Ministry of Natural Resources
Ontario

Hon. Alan W. Pope
Minister
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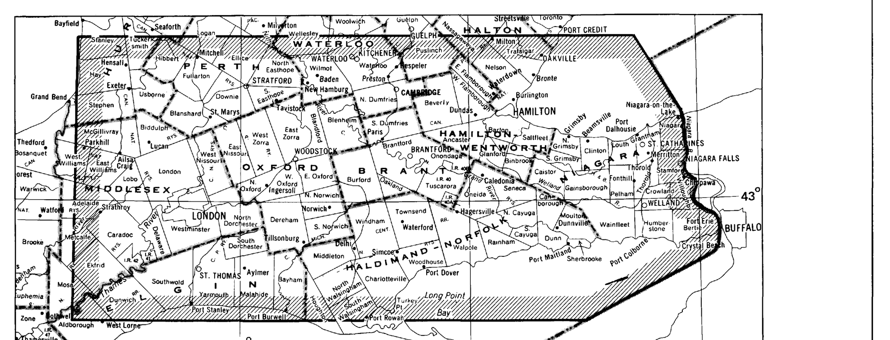
ONTARIO GEOLOGICAL SURVEY
MAP 80 612
GEOCHEMICAL SERIES

The Southwest Ontario Geochemical Survey

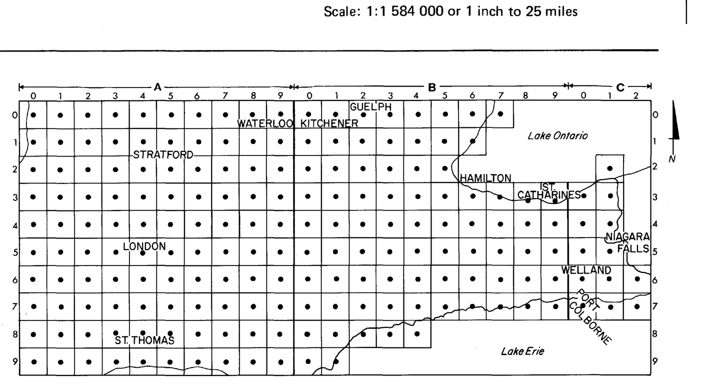
An Example of the Micromodule Approach to Regional Geochemical Mapping

Southern Ontario

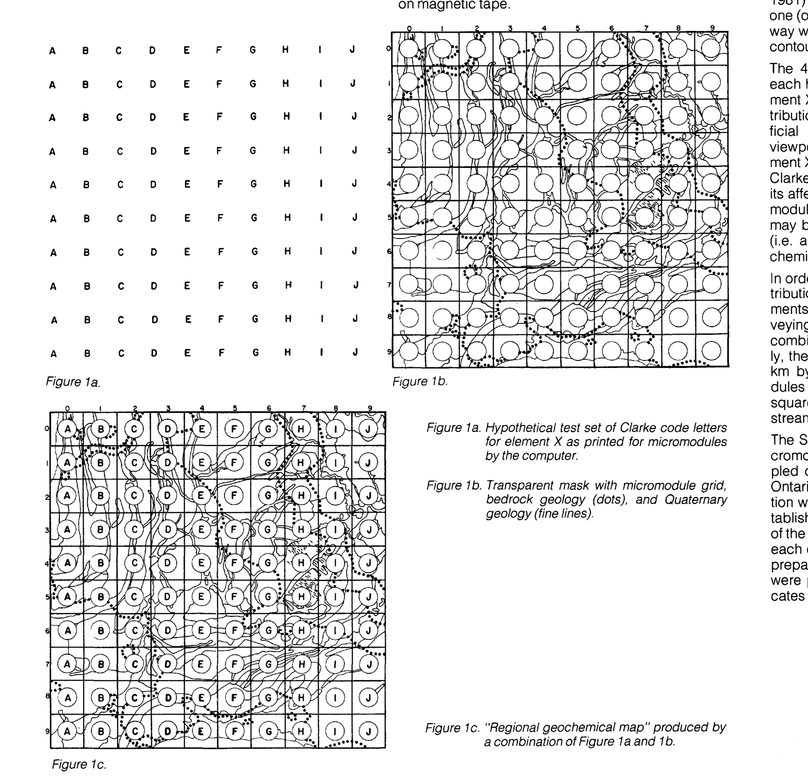
INTRODUCTION



LOCATION MAP



METHODOLOGY



General Descriptive Equation for Element Abundance in Stream Sediments

MICROMODULE GEOCHEMICAL MAPS BASED ON CLARKES

The chemical data from the chemical analysis for element X was transformed into Clarke values and assigned a letter code value according to the ppm limits for the 0.25 K intervals listed in Table 1. A computer program was written to print out these code letters representing the levels of element X in the Micromodule composites on a rectangular grid (Figure 1A). The grid was so arranged that it was on the same scale as a transparent plastic mask (Figure 1B) showing the micromodule grid, the geological formation outlines (dotted), and the features of the Quaternary geology (fine lines). In order to make the regional geochemical map, the mask was photocopied over the grid of code letters. Using this procedure, a set of 20 regional geochemical maps can be prepared in a day and the geochemical patterns for a 100 km by 200 km map area are quite legible at page size (Figure 1C). The area represented on Figure 1 is 100 km by 100 km.

GRADIENT ANALYSIS

Gradient analysis (Fortescue 1981) was devised as a 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.

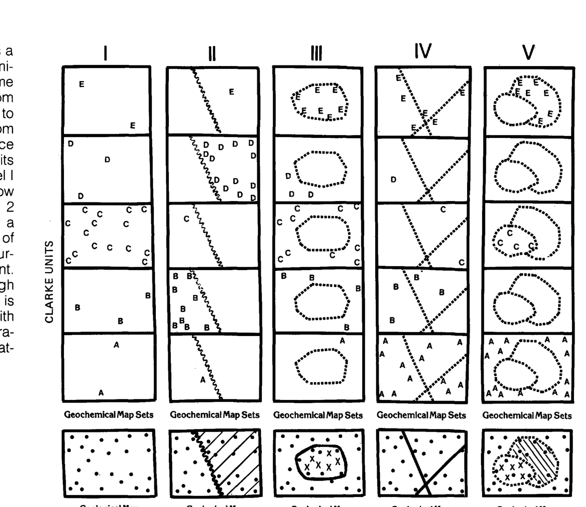


Figure 2. Hypothetical sets of geochemical data and geology designed to illustrate the principles of gradient analysis (from Fortescue 1981).

Table 1. Clarke values and Clarke code values used on the Southwest Ontario Regional Maps in percent (or parts per million) for 20 elements arranged in decreasing abundance in the Earth's Crust (Clarke values from Ronov and Yaroshevski 1972).

KK Units	Si	Al	Fe	Ca	Mg	Na	K	Ti	P	Mn	Ba	Sr	Zr	V	Cr	Ni	Zn	Cu	Co	Li	Pb	Th	U	Be	As	Mo	Cd	Ag	KK Units
Z 25.00	[illegible]	[illegible]	[illegible]				45.00%	15.75%	2.80%	2.65%	9750.0	9600	4050.0	3400	3050.0	2475.00	1900	1700	725.00	450.0	325.00	202.50	57.50	50.0	45.00	30.0	4.00	2.00	Z 25.00
Y 20.00	[illegible]	[illegible]	[illegible]			44.00%	36.00%	12.60%	2.24%	2.12%	7800.0	7680	3240.0	2720	2440.0	1980.00	1520	1360	580.00	360.0	260.00	162.00	46.00	40.0	36.00	24.0	3.20	1.60	Y 20.00
X 15.00	[illegible]	[illegible]	[illegible]		40.500%	33.00%	27.00%	9.45%	1.68%	1.59%	5850.0	5760	2430.0	2040	1830.0	1485.00	1140	1020	435.00	270.0	195.00	121.50	34.50	30.0	27.00	18.0	2.40	1.20	X 15.00
W 10.00	[illegible]	[illegible]	[illegible]	46.00%	27.000%	22.00%	18.00%	6.30%	1.12%	10060	3000.0	3840	1620.0	1360	1220.0	990.00	760	680	290.00	180.0	130.00	81.00	23.00	20.0	18.00	12.0	1.60	0.80	W 10.00
V 5.00	[illegible]	[illegible]	[illegible]	22.00%	13.500%	11.00%	9.00%	3.15%	5600	5300	1950.0	1920	810.0	680	610.0	495.00	380	340	145.00	90.0	65.00	40.50	19.55	10.0	9.00	6.0	0.80	0.40	V 5.00
U 4.75	[illegible]	[illegible]	[illegible]	21.85%	12.830%	10.45%	8.55%	2.99%	5320	5035	1852.5	1824	769.5	646	579.5	470.25	361	323	137.75	85.5	61.75	38.48	18.98	9.5	8.55	5.7	0.76	0.38	U 4.75
T 4.50	[illegible]	[illegible]	[illegible]	20.70%	12.150%	9.90%	8.10%	2.84%	5040	4770	1755.0	1728	729.0	612	549.0	455.50	342	306	130.50	81.0	58.50	36.45	18.40	9.0	8.10	5.4	0.72	0.36	T 4.50
S 4.25	[illegible]	[illegible]	[illegible]	19.55%	11.480%	9.35%	7.65%	2.68%	4760	4505	1657.5	1632	688.5	578	518.5	420.75	323	289	123.25	76.5	55.25	34.43	17.83	8.5	7.65	5.1	0.68	0.34	S 4.25
R 4.00	[illegible]	[illegible]	[illegible]	18.40%	10.800%	8.80%	7.20%	2.52%	4480	4240	1560.0	1536	648.0	544	488.0	396.00	304	272	116.00	72.0	52.00	32.40	17.25	8.0	7.20	4.8	0.64	0.32	R 4.00
Q 3.75	[illegible]	[illegible]	[illegible]	17.25%	10.130%	8.25%	6.75%	2.36%	4200	3975	1462.5	1440	607.5	510	457.5	371.25	285	255	108.75	67.5	48.75	30.38	8.63	7.5	6.75	4.5	0.60	0.30	Q 3.75
P 3.50	[illegible]	[illegible]	[illegible]	16.10%	9.450%	7.70%	6.30%	2.21%	3920	3710	1365.0	1344	567.0	476	427.0	346.50	266	238	101.50	63.0	45.50	28.35	8.05	7.0	6.30	4.2	0.56	0.28	P 3.50
O 3.25	[illegible]	[illegible]	[illegible]	14.95%	8.780%	7.15%	5.85%	2.05%	3640	3445	1267.5	1248	526.5	442	396.5	321.25	247	221	94.25	58.5	42.25	26.33	7.48	6.5	5.85	3.9	0.52	0.26	O 3.25
N 3.00	[illegible]	[illegible]	[illegible]	13.80%	8.100%	6.60%	5.40%	1.89%	3360	3180	1170.0	1152	486.0	408	366.0	297.00	228	204	87.00	54.0	39.00	24.30	6.90	6.0	5.40	3.6	0.48	0.24	N 3.00
M 2.75	[illegible]	[illegible]	[illegible]	12.65%	7.430%	6.05%	4.95%	1.73%	3080	2195	1072.5	1056	445.5	374	335.5	272.25	209	187	79.75	49.5	35.75	22.28	6.33	5.5	4.95	3.3	0.44	0.22	M 2.75
L 2.50	[illegible]	[illegible]	[illegible]	11.50%	6.750%	5.50%	4.50%	1.58%	2800	2650	975.0	960	405.0	340	305.0	247.50	190	170	72.50	45.0	32.50	20.25	5.75	5.0	4.50	3.0	0.40	0.20	L 2.50
K 2.25	[illegible]	[illegible]	[illegible]	10.35%	6.080%	4.95%	4.05%	1.42%	2520	2385	877.5	864	364.5	306	274.5	222.75	171	153	65.25	40.5	29.25	18.23	5.18	4.5	4.05	2.7	0.36	0.18	K 2.25
J 2.00	[illegible]	[illegible]	[illegible]	9.20%	5.400%	4.40%	3.60%	1.26%	2240	2120	780.0	768	324.0	272	244.0	198.00	152	136	58.00	36.0	26.00	16.20	4.60	4.0	3.60	2.4	0.32	0.16	J 2.00
I 1.75	[illegible]	[illegible]	[illegible]	8.05%	4.730%	3.85%	3.15%	1.10%	1968	1855	682.5	672	283.5	238	213.5	173.25	133	119	50.75	31.5	22.75	14.18	4.03	3.5	3.15	2.1	0.28	0.14	I 1.75
H 1.50	[illegible]	[illegible]	[illegible]	6.90%	4.050%	3.30%	2.70%	9480	1680	1590	585.0	576	243.0	204	183.0	148.50	114	102	43.50	27.0	19.50	12.15	3.45	3.0	2.70	1.8	0.24	0.12	H 1.50
G 1.25	34.10%	10.40%	7.75%	5.75%	3.370%	2.75%	2.25%	7900	1400	1325	487.5	480	202.5	170	152.5	123.75	95	85	36.25	22.5	16.25	10.13	2.88	2.5	2.25	1.5	0.20	0.10	G 1.25
CLARKE F 1.00	(273 000) 27.3%	(83 600) 8.30%	(62 200) 6.20%	(46 600) [illegible]	(27 640) 2.700%	(22 700) 2.20%	(18 400) 1.80%	6320 (0.63%)	1120	1060	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 1.00
E 0.75	20.48%	6.23%	4.65%	3.45%	2.020%	1.65%	1.35%	4740	840	795	292.5	288	121.5	102	91.5	74.25	57	51	21.75	13.5	9.75	6.08	1.73	1.5	1.35	0.9	0.12	0.06	E 0.75
D 0.50	13.65%	4.15%	3.10%	2.30%	1.350%	1.10%	0.90%	3160	560	530	195.0	192	81.0	68	61.0	49.50	38	34	14.50	9.0	6.50	4.05	1.15	1.0	0.90	0.6	0.08	0.04	D 0.50
C 0.25	6.83%	2.08%	1.55%	1.15%	0.675%	0.55%	0.45%	1580	280	265	97.5	96	40.5	34	30.5	24.75	19	17	7.25	4.5	3.25	2.03	0.58	0.5	0.45	0.3	0.04	0.02	C 0.25
B 0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0	0	0.0	0	0.0	0.0	0	0	0.00	0.0	0.00	0.00	0.00	0.0	0.00	0.0	0.00	0.00	B 0.00
	Si	Al	Fe	Ca	Mg	Na	K	Ti	P	Mn	Ba	Sr	Zr	V	Cr	Ni	Zn	Cu	Co	Li	Pb	Th	U	Be	As	Mo	Cd	Ag	

Gradient Maps for the Southwest Ontario Survey

So far we have been concerned with hypothetical gradient map patterns. In Figure 4 gradient analysis patterns for 20 elements in the micromodule samples are shown. The elements are arranged in order of increasing K values which range from B(0 to 0.25 K) to N(3.0 K). 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 composite. Because the performance of the chemical analysis for each of the 20 elements is known and the limits of each micromodule are known it is quite practical to reduce the map panel scale and still retain the geochemical patterns (Figure 4).

Conceptual Models for the Interpretation of Patterns on the Multi-Element Scan Sheet for the Southwest Ontario Geochemical Survey Area

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 patterns on the regional geochemical maps of Southwest Ontario. How the concepts of 'geochemical anomalies', geochemical gradients, geochemical barriers, geochemical flows, relative mobility, and historical geochemistry relate to the patterns on the regional geochemical maps derived from gradient analysis is illustrated on Figure 3.

Explanation of Conceptual Model Patterns

Briefly, **geochemical anomalies** due to mineral deposits (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 appear to move across the surveyed area of the 100 km by 100 km area on which this series of models is drawn. **Geochemical barriers** produce abrupt, often linear, changes in the level of element X in stream sediments. 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 atmosphere. 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 weathering. Geochemical patterns due to historical events in landscapes usually overprint all other patterns as a result of man's activity (e.g. smelter operations) or natural catastrophies (e.g. volcanic eruptions). For further information on these models and the scientific approach upon which they are based *see* Fortescue (1980).

THE SCAN SHEET OF THE SOUTHWEST ONTARIO REGIONAL GEOCHEMICAL DATA

Figures 2 and 3 are examples of a scan sheet which is a convenient way of presenting the map panels for 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 Southwest Ontario area depicted on Figure 5. Figure 5 illustrates the relationship between the micromodule grid and the dots shown on Figure 4.

OVERVIEW OF THE GEOLOGY OF SOUTHWEST ONTARIO

On Figure 6 is presented a generalized map of Southwest Ontario showing the outcrop area of the principal 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 Quaternary geology from Chapman and Putman (1972).

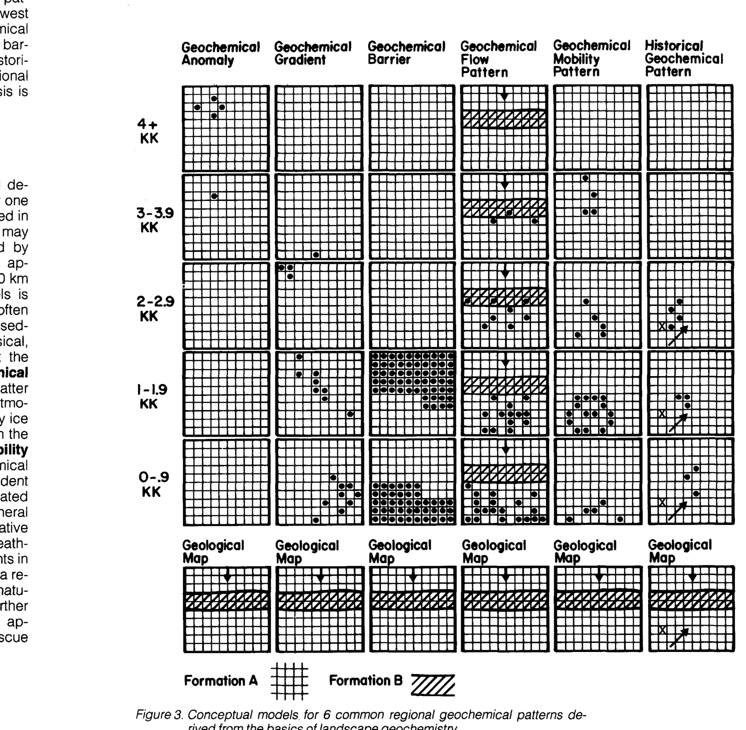
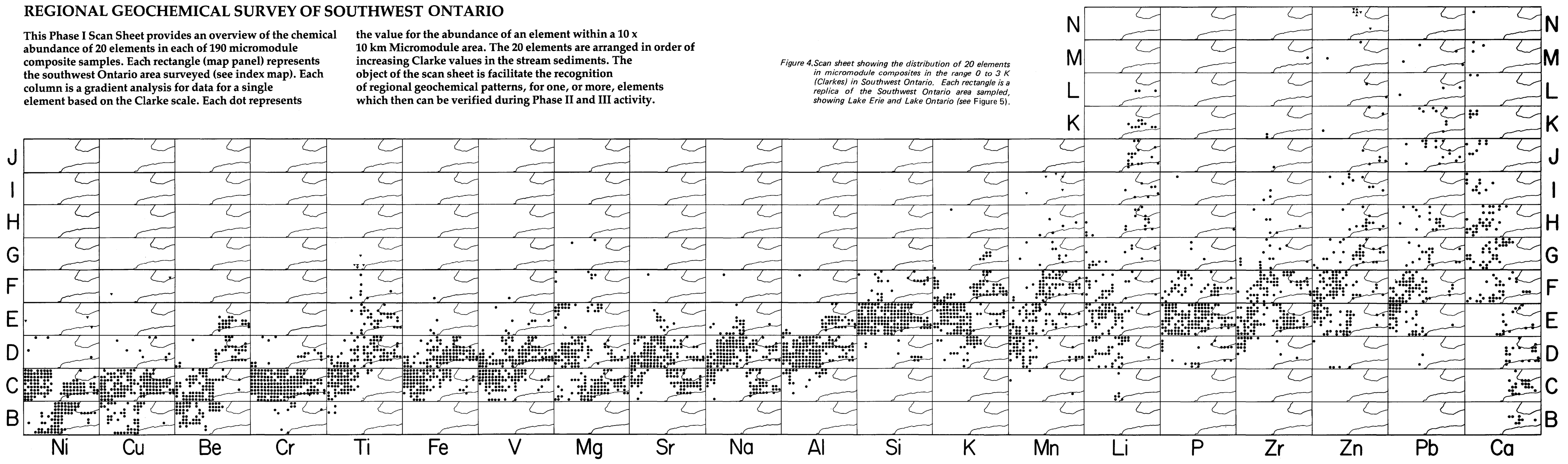


Figure 3. Conceptual models for 6 common regional geochemical patterns derived from the basics of landscape geochemistry.

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 composite samples. Each rectangle (map panel) represents the southwest Ontario area surveyed (see index map). Each column is a gradient analysis for data for a single element based on the Clarke scale. Each dot represents the value for the abundance of an element within a 10 x 10 km Micromodule area. The 20 elements are arranged in order of increasing Clarke values in the stream sediments. The object of the scan sheet is facilitate the recognition of regional geochemical patterns, for one, or more, elements which then can be verified during Phase II and III activity.



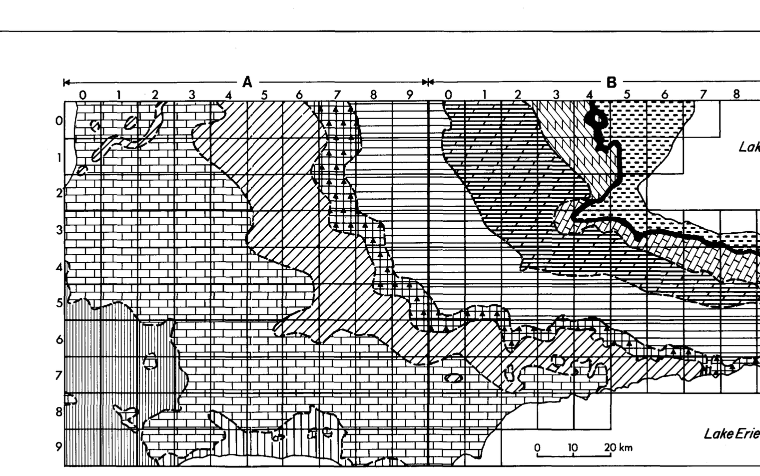


Figure 6. Generalized bedrock geological map of Southwest Ontario (from Hewitt 1972).

LEGEND

MIDDLE DEVONIAN
HAMILTON GROUP: *grey shale and limestone.*
MARCELLUS FORMATION: *grey shale.*
DUNDEE FORMATION: *limestone.*
DETROIT RIVER GROUP: *limestone and dolostone.*

LOWER DEVONIAN AND UPPER SILURIAN
BOIS BLANC FORMATION: *cherty limestone.*
BASS ISLANDS FORMATION: *dolostone.*

UPPER SILURIAN
SALINA FORMATION: *dolostone, shale, gypsum, salt.*

MIDDLE AND LOWER SILURIAN
GUELPH FORMATION: *dolostone.*
AMABEL FORMATION: *dolostone.*
LOCKPORT FORMATION: *dolostone*
CLINTON AND CATARACT GROUPS: *sandstone, shale, dolostone.*

UPPER ORDOVICIAN
QUEENSTON FORMATION: *red shale.*

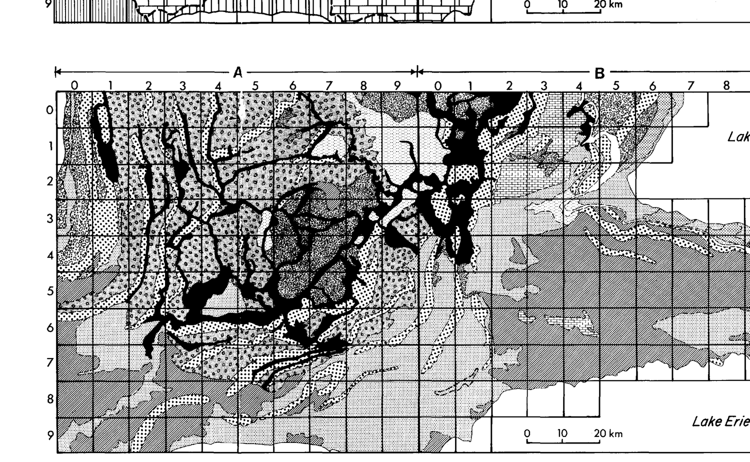


Figure 7. Generalized surficial geology map of Southwest Ontario (from Chapman and Putnam 1972)

LEGEND

Escarpments
Till Moraines
Spillways
Kame Moraines
Till Plains (Undrumlinized)
Till Plains (Drumlinized)
Bevelled Till Plains
Limestone Plains
Shale Plains
Sand Plains
Clay Plains
Peat and Muck

EXAMPLES

Example I: Geochemical Anomaly Pattern

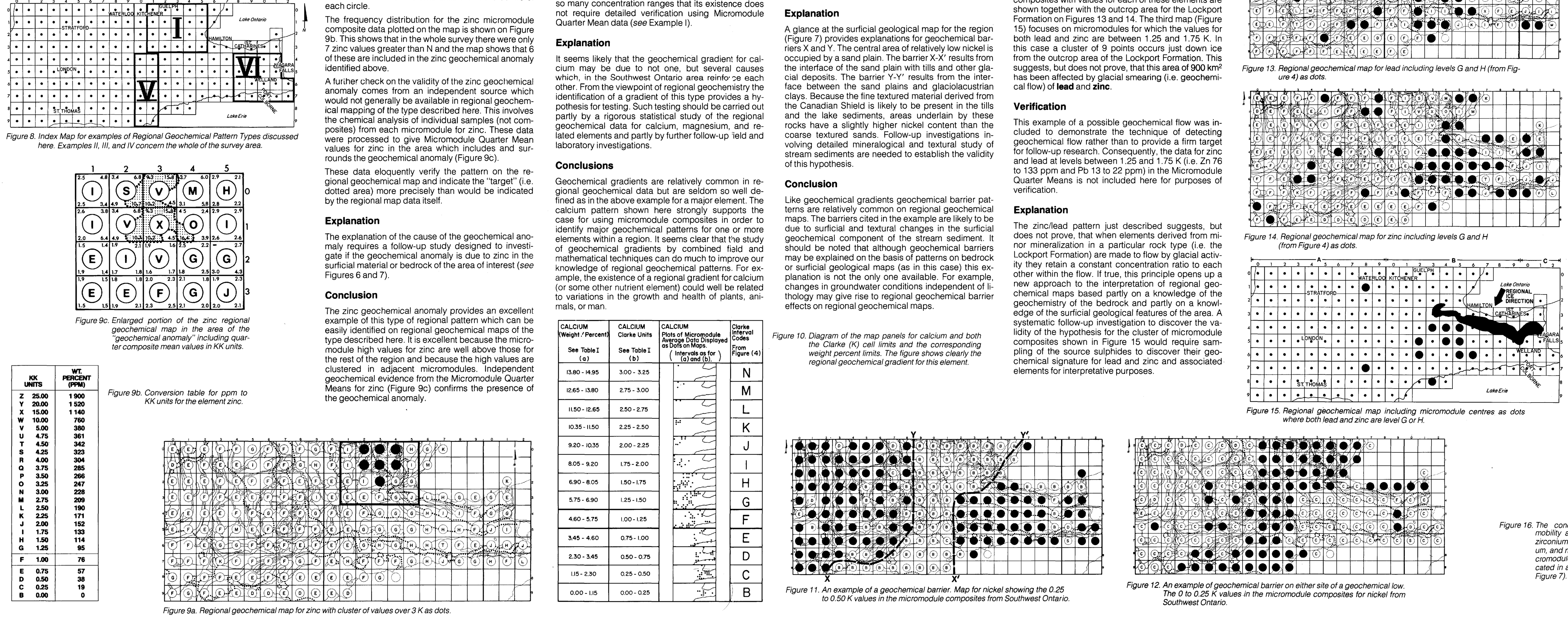
Example II: Geochemical Gradient Pattern

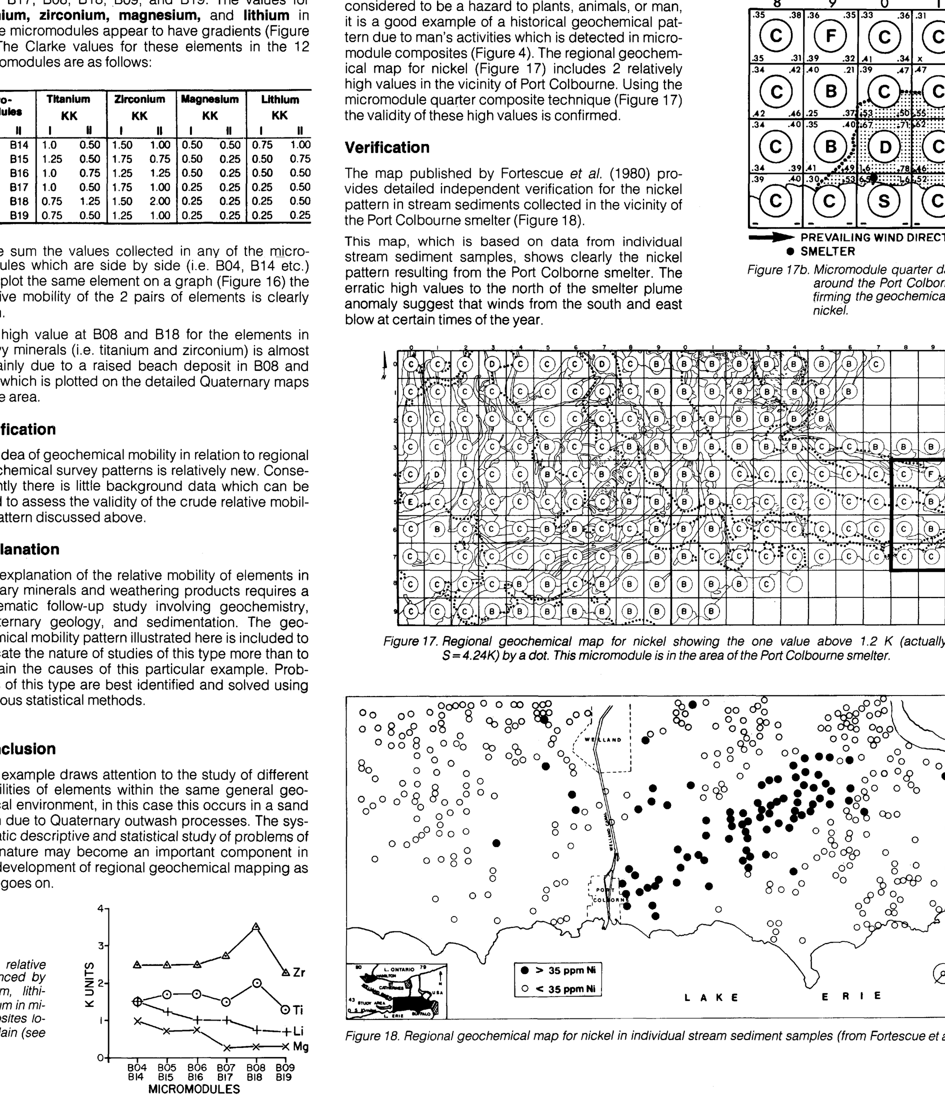
Example III: Geochemical Barrier Pattern

Example IV: Geochemical Flow Patterns

Example V: Geochemical Mobility Patterns

Example VI: Historical Geochemical Patterns





SUMMARY

CONCLUSIONS

GEOSCIENCE IMPLICATIONS OF THE MICROMODULE APPROACH TO REGIONAL GEOCHEMICAL MAPPING

REFERENCES

Beus, A.A.
1976: The Geochemistry of the Lithosphere; Translated from the Russian by V. Agranat, MIR Publishers, Moscow, 391p.

CREDITS