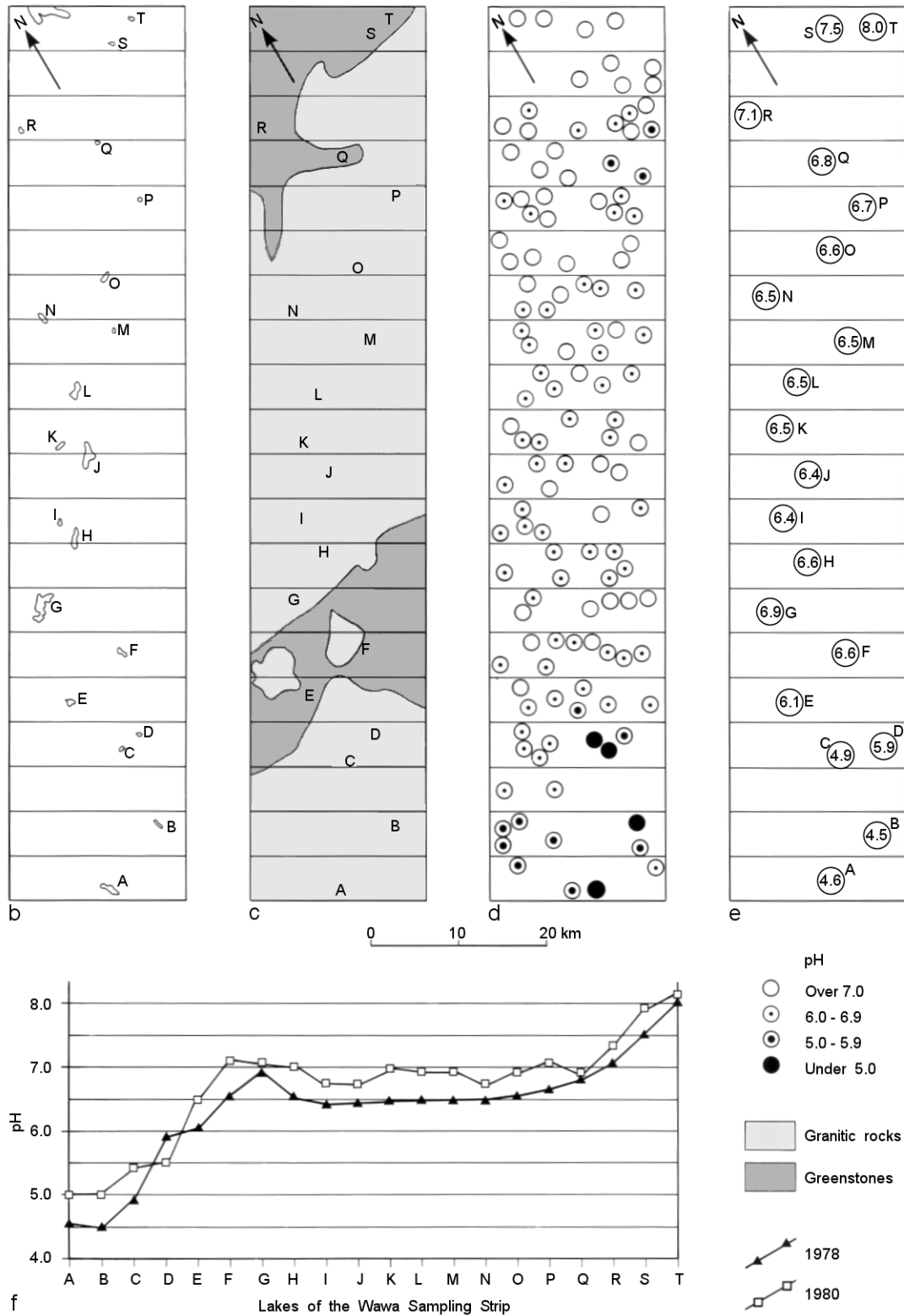


Figure 27.24b to f. Sketch maps of the Wawa sampling strip showing the: b) area of each study lake; c) bedrock geology; d) pH of all lakes tested in 1978; and e) pH of 20 lakes studied in 1978 by the Ontario Geological Survey. A separate graph f includes lakewater pH values recorded in 1978 and 1980 (modified from Fortescue et al. 1981).

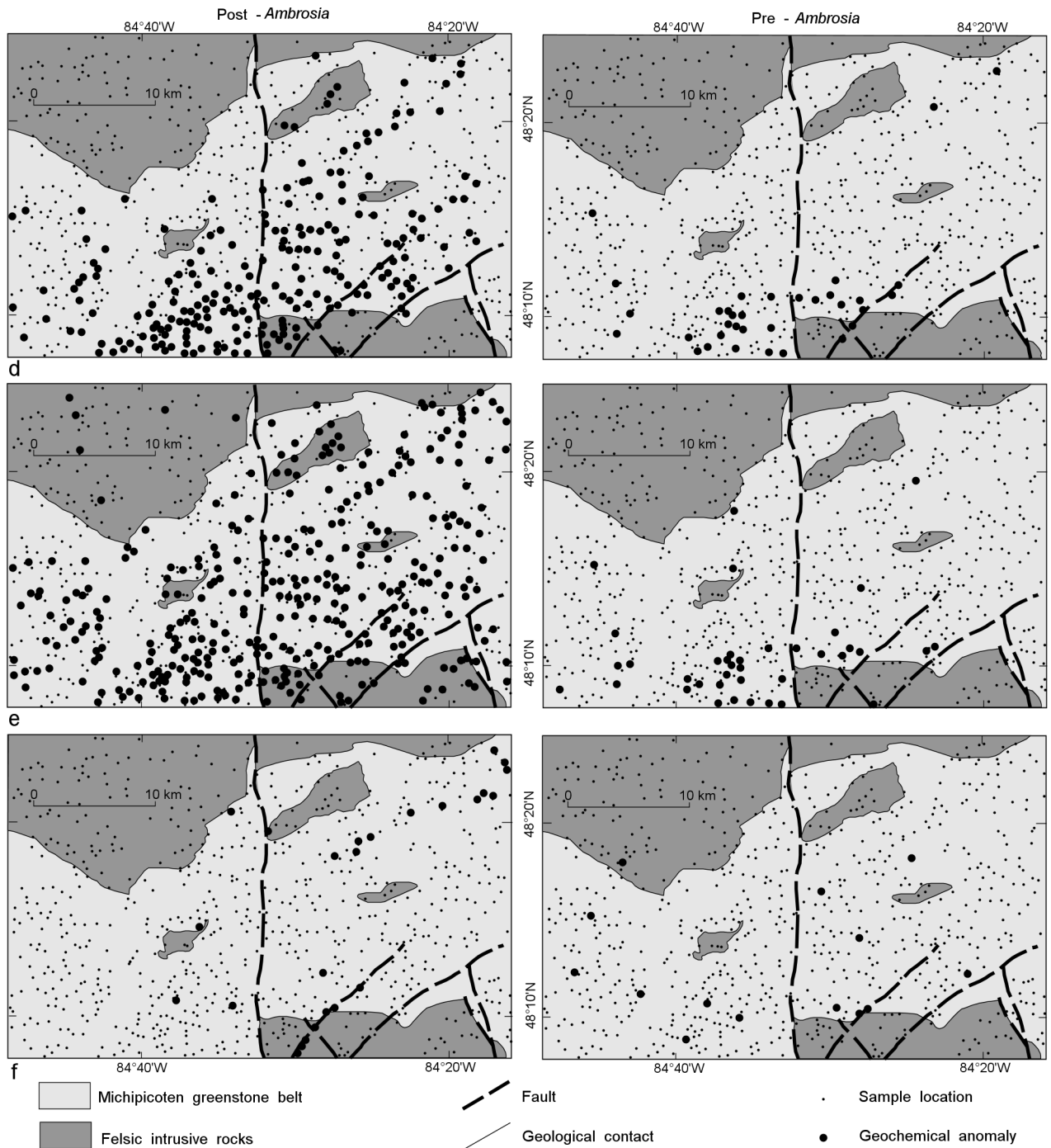


Figure 27.25d to f. Pairs of generalized geological maps of the Herman Lake area showing post- and pre-*Ambrosia* geochemical province patterns. Geochemical anomalies are represented by Clarke Index-I values of: **d**) greater than or equal to 10.0 for arsenic (As); **e**) greater than or equal to 2.5 for antimony (Sb); and **f**) greater than or equal to 3.0 for gold (Au). See Figure 27.17 for a location map of the Herman Lake study area (*modified from Fortescue and Vida, in prep.*).

THE DEDICATION OF A CHEMICAL LABORATORY TO OGS GEOCHEMICAL MAPPING

It is generally agreed among geochemists that, in order to obtain maps of high quality, the same standardized methodology must be rigorously applied throughout geochemical mapping. The standardization of a methodology of this kind for OGS regional geochemical mapping has already been described (*see* Figure 27.6).

It is clear that geochemical mapping programs in the 1990s will need to: 1) increase the number of elements determined in each sample; 2) increase the performance of chemical analysis for elements now included; and 3) reduce the time from sample collection to geochemical map and data base release.

The author proposed a novel solution to these problems based on a modern Mobile Laboratory Unit (MLU) to be constructed and dedicated entirely to the OGS geochemical mapping program (Fortescue 1990a). While parked at the base camp, the MLU would process 100 samples per day of lake sediment and lakewater (using a completely standardized methodology). It is considered feasible for the MLU to determine quantitatively some 50 elements in each lake sediment sample. In each lakewater sample, 20 elements would be determined quantitatively also.

At a field location, the MLU should be able to produce sufficient geochemical data for 2 regional maps without need for major resupply of gasses, chemicals and sample containers. During an environmental emergency, the MLU could produce geochemical maps within a few hours of sample collection, using an in-house geoscience GIS.

THE GEOCHEMICAL MAP OF ONTARIO

In 1983, the author suggested that the OGS geochemical mapping program could lead to the production of a geochemical map of Ontario (Fortescue 1983b). At that time, a geochemical survey area of 890 000 km² was clearly impractical using a reconnaissance geochemical mapping methodology.

The recent development of low density-overbank geochemical mapping methodologies in Norway (Ottesen et al. 1989) and Finland (Koljonen et al. 1989) has demonstrated the feasibility of a modern geochemical map of Ontario. Such a map would require a minimum of 2000 sample sites. According to Ottesen et al. (1989), geochemical province patterns on low density geochemical survey maps are explained by: 1) the geochemical composition of bedrock; 2) the migration of elements in solutions and gasses of deep-seated origin, rising up through the lithosphere; 3) variations in the natural environment due to topography and climate; 4) long transported airborne elements of marine, volcanic and/or other natural derivation; and 5) local and/or regional contamination due to pollution from industry and other man-made sources. It is very likely that patterns of this kind would be identified on the proposed geochemical map of Ontario.

In August 1989, several overbank geochemical sample sites along the Goulais River (Searchmont area, north of Sault Ste. Marie) were discovered when B. Bolviken, the chief geochemist of the Norwegian Geological Survey, visited Ontario for a single day to search for sampling sites of this kind (Fortescue and Bolviken 1990). Samples were collected from one of these sites a few days later and geochemical data was subsequently obtained from them (Fortescue and Bolviken 1990). The feasibility of overbank sampling in the Sault Ste. Marie area was demonstrated by this experiment.

Conclusions

1. The data obtained from regional geochemical mapping is playing an increasingly important role in the appraisal of Ontario's mineral resources.
2. The data obtained from regional geochemical mapping also plays an increasingly important role in environmental geochemistry in Ontario.
3. Due to variations in the landscape across the province, a single sample medium cannot be used to obtain a regional geochemical map of Ontario. Consequently, 3 different regional geochemical mapping methodologies were developed by the OGS during the 1980s. At least 3 more methodologies will be required to complete regional geochemical mapping of high mineral potential areas in the province.
4. In the 1980s, geochemical mapping evolved from the recognition of geochemical anomalies to the description of both geochemical provinces and geochemical anomalies. This change in emphasis has required: 1) a considerable increase in the scientific rigour of geochemical mapping methodologies; and 2) the introduction of advanced statistical techniques (and image processing and/or GIS) appropriate for the interpretation of multielement data geochemical sets.
5. Today, the OGS is in the vanguard of the development of geochemical mapping methodology. During the 1990s, this may be reflected by: 1) an increase in the number of elements included in regional geochemical maps; 2) the introduction of a Mobile Laboratory Unit dedicated to geochemical mapping; and 3) the production of a geochemical map of Ontario based on low density sampling.

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