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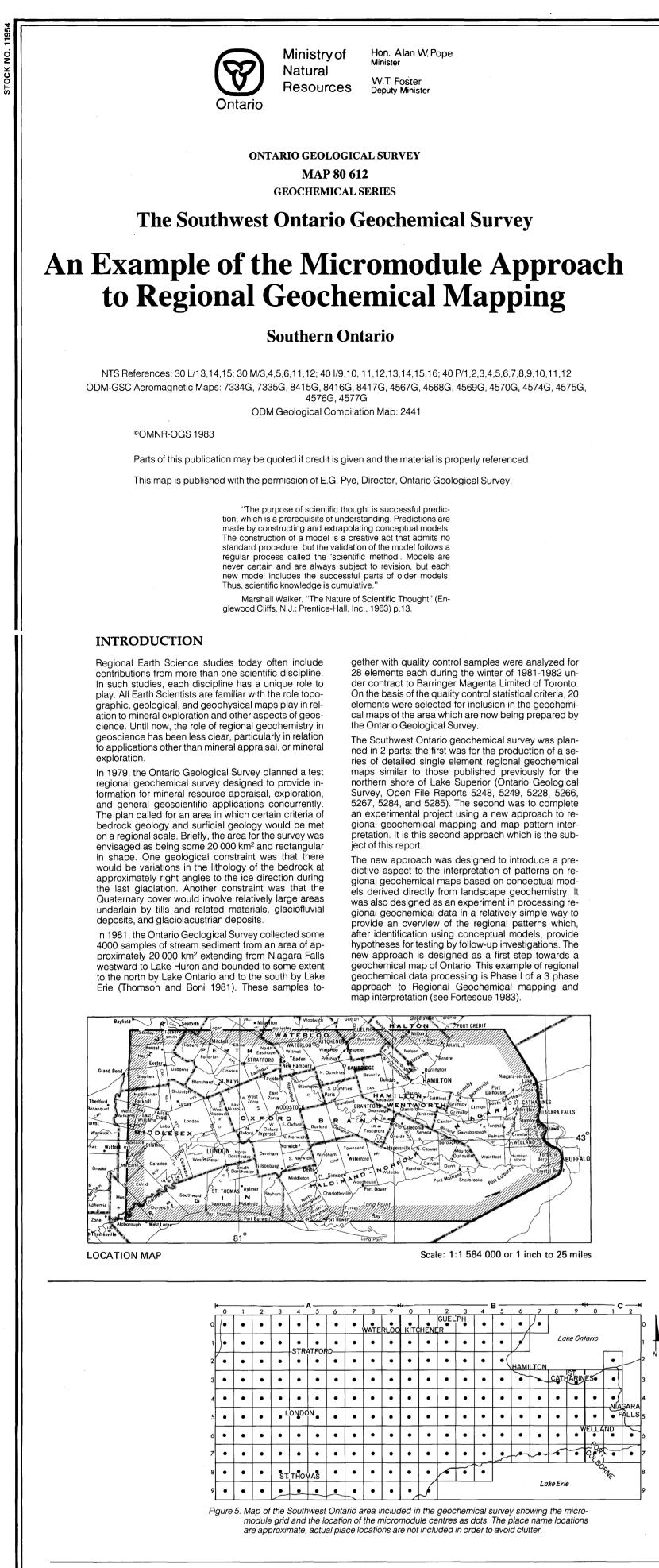
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METHODOLOGY The geoscience-geochemical approach to regional geochemical mapping and interpretation involves the 1—The use of a descriptive equation to focus attention on the problem of the complexity of origin of stream sediments. 2—The use of 10 km by 10 km square areas (micromodules) instead of sample points as a basic unit for the regional geochemical sur-3—The use of 20 sample composite samples representing micromodules for chemical analysis to provide the data for the preparation of the geochemical maps. This reduces the cost of chemical analysis 20 fold and simplifies the task of data processing while enhancing patterns on the geochemical maps. 4—The use of the Clarke unit, K, (i.e. estimate for the weight percent of element in the earth's crust) as a common datum for the preparation of regional geochemical maps with standardzed 0.25 Clarke intervals for each element. A B C D E F G H I J A B C D E F G H I J A B C D E F G H I J A B C D E F G H I J A B C D E F G H I J A B C D E F G H I J A B C D E F G H I J A B C D E F G H I J

5—The use of **gradient analysis**, as described by Fortescue (1981), for the display of regional patterns on single element geochemi-6—The use of a single scan sheet (Fortescue 1970) for the display of the results for gradient analysis for 20 elements to facilitate the recognition and interpretation of single and multi-element geochemical patterns. 7—The use of conceptual models derived from landscape geochemistry as guides for the recognition of regional geochemical patterns. Each of these steps is illustrated on this map using data and information derived from the Southwest Ontario geochemical survey. It is concluded that the geochemical mapping and interpretative procedure described here, although in an experimental stage of development, provides a logical scientific basis for the identification and preliminary explanation of patterns on regional geochemical maps. It seems clear that standardization of map production and interpretation methods using the 'micromodule' approach is relatively simple and cost effective, particularly if the chemical data is available

Figure 1a. Hypothetical test set of Clarke code letters

gure 1b. Transparent mask with micromodule grid,

Figure 1c. "Regional geochemical map" produced by

a combination of Figure 1a and 1b.

by the computer.

geology (fine lines).

for element X as printed for micromodules

bedrock geology (dots), and Quaternary

 $x_{Pedology}$ is the contribution to X from processes of weathering and soil formation x_{Ecology} is the contribution to X from organic matter $x_{\text{Technology}}$ is the contribution to X derived from man's e is the percent of error in the value of X derived from sampling, sample preparation, and chemical analysis Thus stream sediments are seen as mixtures of 4 components each of which is a complex natural, or man derived material. At present there is no simple way to solve the equation in order to discover the relative proportions of each component in a given sample of stream sediment. Consequently, it is not possible to contour the contributions to X from each of the 4 components individually. But, provided the value of e is small compared with X, a comparison of element abundance patterns on gradient maps (Fortescue 1981) does enable patterns for elements derived from one (or several of the components) to be identified in a way which is much clearer than when the data for X is contoured (see Explanation of Gradient Analysis). The 4 components of the stream sediment mixture each have a characteristic effect on the value for element X. The geological component is the sum of contributions from the minerals derived from bedrock, sur ficial materials, and mineral deposits. From the viewpoint of geoscience the range in values for element X is usually between 0 to 3 K (i.e. 1 to 3 times the Clarke of the element). In areas where mineral depos its affect the levels, very high (10 + K) values in micro module composites can be expected. Similar values may be derived from man's activity in polluted areas (i.e. as $x_{Technology}$). These values for X are true geochemical anomalies. In order to provide an overview of the amount and dis-

General Descriptive Equation for

If X is the weight percent (1% = 10,000 parts per mil-

lion) of an element in a sample of oven dried -80 mesh

 $X = X_{Geology} + X_{Pedology} + X_{Ecology} + X_{Technology} + e$

where $x_{Geology}$ is the contribution to X from bedrock and

used for mapping purposes.

corresponding Clarke values.

(who are not geochemists) to relate multi-element geo-

chemical data to a common datum, like the use of sea

Statistical analysis of the quality control samples within

the batch of 240 samples resulted in the selection of

20 elements for inclusion in the regional geoscience

geochemical maps. These are, in order of increasing

Clarkes: Ni, Cu, Be, Cr, Ti, Fe, V , Mg, Sr, Na, Al, Si, K

Mn, Li, P, Zr, Zn, Pb, and Ca. The weight percent

values of these elements are listed in Table 1 with their

stream sediment material, then, in theory, X can be de-

Element Abundance in Stream

scribed by the following equation:

surficial geological material

tribution of 20 chemical elements in the stream sedi ments a new approach to regional geochemical surveying has been evolved. The research is based on a combination of several previously untried ideas. Briefly, the survey is organized around area units each 10 km by 10 km called **micromodules**. The micromodules are envisaged as having four 21/2 km by 21/2 km square quarters from each of which 5 samples of stream sediment are collected. The Southwest Ontario survey included 190 such micromodules (some of which were not completely sampled owing to the coastlines of Lake Erie, Huron, or Ontario). Samples were dried and the -80 mesh fraction was selected for chemical analysis using well established methods. Prior to chemical analysis mixtures of the same weight (i.e. 2 g) of the sieved material from each of the 20 samples from each micromodule were prepared. There were 190 of these mixtures which were placed in random order (together with 10 replicates of each of 5 reference standards) prior to chemi-

the value for the abundance of an element within a 10 x

increasing Clarke values in the stream sediments. The

of regional geochemical patterns, for one, or more, elements

which then can be verified during Phase II and III activity.

object of the scan sheet is facilitate the recognition

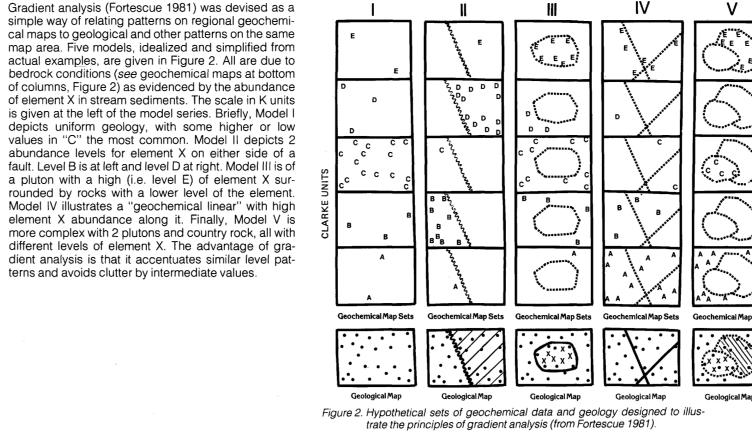
10 km Micromodule area. The 20 elements are arranged in order of

MICROMODULE GEOCHEMICAL MAPS BASED ON CLARKES

cal analysis. The reference standards data were used The chemical data from the chemical analysis for element X was transformed into Clarke values and asfor quality control purposes. Each of the 240 samples was analyzed for 28 elements including Si, Al, Fe, Ca, signed a letter code value according to the ppm limits Mg, Na, K, Ti, P, Mn, Ba, Sr, Zr, V, Cr, Ni, Zn, Cu, Co, for the 0.25 K intervals listed in Table 1. A computer i, Pb, Th, U, Be, As, Mo, Cd, and Ag. The data from program was written to print out these code letters the quality control samples and the unknowns were representing the levels of element X in the Micromothen processed by the computer and transformed into dule composites on a rectangular grid (Figure 1A). Clarke units and only elements with a coefficient of The grid was so arranged that it was on the same variation less than 5% in the quality control data were scale as a transparent plastic mask (Figure 1B) showing the micromodule grid, the geological formation The geoscience geochemical maps were designed outlines (dotted), and the features of the Quaternary around the Clarke unit. As defined by the Russian geogeology (fine lines). In order to make the regional geochemist A.E. Fursman in 1923, (Beus 1976), the Clarke chemical map, the mask was photocopied over the is a general estimate of the weight percent of an elegrid of code letters. Using this procedure, a set of 20 ment in the earth's crust. Although estimates for the regional geochemical maps can be prepared in a day values of the Clarke differ, those listed by Ronov and and the geochemical patterns for a 100 km by 200 km Yaroshevski (1972) are often quoted and are used map area are quite legible at page size (Figure 1C) here. The advantage of using Clarke (K) units is that it The area represented on Figure 1 is 100 km by 100 enables interpreters of geochemical map patterns

GRADIENT ANALYSIS

simple way of relating patterns on regional geochemical maps to geological and other patterns on the same map area. Five models, idealized and simplified from actual examples, are given in Figure 2. All are due to bedrock conditions (see geochemical maps at bottom of columns, Figure 2) as evidenced by the abundance of element X in stream sediments. The scale in K units is given at the left of the model series. Briefly, Model I depicts uniform geology, with some higher or low values in "C" the most common. Model II depicts 2 abundance levels for element X on either side of a fault. Level B is at left and level D at right. Model III is of a pluton with a high (i.e. level E) of element X surrounded by rocks with a lower level of the element. Model IV illustrates a "geochemical linear" with high element X abundance along it. Finally, Model V is more complex with 2 plutons and country rock, all with different levels of element X. The advantage of gradient analysis is that it accentuates similar level patterns and avoids clutter by intermediate values.



Gradient Maps for the Southwest

Ontario Survey

So far we have been concerned with hypothetical gra-

dient map patterns. In Figure 4 gradient analysis pat-

cal to reduce the map panel scale and still retain the

nterpretation of Patterns on the Multi-

Concepts of landscape geochemistry, as described

by the Russian workers and in the book by Fortescue

(1980), form the basis for 6 types of conceptual model

designed to act as guides for the interpretation of pat-

terns on the regional geochemical maps of Southwest

Ontario. How the concepts of 'geochemica

anomalies', geochemical gradients, geochemical bar-

riers, geochemical flows, relative mobility, and histori-

cal geochemistry relate to the patterns on the regional

geochemical maps derived from gradient analysis is

Briefly, geochemical anomalies due to mineral de-

posits (or environmental pollution) are typified by one

or more values for element X over 4KK as illustrated in

Model I. Geochemical gradients, which may, or may

not relate to geological conditions, are typified by

bands of micromodule composite values which ap-

pear to move across the surveyed area of the 100 km

by 100 km area on which this series of models is

linear, changes in the level of element X in stream sed-

iments. They may be due to one, or more, physical

chemical, or biological processes which affect the

level of element X in the sediments. Geochemical

flow patterns result from the movement of matter

across the landscape by ice, water, or in the atmo-

sphere. On the model shown above movement by ice

is depicted from a geological formation located in the

direction of the arrow. **Geochemical relative mobility**

patterns are evidenced by a series of geochemical

gradients for different elements which are coincident

for one another. This concept is usually associated

with movement of ions on the local scale near mineral

deposits but can also be associated with the relative

migration rates of mineral species resistant to weath

ering. Geochemical patterns due to historical events in

sult of man's activity (e.g. smelter operations) or natu

landscapes usually overprint all other patterns as a re-

ral catastrophies (e.g. volcanic eruptions). For further

information on these models and the scientific ap-

proach upon which they are based see Fortescue

drawn. Geochemical barriers produce abrupt, often

Explanation of Conceptual Model

Element Scan Sheet for the Southwest

Ontario Geochemical Survey Area

geochemical patterns (Figure 4).

illustrated on Figure 3.

Conceptual Models for the

GEOCHEMICAL DATA Figures 2 and 3 are examples of a scan sheet which is a convenient way of presenting the map panels for terns for 20 elements in the micromodule samples are gradient analysis for more than 1 element. On Figure 4, a scan sheet for the Southwest Ontario Regional geochemical survey geochemical data for 20 elements in each of the 190 micromodule composites is presented. Each map panel is a replica of the South-

THE SCAN SHEET OF THE

SOUTHWEST ONTARIO REGIONAL

shown. The elements are arranged in order of increasing K values which range from B(0 to 0.25 K) to N(3.0 The gradient map panels on the Southwest Ontario scan sheet are made up of dots each of which is the level of element X in a 20 sample micromodule comwest Ontario area depicted on Figure 5. Figure 5 illusposite. Because the performance of the chemical trates the relationship between the micromodule grid analysis for each of the 20 elements is known and the and the dots shown on Figure 4. limits of each micromodule are known it is quite practi-

lithologies. Notice that the strike is generally in the northwest to southeast direction. A similar map for the Quaternary geology of the area is presented on Figure 7. It is important to note that the predominant regional ice direction was from northeast to southwest and that there are 3 general areas of surficial lithologies. These are tills and related deposits in the western part of the map, sand plains in the central part of the map, and glacial lake clays in the eastern part of the area. Hence the grain of the bedrock is at right angles to the grain of the Quaternary deposits. These geological maps provide a general background for the interpretation of the patterns on the multi-element scan sheet (Figure 4). Further information on the bedrock lithology can be obtained from Hewitt (1972), and on the Qua-

SOUTHWEST ONTARIO

OVERVIEW OF THE GEOLOGY OF

On Figure 6 is presented a generalized map of South-

west Ontario showing the outcrop area of the principal

ternary geology from Chapman and Putman (1972).

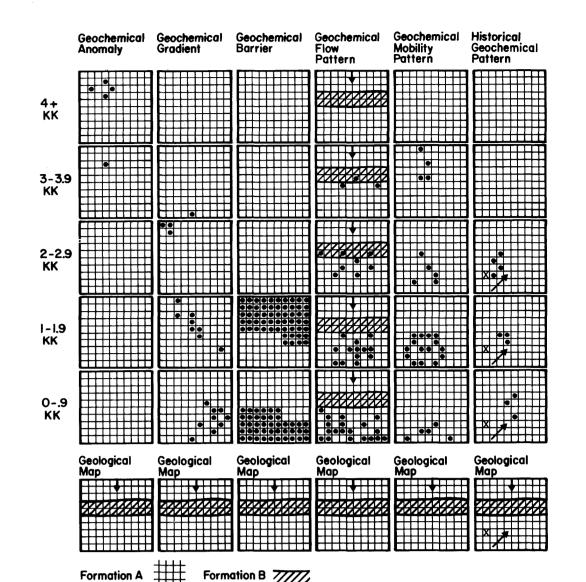


Figure 3. Conceptual models for 6 common regional geochemical patterns derived from the basics of landscape geochemistry

Table I. Clarke values and Clarke code values used on the Southwest Ontario Regional

Figure 4, Scan sheet showing the distribution of 20 elements

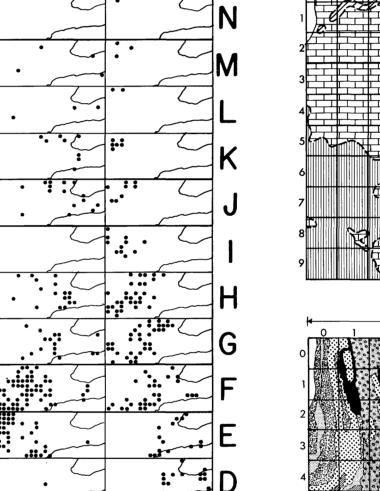
in micromodule composites in the range 0 to 3 K

(Clarkes) in Southwest Ontario. Each rectangle is a

replica of the Southwest Ontario area sampled,

showing Lake Erie and Lake Ontario (see Figure 5).

Units	Si	Al	Fe	Ca	Mg	Na	K	Π	P	Mn	Ba	Sr	Zr	V	Cr	Ni	Zn	Cu	Co	u	Pb	Th	U	Be	As	Mo	Cd	Ag	KK Units
25.00 20.00 15.00 10.00 5.00		41.50%	31.00%	46.00% 22.00%	40.500% 27.000% 13.500%	44.00% 33.00% 22.00% 11.00%	45.00% 36.00% 27.00% 18.00% 9.00%	15.75% 12.60% 9.45% 6.30% 3.15%	2.80% 2.24% 1.68% 1.12% 5 600	2.65% 2.12% 1.59% 10.060 5.300	9 750.0 7 800.0 5 850.0 3 000.0 1 950.0	9 600 7 680 5 760 3 840 1 920	4 050.0 3 240.0 2 430.0 1 620.0 810.0	3 400 2 720 2 040 1 360 680	3 050.0 2 440.0 1 830.0 1 220.0 610.0	2 475.00 1 980.00 1 485.00 990.00 495.00	1 900 1 520 1 140 760 380	1 700 1 360 1 020 680 340	725.00 580.00 435.00 290.00 145.00	450.0 360.0 270.0 180.0 90.0	325.00 260.00 195.00 130.00 65.00	202.50 162.00 121.50 81.00 40.50	57.50 46.00 34.50 23.00 19.55	50.0 40.0 30.0 20.0 10.0	45.00 36.00 27.00 18.00 9.00	30.0 24.0 18.0 12.0 6.0	4.00 3.20 2.40 1.60 0.80	2.00 1.60 1.20 0.80 0.40	Z 25.0 Y 20.0 X 15.0 W 10.0 V 5.0
4.75 4.50 4.25 4.00 3.75		39.43% 37.35% 35.28% 33.20% 31.13%	29.45% 27.90% 26.35% 24.80% 23.25%	21.85% 20.70% 19.55% 18.40% 17.25%	12.830% 12.150% 11.480% 10.800% 10.130%	10.45% 9.90% 9.35% 8.80% 8.25%	8.55% 8.10% 7.65% 7.20% 6.75%	2.99% 2.84% 2.68% 2.52% 2.36%	5 320 5 040 4 760 4 480 4 200	5 035 4 770 4 505 4 240 3 975	1 852.5 1 755.0 1 657.5 1 560.0 1 462.5	1 824 1 728 1 632 1 536 1 440	769.5 729.0 688.5 648.0 607.5	646 612 578 544 510	579.5 549.0 518.5 488.0 457.5	470.25 455.50 420.75 396.00 371.25	361 342 323 304 285	323 306 289 272 255	137.75 130.50 123.25 116.00 108.75	85.5 81.0 76.5 72.0 67.5	61.75 58.50 55.25 52.00 48.75	38.48 36.45 34.43 32.40 30.38	18.98 18.40 17.83 17.25 8.63	9.5 9.0 8.5 8.0 7.5	8.55 8.10 7.65 7.20 6.75	5.7 5.4 5.1 4.8 4.5	0.76 0.72 0.68 0.64 0.60	0.38 0.36 0.34 0.32 0.30	U 4.7 T 4.5 S 4.2 R 4.0 Q 3.7
3.50 3.25 3.00 2.75 2.50		29.05% 26.98% 24.90% 22.80% 20.80%	21.70% 20.15% 18.60% 17.05% 15.50%	16.10% 14.95% 13.80% 12.65% 11.50%	9.450% 8.780% 8.100% 7.430% 6.750%	7.70% 7.15% 6.60% 6.05% 5.50%	6.30% 5.85% 5.40% 4.95% 4.50%	2.21% 2.05% 1.89% 1.73% 1.58%	3 920 3 640 3 360 3 080 2 800	3 710 3 445 3 180 2 195 2 650	1 365.0 1 267.5 1 170.0 1 072.5 975.0	1 344 1 248 1 152 1 056 960	567.0 526.5 486.0 445.5 405.0	476 442 408 374 340	427.0 396.5 366.0 335.5 305.0	346.50 321.25 297.00 272.25 247.50	266 247 228 209 190	238 221 204 187 170	101.50 94.25 87.00 79.75 72.50	63.0 58.5 54.0 49.5 45.0	45.50 42.25 39.00 35.75 32.50	28.35 26.33 24.30 22.28 20.25	8.05 7.48 6.90 6.33 5.75	7.0 6.5 6.0 5.5 5.0	6.30 5.85 5.40 4.95 4.50	4.2 3.9 3.6 3.3 3.0	0.56 0.52 0.48 0.44 0.40	0.28 0.26 0.24 0.22 0.20	P 3.5 O 3.2 N 3.0 M 2.7 L 2.5
1.50	47.70% 40.90% 34.10%	18.70% 16.60% 14.50% 12.50% 10.40%	13.95% 12.40% 10.85% 9.30% 7.75%	10.35% 9.20% 8.05% 6.90% 5.75%	6.080% 5.400% 4.730% 4.050% 3.370%	4.95% 4.40% 3.85% 3.30% 2.75%	4.05% 3.60% 3.15% 2.70% 2.25%	1.42% 1.26% 1.10% 9 480 7 900	2 520 2 240 1 968 1 680 1 400	2 385 2 120 1 855 1 590 1 325	877.5 780.0 682.5 585.0 487.5	864 768 672 576 480	364.5 324.0 283.5 243.0 202.5	306 272 238 204 170	274.5 244.0 213.5 183.0 152.5	222.75 198.00 173.25 148.50 123.75	171 152 133 114 95	153 136 119 102 85	65.25 58.00 50.75 43.50 36.25	40.5 36.0 31.5 27.0 22.5	29.25 26.00 22.75 19.50 16.25	18.23 16.20 14.18 12.15 10.13	5.18 4.60 4.03 3.45 2.88	4.5 4.0 3.5 3.0 2.5	4.05 3.60 3.15 2.70 2.25	2.7 2.4 2.1 1.8 1.5	0.36 0.32 0.28 0.24 0.20	0.18 0.16 0.14 0.12 0.10	K 2 J 2 I 1 H 1 G 1
	(273 000) 27.3%	(83 600) 8.30%	(62 200) 6.20%	(46 600) 4.60%	(27 640) 2.700%	(22 700)	(18 400) 1.80%	6 320 (0.63%)	1 120	1 060	390.0	384	162.0	136	122.0	99.00	76	68	29.00	18.0	13.00	8.10	2.30	2.0	1.80	1.2	0.16	0.08	F 1.0
0.75 20.48% 0.50 13.65% 0.25 6.83% 0.00 0.00	20.48% 13.65% 6.83%	6.23% 4.15% 2.08% 0.00	4.65% 3.10% 1.55% 0.00	3.45% 2.30% 1.15% 0.00	2.020% 1.350% 0.675% 0.000	1.65% 1.10% 0.55% 0.00	1.35% 0.90% 0.45% 0.00	4 740 3 160 1 580 0.00	840 560 280 0.00	795 530 265 0.00	292.5 195.0 97.5 0.0	288 192 96 0	121.5 81.0 40.5 0.0	102 68 34 0	91.5 61.0 30.5 0.0	74.25 49.50 24.75 0.0	57 38 19 0	51 34 17 0	21.75 14.50 7.25 0.00	13.5 9.0 4.5 0.0	9.75 6.50 3.25 0.00	6:08 4.05 2.03 0.00	1.73 1.15 0.58 0.00	1.5 1.0 0.5 0.0	1.35 0.90 0.45 0.00	0.9 0.6 0.3 0.0	0.12 0.08 0.04 0.00	0.06 0.04 0.02 0.00	E 0.7 D 0.5 C 0.2 B 0.0
	Si	Al	Fe	Ca	Mg	Na	K	Ti	P	Mn	Ba	- Sr	Zr	v	Cr	Ni	Zn	Cu	co	Ü	Pb	Th	U	Be	As	Мо	Cd	Ag	



pattern observed in the micromodule composite re-

gional survey was in fact due to a historical event. The

values for nickel above and below 35 ppm tell the

reader nothing about the potential significance of the

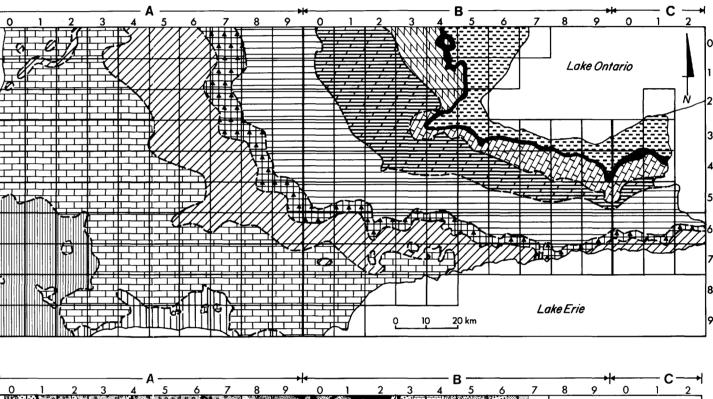
nickel anomaly. Because the Clarke value for nickel is

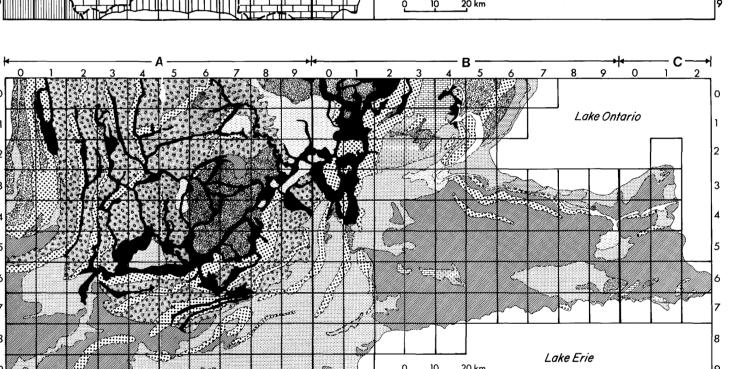
99 ppm, the values on Figure 18 are clearly relatively

low. This is an advantage of using the Clarke units be

cause it places the abundance data for an element in

a specific area directly into a global context.





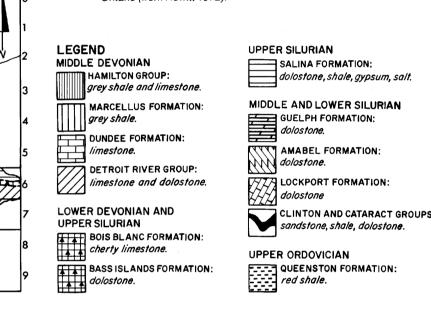
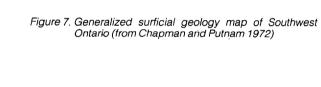
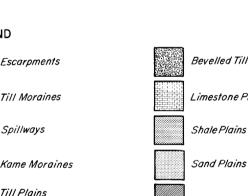


Figure 6. Generalized bedrock geological map of Southwest





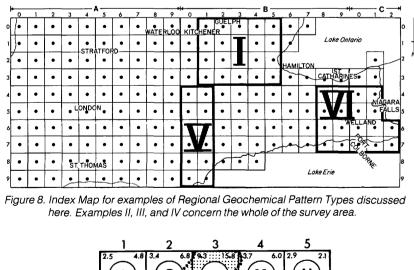
(Undrumlinized)

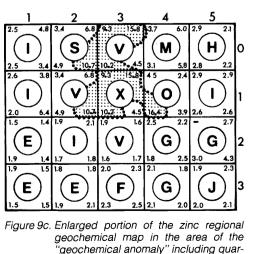
Bevelled Till Plains Limestone Plains

EXAMPLES

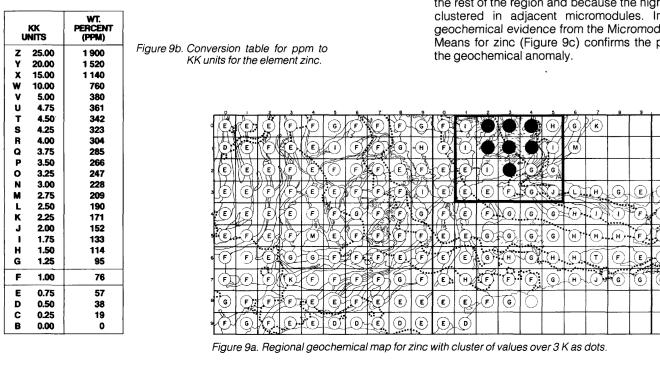
SIX WORKED EXAMPLES OF THE **USE OF CONCEPTUAL MODELS TO** IDENTIFY AND DESCRIBE GEOCHEMICAL PATTERNS ON THE **GEOCHEMICAL MAP OF SOUTHWEST ONTARIO**

The scan sheet display of the abundance data for 20 elements on Figure 4 can be used for the identification of general geochemical patterns in the data, element by element. It is beyond the scope of this presentation to examine in detail all the geochemical patterns which occur on the scan sheet. Instead, 6 examples o geochemical patterns, one for each of the interpretative model types on Figure 3, are included here (Figure 8). Other patterns may be identified by the reade The preliminary overview report on the Southwest Ontario Regional Geochemical Survey (Fortescue, i preparation) will include more examples of single and nulti-element patterns identified from the scan sheet. The purpose of the examples described here is to explain how general regional geochemical patterns of the type described in above theory can be identified, verified and used to provide hypotheses to be tested by follow-up studies





geochemical anomaly" including quar ter composite mean values in KK units.



Example I: Geochemical Anomaly

In the Southwest Ontario Regional Geochemical Survey a "geochemical anomaly" is considered to involve micromodule composite data points individually, or in clusters, which are valued at 3 Clarkes or higher (see Conceptual Model, Figure 3(I)). The most obvious of such geochemical anomalies is for the element **zinc** and involves 6 high values clustered just west of the City of Hamilton (Figures 4, 5,

gether with quality control samples were analyzed for

28 elements each during the winter of 1981-1982 un-

der contract to Barringer Magenta Limited of Toronto.

On the basis of the quality control statistical criteria, 20

cal maps of the area which are now being prepared by

The Southwest Ontario geochemical survey was plan-

ned in 2 parts: the first was for the production of a se-

ries of detailed single element regional geochemical

maps similar to those published previously for the

northern shore of Lake Superior (Ontario Geological

Survey, Open File Reports 5248, 5249, 5228, 5266,

5267, 5284, and 5285). The second was to complete

an experimental project using a new approach to re-

gional geochemical mapping and map pattern inter-

pretation. It is this second approach which is the sub-

The new approach was designed to introduce a pre-

els derived directly from landscape geochemistry. It

was also designed as an experiment in processing re-

gional geochemical data in a relatively simple way to

provide an overview of the regional patterns which

after identification using conceptual models, provide

hypotheses for testing by follow-up investigations. The new approach is designed as a first step towards :

geochemical map of Ontario. This example of regional geochemical data processing is Phase I of a 3 phase

approach to Regional Geochemical mapping and

Scale: 1:1 584 000 or 1 inch to 25 miles

map interpretation (see Fortescue 1983).

dictive aspect to the interpretation of patterns on re-

gional geochemical maps based on conceptual mod-

elements were selected for inclusion in the geochemi-

the Ontario Geological Survey.

The small triangles on the scan sheet (Figure 4) relate to chemical analyses of micromodule composites each containing contributions from the 20 stream sediment samples collected within each of the 10 km by 10 km areas. The regional geochemical map for zinc is eproduced here (Figure 9). This involves the micromodule grid boundaries as a grid and the code for the abundance of zinc in Clarke units within the centre of

each circle. The frequency distribution for the zinc micromodule omposite data plotted on the map is shown on Figure b. This shows that in the whole survey there were only 7 zinc values greater than N and the map shows that 6 of these are included in the zinc geochemical anomaly identified above. A further check on the validity of the zinc geochemical anomaly comes from an independent source which would not generally be available in regional geochem-

ical mapping of the type described here. This involves the chemical analysis of individual samples (not composites) from each micromodule for zinc. These data were processed to give Micromodule Quarter Mean values for zinc in the area which includes and surrounds the geochemical anomaly (Figure 9c). These data eloquently verify the pattern on the regional geochemical map and indicate the "target" (i.e. dotted area) more precisely than would be indicated by the regional map data itself.

The explanation of the cause of the geochemical anomaly requires a follow-up study designed to investigate if the geochemical anomaly is due to zinc in the surficial material or bedrock of the area of interest (see Figures 6 and 7).

The zinc geochemical anomaly provides an excellent example of this type of regional pattern which can be easily identified on regional geochemical maps of the type described here. It is excellent because the micromodule high values for zinc are well above those for the rest of the region and because the high values are clustered in adjacent micromodules. Independent geochemical evidence from the Micromodule Quarter Means for zinc (Figure 9c) confirms the presence of

13.80 - 14.95 3.00 - 3.25 12.65 - 13.80 2.75 - 3.00 11.50 - 12.65 2.50 - 2.75 10.35 - 11.50 2.25 - 2.50 9.20 - 10.35 2.00 - 2.25 8.05 - 9.20 1.75 - 2.00 6.90 - 8.05 4.60 - 5.75 1.00 - 1.25 2.30 - 3.45 | 0.50 - 0.75 1.15 - 2.30 0.25 - 0.50 0.00 - 1.15 0.00 - 0.25

Example II: Geochemical Gradient

Using the conceptual model for a "Geochemical Linear abrupt changes in the abundance level of an elscan sheet (Figure 4) reveals the presence of geochemical gradients for several elements including shown as a conceptual model on Figure 3. Several a result of waters flowing at the surface (rivers or lithium, zinc, and lead but the best example of a gra-The calcium gradient is almost ideal because it involves all the Clarke cell limits from B through N (Table I, Figure 10), it follows a direction somewhat different

from either the strike of the bedrock or the direction of the Quaternary deposits of the region (see maps for Bedrock Geology (Figure 6) and Quaternary geology (Figure 7)) and it can be identified even though values for individual micromodule composites overlap within the same general area. For example, Clarke patterns F. G. and H can be identified as a part of the gradient which would be hard to identify if the micromodule composite geochemical data were contoured. The gradient for calcium is so clear and extends over so many concentration ranges that its existence does ot require detailed verification using Micromodule Quarter Mean data (see Example I).

It seems likely that the geochemical gradient for calcium may be due to not one, but several causes the interface of the sand plain with tills and other glaother. From the viewpoint of regional geochemistry the face between the sand plains and glaciolacustrian cal flow) of **lead** and **zinc**. identification of a gradient of this type provides a hy- clays. Because the fine textured material derived from pothesis for testing. Such testing should be carried out the Canadian Shield is likely to be present in the tills partly by a rigorous statistical study of the regional and the lake sediments, areas underlain by these geochemical data for calcium, magnesium, and re-rocks have a slightly higher nickel content than the lated elements and partly by further follow-up field and coarse textured sands. Follow-up investigations in laboratory investigations.

Geochemical gradients are relatively common in regional geochemical data but are seldom so well defined as in the above example for a major element. The Like geochemical gradients geochemical barrier patcalcium pattern shown here strongly supports the terns are relatively common on regional geochemical case for using micromodule composites in order to maps. The barriers cited in the example are likely to be identify major geochemical patterns for one or more due to surficial and textural changes in the surficial elements within a region. It seems clear that the study of geochemical gradients by combined field and should be noted that although geochemical barriers mathematical techniques can do much to improve our may be explained on the basis of patterns on bedrock knowledge of regional geochemical patterns. For example, the existence of a regional gradient for calcium planation is not the only one available. For example, (or some other nutrient element) could well be related to variations in the growth and health of plants, ani-

CALCIUM (Weight / Percent)

Clarke Units

Calcium Plots of Micromodule Average Data Displayed as Dots on Maps.

Calcium Clarke Interval Codes

Codes

From ure 10. Diagram of the map panels for calcium and both See Table I See Table I

Example III: Geochemical Barrier

effects on regional geochemical maps.

the Clarke (K) cell limits and the corresponding

weight percent limits. The figure shows clearly the

Figure 11. An example of a geochemical barrier. Map for nickel showing the 0.25

regional geochemical gradient for this element.

REGIONAL GEOCHEMICAL SURVEY OF SOUTHWEST ONTARIO

This Phase I Scan Sheet provides an overview of the chemical

abundance of 20 elements in each of 190 micromodule

element based on the Clarke scale. Each dot represents

column is a gradient analysis for data for a single

composite samples. Each rectangle (map panel) represents

the southwest Ontario area surveyed (see index map). Each

lakes). Yet another transport mechanism is ice movegeochemical barrier patterns can be identified on the ment particularly in areas where the regional ice direcscan sheet (Figure 4). Perhaps the best example is for **nickel** where 2 geochemical barriers are seen side by tion is known and the bedrock strike is approximately within the same concentration limits. This example foat right angles to it. The detection of flow patterns deside in the data for Clarke codes B and C (Figures 11 and 12). Of the 2 geochemical barriers (X-X') and rived from bedrock under these conditions is simpli-(Y-Y') (Figures 11 and 12) the most clear cut is the second. The first is accompanied by a transition zone suggesting that the barrier is due to the effect of 2 components of the sediments which have mixed une-

ements which may be used as indicator elements. These conditions are met in the northern part of the Niagara Peninsula. It can be shown that zinc and lead derived from minor mineralization in the Lockport Formation were transported by ice towards the southwest (personal communication, Peter Barnett, Quaternary Geologist, Ontario Geological Survey, 1983). The scan As in the case of geochemical gradients, no detailed sheet for the area (Figure 4) indicates patterns likely to verification is required to confirm such a major feature be due to this cause in levels of G and H. Micromodule of the geochemical data for nickel. composites with values for each of these elements are shown together with the outcrop area for the Lockport Formation on Figures 13 and 14. The third map (Figure A glance at the surficial geological map for the region 15) focuses on micromodules for which the values for Figure 7) provides explanations for geochemical bar- both lead and zinc are between 1.25 and 1.75 K. In riers X and Y. The central area of relatively low nickel is this case a cluster of 9 points occurs just down ice occupied by a sand plain. The barrier X-X' results from from the outcrop area of the Lockport Formation, This which, in the Southwest Ontario area reinforce each cial deposits. The barrier Y-Y' results from the inter- has been affected by glacial smearing (i.e. geochemi-

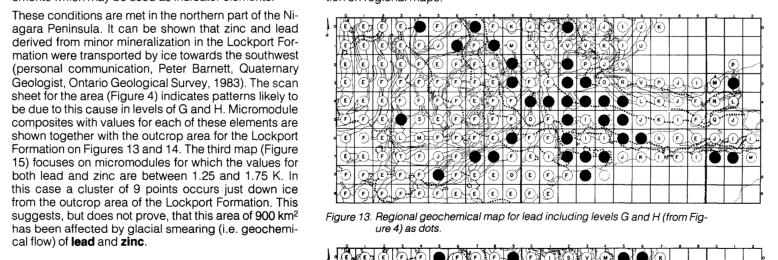
This example of a possible geochemical flow was included to demonstrate the technique of detecting geochemical flow rather than to provide a firm target volving detailed mineralogical and textural study of or follow-up research. Consequently, the data for zinc stream sediments are needed to establish the validity and lead at levels between 1.25 and 1.75 K (i.e. Zn 76 to 133 ppm and Pb 13 to 22 ppm) in the Micromodule Quarter Means is not included here for purposes of

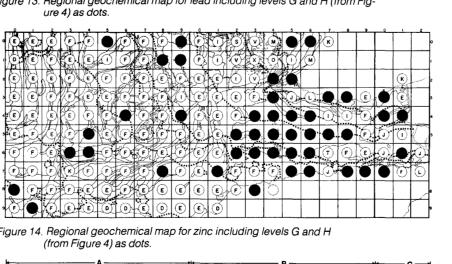
Example IV: Geochemical Flow

The zinc/lead pattern just described suggests, but does not prove that when elements derived from migeochemical component of the stream sediment. I nor mineralization in a particular rock type (i.e. the Lockport Formation) are made to flow by glacial activity they retain a constant concentration ratio to each other within the flow. If true, this principle opens up a new approach to the interpretation of regional geochanges in groundwater conditions independent of lichemical maps based partly on a knowledge of the thology may give rise to regional geochemical barrier geochemistry of the bedrock and partly on a knowledge of the surficial geological features of the area. A systematic follow-up investigation to discover the validity of the hypothesis for the cluster of micromodule composites shown in Figure 15 would require sampling of the source sulphides to discover their geochemical signature for lead and zinc and associated elements for interpretative purposes.

Example V: Geochemical Mobility

Geochemical flow patterns on the local, or regional Geochemical flow patterns on the regional scale can Gradient" (Figure 3(II)) as a guide, inspection of the ement on the regional scale are due to geochemical scale may relate to movement of material through the result from any one of a number of causes. In the exbarriers. A general model of a geochemical barrier is air, within waters (groundwaters or precipitation), or as ample quoted here prior research had indicated the movement of material by ice from the Lockport Formation to the southwest and this movement appears to be confirmed by the patterns for zinc and lead combined cuses attention on the idea of geochemical flows of relatively constant chemical composition but more refied if the bedrock is known to contain certain trace el-search is required to establish rules for their recogni-





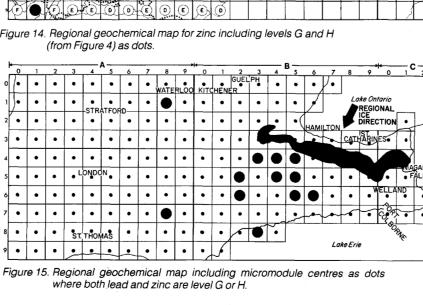


Figure 12. An example of geochemical barrier on either site of a geochemical low.

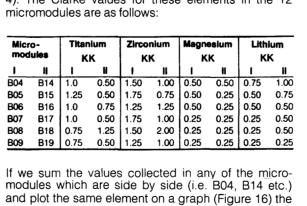
The 0 to 0.25 K values in the micromodule composites for nickel from

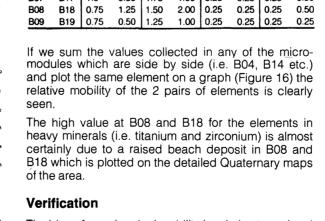
Figure 14. Regional geochemical map for zinc including levels G and H 8 • • ST.THOMAS • • • Figure 15. Regional geochemical map including micromodule centres as dots

logical environment, in this case this occurs in a sand plain due to Quaternary outwash processes. The systematic descriptive and statistical study of problems of time goes on. Figure 16. The concept of relative mobility as evidenced by zirconium, titanium, lithium. and magnesium in micromodule composites located in a sand plain (see Figure 7).

rigorous statistical methods.

The relative mobility of chemical elements can be dentified on a regional scale on gradient maps. For example, in the sand plain in the centre of the region (Figure 7) elements such as titanium and zirconium, may be expected to increase in sediments due to the outwash process which winnows heavy minerals. In contrast other elements, such as magnesium and lithiments in detectable, but minor, ways. um, which are present in less resistant minerals, may be expected to decrease. Examination of the surficial geological map of the region (Figure 7) reveals the presence of a sand plain, associated with some till noraines in micromodules B04, B14, B15, B06, B16, B07, B17, B08, B18, B09, and B19. The values for titanium, zirconium, magnesium, and lithium in hese micromodules appear to have gradients (Figure . The Clarke values for these elements in the 12 micromodule quarter composite technique (Figure 17)





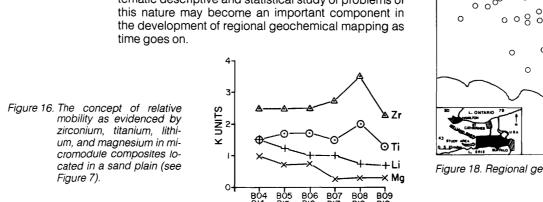
The idea of geochemical mobility in relation to regiona geochemical survey patterns is relatively new. Consequently there is little background data which can be used to assess the validity of the crude relative mobilty pattern discussed above. The explanation of the relative mobility of elements in primary minerals and weathering products requires a systematic follow-up study involving geochemistry Quaternary geology, and sedimentation. The geo chemical mobility pattern illustrated here is included to

indicate the nature of studies of this type more than to

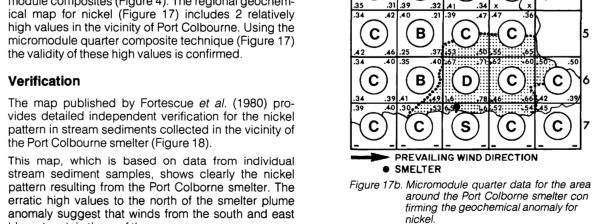
explain the causes of this particular example. Prob-

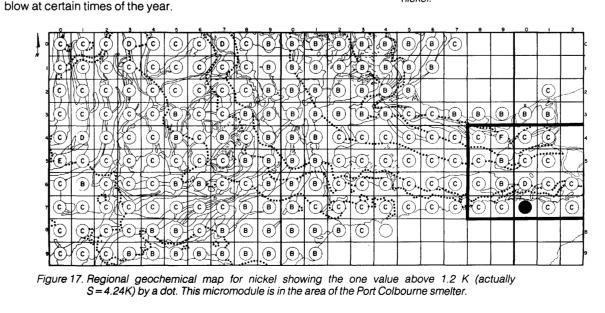
lems of this type are best identified and solved using

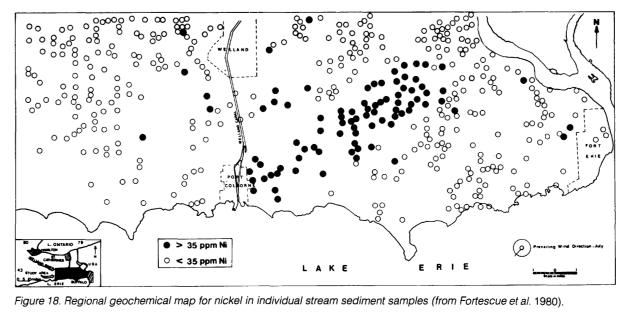
Conclusion This example draws attention to the study of different mobilities of elements within the same general geo-



At times some event which can be dated in the land- The detailed map of the level of nickel in stream sediscape gives rise to a geochemical pattern which can ments in the Niagara Peninsula provides proof that the overprint natural regional geochemical patterns for one or more elements. Examples of natural events of this type include major floods and volcanic eruptions. Man may also affect the geochemistry of stream sedi-Fortescue (1976) in a detailed study of stream sediments at the eastern end of the Niagara peninsula described an area of slightly enhanced nickel content in stream sediments collected downwind from the Port Colborne smelter. Although this pattern is certainly not considered to be a hazard to plants, animals, or man, it is a good example of a historical geochemical pattern due to man's activities which is detected in micromodule composites (Figure 4). The regional geochemical map for nickel (Figure 17) includes 2 relatively high values in the vicinity of Port Colbourne. Using the







SUMMARY

of interpreting chemical data for each of 20 elements in a total of over 4000 samples simply, rapidly, and reliably in relation to data and information from the other Beosciences. The first step was to base the study or 10 km by 10 km areas and by compositing the 20 samples collected from such areas, reduce the number of samples for chemical analysis 20 fold and the numbers of sample points for mapping from over 4000 to 190. The second step was to produce regional geochemical maps of the data for each element in a form in which they were comparable with each other and with similar maps produced anywhere in Ontario. This was done using the Clarke unit, which although it is relative rather than absolute, does provide a general guide to regional geochemistry. The use of 0.25 K intervals between levels for Clarkes is also relative but here again, experience shows that patterns with this interval may often relate directly to geological, pedological, ecological, or technological inputs to the sediments which would otherwise not be apparent. Although simple letter code regional geochemical maps are often difficult to interpret because of clutter, the parallel use of gradient analysis reduces clutter to a minimum and enhances patterns even in areas where gradient map panels into a scan sheet facilitates the recognition of gradients and other patterns. The use of conceptual models for the recognition of geochemical gradients (and related concepts derived from landscape geochemistry) focuses attention on the use of the predictive models for the interpretation of geochemical maps. Once identified, hypotheses for pattern causes can be established and proven by rigorously designed follow-up investigations. Further information on the scope of this approach to regional geochemistry for geoscience will be provided in a series of reports now in preparation which will describe details of the Southwest Ontario Geochemical Survey, It is hoped that the approach described here will lead to the broadening of interest in regional ged chemical surveys to include interdisciplinary activity involving other Earth Sciences and towards the day

This approach was designed to cope with the problem

CONCLUSIONS

activity is generally recognized.

1. The study supports the view that mineral appraisal and general geoscience regional geochemical patterns can be carried out simultaneously and effectively based on chemical data obtained from 20 sample composite samples of stream sediment collected from 10 km by 10 km micromodules. 2. The basing of data points for regional geochemical surveys using stream sediments collected from a 10 km by 10 km area (i.e. a micromodule) instead of single sites combined with the Clarke transform appears to have the following advantages in the Southwest-Ontario area: It reduces errors and stabilizes patterns at the

when the unique contribution of geochemistry to such

regional level thus facilitating interpretation. · Although the estimates for Clarke values are relative rather than absolute, the Clarke transformation of chemical data facilitates element to element pattern comparisons during the interpretative process. The combination of the use of the Clarke, the use of 0.25 K intervals for plotting micromodule values on regional geochemical maps, and gradient analysis of the maps themselves enables preliminary recognition of geochemical patterns for 20 elements in 4000 samples to be completed using a single scan sheet. The interpretation of regional geochemical patterns in terms of the presence of mineralization, bedrock geology, surficial deposits, and anthropogenic causes is facilitated using conceptual models based on the fundamentals of landscape geochemistry (eg. gradients, barriers,

· Although not essential, the confirmation of regional geochemical patterns using micromodule quarter composite data based on independent analyses of the same stream sediment samples provides a bridge between the proce-

dure of regional geochemical mapping as described here and Follow-up Level surveys de signed to explain regional patterns. From the practical viewpoint, the use of 20 sample micromodule composites reduces the cost of chemical analysis of samples nearly 20 fold while at the same time, focussing attention on single, or multi-element variations in the stream sediments. 4. The "micromodule composite" approach to re gional geochemical surveying depends upon strict quality control of the chemical analysis of samples using replicated reference standards within the batches of unknown. The "micromodule composite, clarke transform gradient analysis" approach to multi-element re gional geochemistry is applicable to simultaneous studies of the behaviour of any number of elements

GEOSCIENCE IMPLICATIONS OF THE MICROMODULE APPROACH TO REGIONAL GEOCHEMICAL MAPPING

To date, the technique of multi-element regional geo

chemical surveying based on chemical analysis of stream sediments (or similar materials) has been used argely for purposes of mineral exploration as described by Howarth (1983). The interpretation of regional surveys of this type is now considered largely as a complex problem in geomathematics. But deochemical anomalies' due to mineral deposits, pol lution, or some other cause, are rare in the context of multi-element regional geochemical mapping. Geochemical anomalies due to mineral deposits are not the only geochemical features of landscape of interest in geoscience.

The implications of the research described here are that certain other patterns (in addition to geochemical anomalies) can be predicted to occur in regional geochemical data and these predictions can be summa rized in a series of conceptual model patterns. It is demonstrated that if a regional geochemical survey is conducted in order to reveal the existence of the pat terns described in the conceptual models (i.e. using the micromodule/clarke/scan sheet approach) such patterns can be found. When such patterns are found on maps based on data from single chemical analyses of 20 sample composites, the patterns can be verified using techniques described by Howarth (1983) and

From the geoscience viewpoint, the study of regional geochemical model patterns obtained from relatively ew multi-element chemical anlayses paves the way for the preparation of geochemical surveys including most elements in the Periodic Table and the interpretation of their patterns in terms of mineral exploration bedrock geology (in covered areas), surficial geology (on the basis of geochemical signatures of specific lithologies), pollution due to man's activities, and the health and nutrition of plants, animals, and man. In summary, this study has demonstrated the feasibility of a predictive approach to regional geochemical mapping. As times goes on, the approach described here will certainly evolve and the conceptual models will be refined and described using geomathematics When that times comes, geochemistry along with geophysics, remote sensing, and other disciplines will be integrated with geology, soil science, and related disciplines to provide a truly interdisciplinary approach to

Earth Sciences.

the solution of complex problems in environmental

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CREDITS

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