INTEGRATING BEDROCK GEOLOGY WITH STREAM-SEDIMENT GEOCHEMISTRY IN A GEOGRAPHIC INFORMATION SYSTEM (GIS): CASE STUDY NTS 92H

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INTRODUCTION

Two data sets commonly used for geological resource assessment include bedrock geology and stream-sediment geochemistry. Traditional methods for determining relationships between these data include both qualitative and quantitative techniques. Qualitative interpretation and integration is generally based upon visual observations of spatial coincidence between the data. Quantitative results can be derived by summarising point values according to the dominant lithology of a sample's drainage area, or according to the geological unit it coincides with. Qualitative methods lack numerical explicitness, reproducability and rigour. Quantitative methods struggle with the fact that stream-sediment geochemistry sample points are manipulated to represent areal distributions, where the area represented by each sample must somehow be inferred before quantitative analysis can take place. This study concerns quantitative techniques.

Geographical information systems (GIS) offer several methods for transforming geochemical points into areal coverage, allowing the resulting choropleth map to be integrated with maps depicting bedrock geology and used in the preparation of quantitative summaries or for further analysis. For example, points can be transformed into discrete homogeneous polygons (Thiessen polygons, drainage basins), or into continuous surfaces via interpolation (contouring, moving averages). This capability obviously has tremendous potential for geological interpretation and mineral exploration.

An ongoing research project at the University of Victoria, conducted in conjunction with the British Columbia Geological Survey Branch, is examining alternative methodologies for computationally integrating bedrock geology with stream-sediment geochemistry in GIS, including comparing and contrasting different results obtained. This research note presents a cursory discussion of general methodologies for interpolating stream-sediment geochemical sample points for integration with bedrock geology within GIS. Preliminary results are discussed.

Use of commercial names in this paper is for descriptive purposes only. It does not constitute endorsement by the University of Victoria or the British Columbia Geological Survey.

JUSTIFICATION FOR STREAM-SEDIMENT POINT TRANSFORMATION

For the purposes of the following discussion, the basis for transforming stream-sediment point samples into areal coverages can be discussed in terms of physical factors and spatial analytical concepts. Physical factors are those which are responsible for the sediment make-up of a sample site before collection takes place. They include surficial geomorphology, bedrock geology, structure, atmospheric pollutants, fauna, flora and other physiographical variables. Spatial concepts entail upstream analysis, spatial autocorrelation, proximity, and distance decay. There are also other non-physical factors, including sampling and recording techniques, and analytical procedures, which may contribute to error and uncertainty in geochemical determinations, but these do not constitute a basis for spatial transformation. The latter non-physical factors are beyond the control of this study and will not be considered further.

PHYSICAL FACTORS

The catchment basin associated with a given stream-sediment sample is the dominant physical factor controlling input of material. It can be determined by including successively adjacent locations with elevations higher than the point of sampling. Within a basin, various other physical factors may influence the composition of the stream sediment sample, or contribute to within-basin variation. These include slope, aspect, curvature, vegetation, differential weathering of bedrock, rainfall and wildlife. There are also factors which transcend drainage basin boundaries. Geological material from beyond the catchment boundary may be present due to glacial transport or atmospheric pollution; it is also possible for groundwater flow and biological activity to transport material across watershed boundaries.

SPATIAL ANALYSIS

'The first law of geography' states ". . . everything is related to everything else, but near things are more related than distant things." (Tobler, 1970). In map variables exhibiting spatial pattern due to proximity, spatial autocorrelation is said to exist (Johnston, 1986). Assuming spatial autocorrelation exists, how does it affect the nature of spatial patterns? Spatial autocorrelation is associated with the topological relationships and metric relationships between spatial phenomena. Spatial patterns can therefore be discerned based upon topological and metric analysis, including directional relationships (upstream versus downstream), adjacency, proximity and through metric-distance decay.

The role of stochastic processes, of course, should not be ignored. Given these constraints, a number of techniques have been developed to translate point data into areal coverage based upon the concept of spatial autocorrelation.

TECHNIQUES FOR TRANSFORMING POINT DATA

Techniques for transforming point data into thematic maps can be divided into discrete and continuous methods. Discrete methods assume that a distinct area can be associated with each point, and that there is no variation within this area; variation occurs abruptly along polygon boundaries only. In contrast, continuous methods assume that variation is gradual between observation points or over the entire area of interest. A number of transformations are briefly introduced below. Most commercial GIS support one or a number these techniques. The reader is referred to Burrough (1987), George and Bonham-Carter (1990), McCullagh (1988), Davis (1986) or Lam (1983) for in-depth discussions.

CATCHMENT BASINS

Catchment basins have been used to define area-of-influence polygons for stream-sediment samples (*see*, for example, Bonham-Carter *et al.*, 1988; Dwyer and Nash, 1987; Rogers *et al.*, 1990). Catchment basins assume elevation to be the defining criterion for area-of-influence of a sample point. This is a discrete polygon method and therefore assumes within-polygon uniformity of geochemistry. Catchment basins can be determined manually from elevation contours, a time-consuming and tedious task, or digitally from a digital terrain model. Not all GIS support automatic digital watershed-identification routines.

THIESSEN POLYGONS

Thiessen polygons, also known as Voronoi or proximal polygons, assume that the extent of a point's influence can be strictly defined by its proximity to neighbouring points. Thus, for a given distribution of points, Thiessen polygons are defined by joining right-angle bisectors of lines connecting all neighbouring points. All locations in resulting polygons are closer to the defining point than any other (assuming unweighted transformation). Thiessen polygons are a discrete method and the primary drawback is again their inability to reflect within-polygon variation and gradual changes between sample points (Saxton Branson, 1989). For a detailed discussion of Thiessen tessellations refer to Gold (1989) or Burrough (1987).

CONTOURING

This method is analogous to manual contouring approaches traditionally employed by geologists. A continuous surface can be created by determining the values of unknown locations through linear interpolation between known values. This method assumes sample points represent exact locational values, and the method may not be appropriate if critical values (local maxima, minima) are not defined by the point distribution. Interpolation between sample points can be both linear or nonlinear.

WEIGHTED AVERAGES

This represents a local interpolation method which considers the values of several points within a defined window (or kernel) to determine an average value for any point within it. Averaging can be linear or nonlinear by defining appropriate distance-decay parameters. The method is discussed in detail by Burrough (1987) and George and Bonham-Carter (1990). A number of limitations have been identified. Problems may occur if the data points tend to be clustered (Burrough, 1987), and the original data values may be lost due to generalization. The user is also required to have some knowledge of the data which allows for the determination of appropriate kernel size and distance-decay parameters.

OPTIMAL INTERPOLATION

Optimal interpolation, or Kriging, assumes that variation is too complex to be modelled using mathematics, and that it therefore must be treated as a stochastic process. The technique depends upon the variogram for summarizing the form of the variation, its magnitude and spatial scale (Oliver and Webster, 1990). Original data values are maintained and estimates of error can be obtained (Burrough, 1987). This type of optimal interpolation procedure is largely absent in commercial GIS software, however, Oliver and Webster (1990) believe it can be incorporated.

TREND-SURFACE ANALYSIS

Trend-surface analysis is a global interpolation technique, that is values for a given location are determined by considering the entire data set (the methods listed above are local interpolators). This method employs multiple regression to determine a polynomial equation which can be used to estimate the value for any given location. It is susceptible to highly anomalous values (Burrough, 1987) and original data values are not represented in resulting surfaces.

CLASSIFYING CONTINUOUS SURFACES

Point data transformed into continuous surfaces can be made discrete through classification methods. This may be useful for display purposes but results in generalization and loss of resolution if used for analysis. Classifying continuous data also requires an appropriate scheme for grouping data values based upon some underlying nature (*e.g.* statistical). Refer to Burrough (1987) for a discussion on techniques and problems associated with classifying continuous data.

INTEGRATING STREAM-SEDIMENT GEOCHEMISTRY WITH GEOLOGY IN A GIS

The practical aspects of data input, transformation and integration of the two geoscience data sets are described in

TABLE 4-4-1
DESCRIPTION OF GEOLOGICAL UNITS

	QUATERNARY
1	Drift; alluvium; colluvium, recent deposits.
2	Basaltic flows.
	TERTIARY
3	Basalt, olivine basalt, minor flows.
4	Intermediate, felsic pyroclastics and flows.
5	Granodiorite.
6	Intermediate, felsic pyroclastics and flows.
7	Granodiorite.
8	Granodiorite.
9	Intermediate with local mafic and felsic flows, volcaniclastics.
10	Sandstone, conglomerate, argillite.
11	Granodioritic and intermediate intrusions.
	CRETACEOUS AND/OR TERTIARY
12	Pegmatitic granite gneiss; pelitic schist, amphibolite, minor marble, ultramafic rocks.
13	Blueschist, local amphibolite, minor marble and ultramafic rock.
14	Greenschist: mafic to intermediate volcanics, phyllite, minor volcanic, conglomerate.
	CRETACEOUS
15	Granodiorite, quartz monzonite.
16	Mainly granite.
17	Felsic intrusions.
18	Intermediate, locally felsic, mafic volcanics sandstone, shale, conglomerate.
19	Mafic volcanics.
20	Chert-grain sandstone and conglomerate.
21	Undifferentiated sediments.
22	Sandstone, argillite, conglomerate.
23	Intermediate intrusions, minor ultramafic rock.
24	Felsic and mafic gneiss.
	JURASSIC(?) AND CRETACEOUS
25	Intermediate pyroclastics and flows.
26	Sandstone, conglomerate.
27	Granodiorite and gneiss.
28	Diorite and amphibolite.
29	Granite and pegmatite.
30	Sandstone, conglomerate, argillite.
31	Conglomerate, sandstone, argillite.
32	Granite and granodiorite.
33	Intermediate volcaniclastics.
34	Argillite, tuff.
35	Intermediate, locally felsic flows and pyroclastics; local argillite, conglomerate.
36	Argillite, slate, siltstone, tuff.
37	Sandstone, argillite; local mafic, intermediate volcanics.
	TRIASSIC AND/OR JURASSIC
38	Granodiorite.
39	Diorite, amphibolite.
40	Syenite, diorite, gabbro, ultramafic rock.
41	Argillite, sandstone, minor carbonate.
42	Mafic to felsic volcanics, minor argillite.
43	Felsic to intermediate pyroclastics, argillite.
44	Intermediate pyroclastics and flows.
45	Mafic pyroclastics and flows.
46	Argillite, sandstone, tuff, breccia, conglomerate.
47	Amphibolite, diorite, mylonite, schist, marble.
48	Siliceous argillite, mafic volcanics.
49	Mafic volcanics.
50	Granite gneiss.
51	Carbonate.
52	Schist, metachert, pelite, amphibolite, marble, ultramafic rock.
53	Ultramafic rock, local gabbro.
	PERMIAN TO JURASSIC
54	Chert, pelite, mafic volcanics, minor limestone, gabbro and ultramafic rock.
55	Mafic volcanics.
56	Siliceous and chlorite schist, phyllite.
57	Ultramafic rock and local gabbro.
	ORDOVICIAN TO TRIASSIC
58	Argillite, chert, mafic volcanics, minor carbonate and ultramafic rock.
59	Amphibolite, gneiss, minor ultramafic rock.
	DEVONIAN TO PERMIAN
60	Pelite, sandstone, minor conglomerate, mafic and felsic volcanics; carbonate.
61	Metadiorite and gabbro.
70	Water bodies.

Generalized after Monger, 1989.

TABLE 4-4-2
SUMMARY OF DATA VARIABLES USED FOR THE STUDY

Data Variable	Data Type	Attributes	Input/Source
Stream-sediment Geochemistry	Points	Geochemical Elements	Digital files; GSC OF 865/MEMPR BC RGS 7
Drainage Basins	Polygonal	Geochemical Elements	Digitized; derived from NTS 92H using geochemical points as criteria
Bedrock Geology	Polygonal	Geological Classes	Digitized from 1:250 000 GSC geology map 92H
Geology Cut To Drainage Cover	Polygonal	Geological Classes	Derived from intersection of geology/drainage maps
Thiessen Polygons	Polygonal	Geochemical Elements	Computed from geochemical point locations

this section. The study area used is as defined by the boundary of map-sheet NTS 92H, located in southwestern British Columbia.

DATA INPUT

A 1:250 000-scale bedrock geology map (NTS 92H, Monger, 1989) containing 791 polygons was manually digitised. Attribute tags identifying map units were added to each polygon. Including water bodies, there are 62 classes; a generalized description of each class is provided in Table 4-4-1. Catchment basins were manually determined from elevation contours (NTS 92H) according to the location of stream-sediment sample points (BC-RGS-7). Of the 995 sample locations for 92H, 55 are duplicate samples and another 27 lack elemental analyses; these sample locations were discarded. Of the remaining 913, two fell on the southern map-sheet boundary and appreciable catchment

TABLE 4-4-3
OVERLAY SUMMARIES

Unit	Area (Square km)		Pts	Zinc (ppm)			Copper (ppm)			Lead (ppm)			Nickel (ppm)		
	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP
1	964.6	2091.6	206	60.6	72.4	75.4	30.5	31.4	34.9	4.53	5.96	5.7	16.4	16.2	18.0
2	5.2	6.9	0	50.6	53.2		21.6	23.7		1.86	2.44		8.6	8.9	
3	8.4	11.8	0	57.7	64.4		16.2	20.8		3.82	6.30		7.3	13.6	
4	9.1	9.1	1	123.4	61.4	56.0	53.5	36.4	33.0	16.81	12.07	12.0	36.7	11.4	10.0
5	151.1	206.0	12	39.7	40.9	30.9	22.1	21.8	21.2	4.87	6.20	5.2	15.0	11.6	9.1
6	53.7	70.1	2	72.2	68.3	79.5	18.6	19.7	16.0	11.59	10.10	19.5	16.6	8.8	9.5
7	170.2	312.7	24	62.9	50.8	57.0	32.2	30.2	32.8	10.25	6.80	7.5	19.0	12.9	12.5
8	209.2	240.7	10	60.9	52.1	44.7	15.5	14.4	9.0	4.04	4.45	3.9	11.3	12.8	4.0
9	271.3	429.7	15	54.6	52.1	51.0	30.0	27.4	32.3	5.92	5.35	6.3	13.4	13.8	12.1
10	63.9	167.6	12	52.7	60.7	55.0	24.7	28.9	20.5	6.04	6.80	5.1	17.8	14.3	11.4
11	96.2	182.0	9	68.9	68.7	88.2	30.4	29.4	28.2	4.81	5.26	9.4	31.8	29.1	17.4
12	111.7	218.4	22	66.7	62.5	63.4	33.4	30.5	33.0	6.29	3.89	3.3	35.4	52.3	63.9
13	210.9	344.4	22	50.6	49.8	49.9	35.6	32.0	35.3	2.66	2.90	2.5	43.9	37.2	39.7
14	13.2	17.1	0	126.6	104.8		53.3	47.8		6.96	6.22		61.0	52.8	
15	495.4	705.3	32	43.6	36.9	34.7	6.7	4.7	3.2	3.09	3.27	3.0	8.9	7.0	5.9
16	315.6	377.5	13	93.5	83.9	49.3	41.8	33.0	15.8	10.77	9.07	5.8	5.8	5.1	5.7
17	45.0	93.9	6	125.5	172.1	84.7	93.6	95.5	48.2	14.14	19.58	11.7	7.8	10.3	9.0
18	401.2	696.6	41	61.6	63.5	62.9	18.9	20.5	20.2	4.15	4.48	3.8	9.3	9.4	9.4
19	115.5	264.0	17	58.5	64.2	62.5	32.1	37.4	39.1	2.81	3.22	3.6	51.2	36.4	25.2
20	12.0	13.0	1	70.2	70.1	73.0	29.7	38.7	29.0	4.50	3.97	1.0	8.3	10.2	9.0
21	346.0	478.3	21	60.7	62.3	63.0	20.3	21.3	20.0	4.48	5.58	8.0	14.3	14.4	12.0
22	165.1	294.5	22	102.2	102.2	102.7	31.0	38.4	54.5	6.20	7.52	9.0	21.4	18.6	17.6
23	455.0	816.2	52	39.8	42.6	43.6	22.0	21.7	20.0	2.97	3.59	3.7	26.1	24.5	24.0
24	29.7	71.0	2	32.6	37.4	34.5	32.6	30.4	18.0	4.43	4.60	3.0	3.7	4.7	8.0
25	50.6	87.5	7	63.2	70.1	68.4	31.7	31.4	34.1	3.84	4.61	5.9	9.0	9.8	9.6
26	5.8	61.3	2	73.7	89.3	105.0	26.3	37.5	46.0	3.11	3.05	2.5	10.8	26.6	35.0
27	370.5	611.4	38	46.8	50.5	50.9	16.5	17.2	16.3	3.14	3.81	4.1	7.0	7.0	8.5
28	15.6	46.7	2	58.6	66.0	57.0	29.4	23.6	20.0	6.18	9.30	9.0	14.8	14.9	30.0
29	125.4	161.9	8	54.7	53.0	51.2	22.3	17.6	15.2	4.32	5.01	5.6	10.3	7.9	6.8
30	6.0	10.3	0	130.2	201.8		58.9	91.9		9.64	16.64		20.8	26.7	
31		15.6	0		154.7			31.9			15.04			10.2	
32	660.6	993.4	33	58.6	64.1	86.3	12.3	13.6	13.7	5.50	5.41	7.8	4.1	4.1	4.2
33	6.0	9.4	1	79.8	84.5	70.0	23.9	22.9	20.0	4.68	6.45	4.0	7.4	7.0	6.0
34	12.4	13.7	2	85.0	92.8	95.0	23.4	23.9	24.0	8.21	9.62	9.0	6.4	6.2	6.5
35	127.1	258.7	13	192.3	131.6	111.5	30.0	30.9	31.2	12.06	9.58	7.9	5.3	5.5	4.8
36	219.8	281.2	15	128.5	142.1	97.7	35.5	59.5	26.9	17.87	22.49	5.5	43.4	35.9	36.8
37	227.2	331.1	19	109.1	97.3	90.1	24.1	24.1	21.8	8.60	6.35	5.0	16.7	14.8	11.6
38	533.3	1117.7	51	54.6	54.0	54.5	17.3	20.4	20.3	3.79	3.66	3.6	7.8	7.1	7.0
39	136.6	181.6	5	42.4	41.1	42.4	27.1	29.3	29.6	1.74	1.91	2.4	12.7	8.7	9.6
40	63.5	104.0	4	64.1	58.7	54.2	59.6	77.2	115.8	3.30	4.06	3.0	27.1	38.4	44.8
41	44.3	166.7	9	127.7	117.6	122.8	46.2	45.0	48.1	4.78	5.02	5.1	25.6	27.6	31.2
42	210.5	338.0	17	71.2	71.1	65.4	33.9	35.7	34.8	4.25	3.87	3.4	14.7	16.0	18.1
43	63.8	88.7	7	70.0	70.5	70.7	33.8	38.4	37.7	1.36	1.83	1.6	9.6	10.2	10.3
44	165.9	190.4	6	72.4	65.5	61.7	30.6	37.3	37.0	3.89	4.93	3.0	6.0	9.2	8.5
45	440.1	715.0	32	65.0	65.2	71.9	48.1	58.5	66.5	4.10	3.94	4.3	10.3	10.4	10.7
46	220.0	324.3	10	52.2	52.2	50.8	17.0	19.2	22.4	2.40	2.77	2.9	6.9	8.5	10.5
47	91.6	237.8	10	61.4	59.9	56.6	39.5	32.1	37.5	3.55	4.21	3.2	15.6	13.1	10.3
48		1.6	0		73.0			31.3			4.00			4.3	
49	4.2	6.3	0	68.5	71.8		27.2	25.7		3.05	5.02		98.4	103.0	
50	25.9	25.9	2	38.7	34.8	34.0	23.5	19.1	13.5	2.74	3.00	4.5	15.0	13.3	8.0
51	0.8	0.9	0	38.0	34.7		22.0	25.0		2.00	1.67		18.0	6.7	
52	49.3	71.3	5	43.1	46.8	47.8	28.4	32.6	43.2	2.93	3.23	2.0	47.2	48.0	39.0
53	28.7	40.2	2	69.5	70.3	65.5	31.9	31.3	23.0	3.48	4.75	3.5	165.6	174.0	
54	368.8	592.9	32	104.5	109.8	121.0	55.8	56.6	58.1	10.18	11.62	25.9	62.3	71.2	59.5
55	133.0	225.7	19	144.7	161.0	135.9	96.0	101.7	97.2	9.87	22.32	10.3	57.6	57.9	58.7
56	1.3	18.4	4	57.9	68.5	64.8	24.8	36.6	31.0	1.31	1.14	1.2	21.5	31.5	24.2
57	2.3	5.1	1	83.4	88.7	94.0	44.5	43.6	40.0	4.05	4.34	7.0	124.6	89.0	96.0
58	37.3	97.0	7	52.0	51.3	55.4	22.5	22.6	28.3	3.53	2.92	3.1	13.2	13.2	19.1
59		8.1	0		105.0			29.0			5.00			11.0	
60	74.9	219.9	8	98.0	101.5	111.5	38.7	39.9	44.0	5.16	5.51	5.6	27.6	24.0	21.8
61	8.8	21.1	0	58.1	60.9		37.4	33.9		4.47	4.54		55.0	60.2	
70	10.0	260.6	0	38.5	99.8		26.0	38.9		5.49	5.08		4.9	17.4	
Total	9261.3	16060.3	913	67.7	69.5	69.7	28.4	30.5	31.9	5.42	5.81	5.9	18.2	18.0	19.5

Note: B — Drainage basin; T — Thiessen polygon; PiP — Point-in-Polygon.

TABLE 4-4-3
OVERLAY SUMMARIES — *Continued*

	Cobalt (ppm)			Silver (ppm)			Manganese (ppm)			Iron (%)			Molybdenum (ppm)			Tungsten (ppm)		
Unit	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP
1	8.4	8.4	8.3	0.12	0.14	0.13	467.1	527.5	461.4	1.93	2.14	2.04	1.3	1.5	1.7	1.2	1.2	1.3
2	7.0	7.1		0.10	0.10		476.7	536.8		1.87	1.87		2.1	1.8		1.0	1.0	
3	7.0	8.3		0.10	0.19		438.1	670.9		2.28	2.45		1.1	1.3		1.0	1.2	
4	16.6	9.8	9.0	0.18	0.10	0.10	811.8	308.4	275.0	3.78	2.58	2.50	2.8	1.9	2.0	1.3	1.0	1.0
5	6.2	5.6	5.4	0.10	0.11	0.10	195.0	214.2	173.0	1.75	1.61	1.49	1.5	1.5	1.4	2.3	2.2	2.2
6	7.0	7.1	7.0	0.22	0.11	0.10	483.8	559.2	810.0	1.68	1.88	1.83	1.2	1.4	2.0	1.0	1.0	1.0
7	7.4	6.4	6.6	0.18	0.13	0.11	325.5	306.7	464.0	1.91	1.76	1.74	1.7	1.3	1.5	2.1	3.6	4.6
8	6.3	6.1	5.1	0.10	0.16	0.10	282.1	270.1	251.2	2.05	2.11	1.38	1.6	1.7	2.4	2.5	1.9	1.0
9	6.4	6.6	6.1	0.13	0.11	0.11	438.8	457.9	298.1	1.69	1.66	1.59	1.3	.1	1.1	1.0	1.1	1.0
10	7.0	7.6	7.3	0.11	0.12	0.10	361.6	446.1	481.3	1.70	1.82	1.74	1.1	1.2	1.1	1.2	1.2	1.2
11	10.1	9.4	8.3	0.12	0.13	0.16	353.4	373.6	455.1	2.28	2.15	2.21	1.4	1.5	1.7	1.0	1.0	1.1
12	8.2	9.6	10.6	0.12	0.11	0.11	300.4	303.9	310.9	2.11	2.14	2.27	1.7	1.3	1.3	2.3	1.0	1.0
13	8.5	8.6	8.9	0.11	0.11	0.10	197.3	194.6	175.6	1.73	1.70	1.75	1.6	1.5	1.4	3.8	2.7	1.3
14	17.2	14.9		0.10	0.10		619.4	504.0		4.32	3.72		3.0	2.5		1.0	1.0	
15	3.3	2.4	2.1	0.10	0.10	0.10	187.6	135.1	131.7	0.92	0.71	0.67	1.1	1.1	1.1	1.1	1.1	0.9
16	3.7	4.0	3.7	0.16	0.14	0.15	505.7	618.7	667.1	1.44	1.48	1.43	1.8	2.1	2.0	1.3	1.6	1.5
17	5.3	5.9	5.2	0.37	0.37	0.23	650.9	666.7	514.7	2.28	2.19	2.13	2.7	2.4	1.8	1.1	1.1	1.0
18	7.3	7.6	7.8	0.12	0.13	0.11	568.2	646.3	670.1	2.11	2.15	2.16	1.3	1.5	1.4	1.0	1.0	1.1
19	9.1	10.2	9.5	0.10	0.11	0.11	260.7	258.3	245.0	1.91	2.09	2.07	1.2	1.3	1.4	3.1	2.7	1.9
20	7.5	8.1	8.0	0.10	0.10	0.10	744.2	687.7	680.0	2.00	2.10	2.10	1.0	1.0	1.0	1.0	1.0	1.0
21	7.8	7.5	6.6	0.21	0.27	0.15	427.8	434.5	368.4	2.01	1.91	1.72	1.2	1.2	1.4	1.0	1.0	1.0
22	12.0	12.0	13.3	0.15	0.18	0.23	590.7	623.8	592.0	2.95	2.87	3.02	1.7	1.5	1.7	1.0	1.4	2.1
23	6.3	6.8	6.5	0.11	0.10	0.11	170.6	193.7	129.9	1.32	1.38	1.34	1.2	1.4	1.3	1.7	1.6	1.0
24	4.9	5.6	5.5	0.12	0.12	0.15	153.8	161.8	130.0	1.26	1.30	1.02	1.9	1.8	1.5	8.3	7.4	13.0
25	13.1	13.7	13.6	0.11	0.11	0.13	513.9	582.3	543.1	3.07	3.25	3.09	1.1	1.0	1.1	1.0	1.0	1.0
26	11.2	12.0	13.5	0.16	0.11	0.10	540.0	412.9	338.0	3.14	3.14	3.23	1.7	1.1	1.0	1.0	1.0	1.0
27	5.1	6.0	6.1	0.11	0.11	0.11	375.4	451.8	450.9	1.52	1.68	1.71	1.4	1.3	1.1	0.9	1.0	1.0
28	8.1	7.7	8.5	0.10	0.17	0.10	422.8	461.6	370.0	1.72	1.78	1.70	1.1	1.8	1.0	1.0	1.0	1.0
29	6.8	5.7	4.5	0.10	0.11	0.12	370.2	418.8	405.4	1.60	1.43	1.22	1.4	1.2	1.1	1.5	1.0	1.0
30	13.0	16.7		0.25	0.46		693.5	826.4		3.30	3.93		2.0	3.4		2.2	3.6	
31		8.9			0.21			1136.9			2.97			1.6			1.0	
32	4.1	4.1	4.6	0.11	0.12	0.14	639.6	589.9	744.0	1.73	1.61	1.74	1.5	1.7	1.5	1.1	1.5	1.5
33	12.7	12.6	9.0	0.14	0.11	0.10	728.0	792.1	467.0	3.63	3.76	3.00	1.4	1.1	1.0	1.0	1.0	1.0
34	11.4	12.7	14.0	0.16	0.16	0.15	745.6	898.0	990.0	3.36	3.77	4.15	1.6	1.6	1.5	1.0	1.0	1.0
35	10.4	9.1	8.7	0.19	0.14	0.12	1120.8	768.5	545.4	3.18	3.10	3.10	2.3	2.3	2.6	1.0	0.9	1.0
36	12.8	12.9	10.5	0.37	0.53	0.11	542.4	565.8	450.5	3.14	3.04	2.65	2.1	2.4	1.7	1.1	2.4	1.9
37	9.6	9.6	8.8	0.31	0.15	0.25	532.2	518.6	474.4	2.59	2.47	2.20	1.4	1.4	1.3	1.2	1.0	1.0
38	5.9	5.6	5.8	0.14	0.13	0.13	565.6	563.8	562.0	1.93	1.95	1.94	1.4	1.6	1.4	1.3	1.3	1.7
39	9.8	8.0	9.6	0.10	0.10	0.10	359.6	314.8	401.2	1.75	1.65	2.00	1.1	1.2	1.2	1.1	1.0	1.0
40	14.8	13.8	13.8	0.15	0.11	0.12	612.2	674.3	1113.8	2.79	2.53	2.45	1.2	1.0	1.0	1.0	1.0	1.0
41	13.3	13.0	13.8	0.18	0.16	0.17	643.2	758.4	852.7	3.80	3.61	3.70	2.4	2.0	1.8	1.0	1.0	1.0
42	11.1	11.7	11.7	0.20	0.13	0.15	502.0	567.5	600.6	2.53	2.49	2.47	1.3	1.3	1.4	1.0	1.1	1.1
43	9.3	9.7	9.4	0.10	0.10	0.10	2581.6	1127.4	1602.9	2.45	2.51	2.46	1.6	1.4	1.4	1.1	1.1	1.0
44	6.4	7.5	7.7	0.10	0.10	0.10	664.9	530.4	489.5	1.93	1.93	1.88	1.1	1.2	1.2	1.0	1.0	1.0
45	7.6	7.8	8.4	0.12	0.12	0.12	690.0	792.4	791.5	1.99	2.18	2.57	1.6	1.5	1.6	1.0	1.1	1.1
46	4.8	4.9	5.2	0.13	0.13	0.12	464.1	516.2	681.7	1.39	1.53	1.83	1.6	2.0	1.6	1.2	1.0	1.0
47	11.2	8.8	7.7	0.24	0.12	0.11	501.8	443.8	383.4	2.44	2.11	1.99	1.5	1.5	1.9	1.1	1.1	1.1
48		7.8			0.10			370.0			3.05			3.5			1.0	
49	13.8	14.3		0.10	0.11		413.9	432.3		2.70	2.75		1.3	1.5		1.0	1.0	
50	6.8	5.8	5.0	0.10	0.10	0.10	136.5	152.2	136.0	1.19	1.09	1.00	2.1	2.2	3.0	16.4	10.4	20.5
51	10.0	7.3		0.10	0.10		265.0	200.0		1.55	1.32		1.0	1.0		1.0	1.0	
52	8.9	9.3	10.4	0.10	0.10	0.10	159.1	174.7	175.6	1.35	1.46	1.52	1.3	1.2	1.0	5.5	1.7	1.0
53	17.7	18.2	26.0	0.11	0.13	0.10	395.6	399.7	470.0	2.63	2.58	2.95	1.2	1.2	1.0	1.1	1.1	1.0
54	17.5	18.5	18.7	0.17	0.20	0.51	613.1	637.5	675.8	3.51	3.46	3.66	2.3	2.4	2.4	1.6	1.4	1.2
55	26.9	27.3	26.1	0.16	0.38	0.18	748.3	754.3	733.4	4.28	4.11	3.91	3.2	3.7	3.6	1.5	1.9	2.2
56	9.9	12.1	11.0	0.10	0.10	0.10	234.7	237.4	218.0	1.88	2.26	2.11	1.0	1.3	1.0	1.0	1.0	1.0
57	20.0	17.1	20.0	0.10	0.10	0.10	519.8	461.2	435.0	3.34	3.01	3.80	2.1	2.1	2.0	1.0	1.0	1.0
58	7.0	6.7	8.4	0.12	0.14	0.14	383.6	368.2	360.6	1.96	1.83	1.94	1.3	1.3	1.3	2.5	2.5	1.6
59		9.0			0.20			2400.0			2.75			3.0			1.0	
60	11.5	11.5	12.0	0.15	0.16	0.21	483.9	515.3	507.9	3.30	3.34	3.62	2.2	2.0	2.0	1.0	1.1	1.0
61	11.6	11.2		0.11	0.11		275.4	271.6		2.13	2.00		1.7	1.4		1.0	1.0	
70	4.7	11.4		0.10	0.12		205.4	589.0		1.41	2.80		1.2	1.4		5.2	2.2	
Total	8.0	8.2	8.5	0.14	0.14	0.14	482.8	495.7	483.3	2.02	2.07	2.09	1.5	1.6	1.6	1.4	.4	1.4

Note: B — Drainage basin; T — Thiessen polygon; PiP — Point-in-Polygon.

basins could not be determined. A total of 911 stream-sediment catchment polygons were thus determined and digitized. Each polygon on the catchment map is treated as a unique class unto itself, and geochemical records in flat ASCII format were attached to corresponding catchment polygon tags. Both maps were digitised in an arc-node vector format using PC-ARC/INFO software. Upon completion of input, both polygonal data sets were formatted into an ASCII file and re-input to TYDAC SPANS GIS for further processing. The original geochemistry point file (913 points including the two points along the southern boundary) was input to SPANS as a third primary data set.

Data Transformation

In the SPANS GIS environment, both polygonal maps were rasterized to a resolution such that the accuracy of the digitized boundaries was not compromised (final resolution exceeds 100 metres on the ground). Using the coverage of the catchment basins as a binary template (coverage present, coverage absent), a second geology map was "cut out" such that the resulting area matched exactly with the catchment coverage. A Thiessen polygon map, totalling 913 separate polygons, was generated from geochemical point locations, and geochemical determinations were assigned as attributes to each polygon. A summary of each map variable is provided in Table 4-4-2.

Data Integration

Treating the geology and "cut-out" geology maps as dependent variables and the Thiessen and catchment maps as corresponding independent variables, each map-pair was overlaid to determine average elemental concentration for each geology class, weighted to area. Overlay of map-pairs was performed ten times, using the following elements as attributes for the independent maps: zinc, copper, lead, nickel, cobalt, silver, manganese, iron, molybdenum and tungsten. A point-in-polygon overlay was performed using the geochemical point data set as the dependent variable and the geology map as independent, such that the geology classes were appended to spatially coincident points. Subsequent processing on the updated point file using dBASE III+ allowed each geology class to be summarized according to average concentration for each of the ten elements listed above.

The raw results from each overlay set are summarized in Table 4-4-3. The results for the polygon overlay sets are average values weighted to area; the point-in-polygon overlay is averaged by the number of contained points in each geology class. Totals for the entire map are included. The Thiessen map covered the entire map area; therefore all geology classes contain summaries for this overlay set. The catchment map covered only those areas defined by catchment basins; therefore three geology units were missed and could not be summarized. The potential for "miss" is even greater for the point-in-polygon overlay as it is dependent upon point-area intersections; ten units lack summaries from this overlay.

Included in Table 4-4-3 are summaries of the total area and point intersections for each geology map unit as well as total map areas. From this information it can be determined that stream-sediment catchment basins cover 57.7 per cent of the map area. However stream-sediment sample coverage of bedrock is very good as most of the missing coverage is accounted for by Harrison Lake, the city of Hope, samples lacking analyses and valley bottoms.

Edge Problems

Geoscience data sets tend to be collected and distributed according to NTS map boundaries. Such boundaries place limitations, or edge effects, when used as a basis for data integration. Catchment basins of stream-sediment samples are either cut off or not included, depending upon which side of the boundary they fall on. Points immediately adjacent to the map area will also change Thiessen polygon configurations and affect the transformation of geochemical points into continuously varying surfaces through contouring, Kriging and weighted averages. The point-in-polygon method appears to be the only one that is unaffected by edge effects.

SUMMARY AND PROSPECTS

Geological interpretation and explanation of the data is not attempted here since this research note focuses upon the application of various techniques for transforming geochemical point data for subsequent integration with geology. However, a visual examination reveals obvious correlations between the three techniques. Further interpretation is left up to the reader for the purpose of this study, but will be reported in a future paper.

Although there is a conceptual basis for both Thiessen and catchment-basin transformations, the latter is intuitively more appealing. Catchment basins account for a primary physical factor controlling the spatial influence of stream-sediment sample points. Strict proximity of Thiessen polygons is a more abstract concept based upon the assumption that spatial autocorrelation exists. In regions of high relief, where catchment basins are easily defined, it is difficult to understand how Thiessen polygons can offer any advantage. However, as relief becomes flat and drainage boundaries are not as easily defined, then proximity may offer some advantages. Neither method allows for within-polygon variation. If variation is perceived as being important, then techniques for interpolating points into continuous surfaces will be more appropriate.

In applying these techniques, basic questions are raised regarding the nature of geochemical point samples are put forth. Do the samples represent point or areal coverage? Are the distributions discrete or continuous, stochastic or deterministic? What physical and spatial factors determine a sample's area of influence? It is therefore important that the assumptions and limitations of the various methods are understood. Ongoing work includes expanding the study to include additional interpolation techniques and a study of the impact of edge problems on overlay results. Future research will include a quantitative comparison and explanation of the results each interpolation method produces through overlay with geology.

The techniques presented here offer considerable potential to assist with geological research and mineral exploration. However, digital spatial integration of geological data sets currently is not widely practised. The barriers for doing so can be identified as expensive technologies and a lack of digital map databases (geology, topography). Price-performance ratios for computer hardware and software are doubling every one to two years, and provincial coverage of geochemistry and terrain data in digital formats will soon be complete. Development of digital geological map databases by the appropriate authorities must also take place. Such databases should include seamless concepts (geographical elements are logically connected across NTS boundaries) such that users are not restricted to analysis by NTS mapsheets, but can choose regions more appropriate to the task, such as major watershed or geological terrane. The development and adoption of map database standards by various government agencies would also be helpful.

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