PRECIOUS METALS IN THE NORTHERN CORDILLERA

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CINOLA GOLD DEPOSIT, QUEEN CHARLOTTE ISLANDS, B.C. – A GEOCHEMICAL CASE HISTORY

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ABSTRACT

The Cinola deposit, a large tonnage, low grade Carlin-type gold deposit on Graham Island (Queen Charlotte Islands), was subject to extensive geochemical exploration shortly after its discovery in 1970. We have reviewed the available rock, soil, and silt multi-element geochemical data from this early exploration stage in a rigorous, statistically-oriented manner, and in the light of substantial geological information about the deposit. Some specific conclusions from our study are:

1. Ag lithogeochemical data define the centre of the mineralized zone better than does Au. This is due to a more confined primary dispersion of Ag relative to Au.
2. Cu, Ni, Co, Pb, Zn, and Mo in rocks, soils, or silts do not provide clear cut patterns or high enough abundance levels for use in exploration.
3. Hg in soil and Hg in peat show a pronounced secondary dispersion pattern, apparently due to fluid transport eastward from the main centre of mineralization at the Cinola deposit.
4. Threshold selection using probability graphs is a useful practical approach to evaluate spatial distribution patterns of subpopulations in geochemical data sets.

INTRODUCTION

The Cinola gold deposit, located on Graham Island, off the west coast of British Columbia (Fig. 1), has been described geologically by Champigny and Sinclair (1980a, 1981). The deposit is large, more than 45 million tons, with an average of 0.054 oz Au per short ton and has many of the characteristics of a Carlin-type deposit (Richards et al., 1976; Champigny and Sinclair, 1980b, 1981). Geological features characteristic of the deposit include: (1) small particle size of the gold (less than 0.5 μ); (2) mid-Miocene age of mineralization; (3) proximity to a major fault system; (4) argillic alteration; (5) high porosity of the host rock; and (6) spatial and possibly genetic association with a rhyolite-porphyry intrusion. Surficial deposits covering the deposit are glacial tills ranging in thickness from 0 to 35 m, with an average of 3 m. Glacial movement followed a southwest-northeast direction in the area

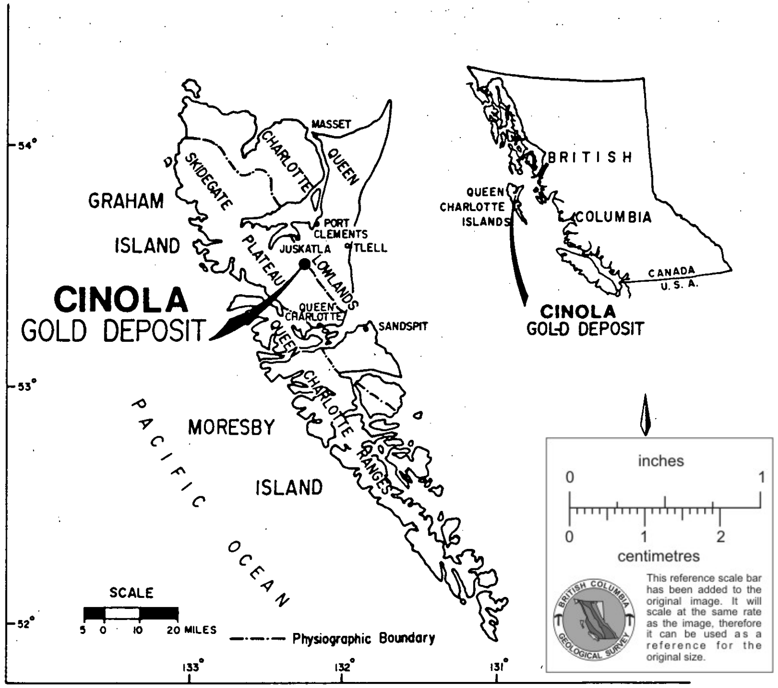

Fig. 1. Location map of the Cinola gold deposit.

(Sutherland Brown, 1968). The area is heavily forested, due to a mild and rainy climate, and outcrops are absent except along fault scarps. Three continually flowing creeks and one river drain the mineralized zone.

This work forms part of a comprehensive study which emphasizes the application of geological and geochemical studies to exploration and evaluation of the Cinola deposit. A systematic evaluation of pre-existing exploration geochemical data was done to:

1. provide a rigorous evaluation of multi-element geochemical data for a Canadian "Carlin-type" gold deposit.
2. evaluate critically the primary and secondary dispersion haloes of elements represented in the various data sets available to us; and
3. illustrate the advantage of a rigorous but simple statistical approach as an evaluation procedure for geochemical data.

THE DATA

Multi-element geochemical data were available for rock, soil, and silt samples taken during routine exploration of the Cinola property in the early and middle 1970's (see Champigny et al., 1980). These data are available in assessment reports filed with the British Columbia government, but were provided to us by G. G. Richards of J.M.T. Services Corp. and R. W. Stevenson of Kennco Exploration Ltd. A brief description of the nature of each data type follows.

Lithogeochemical data. Fifty-nine grab samples from limited surface exposures were analyzed for all or some of Au, Ag, Hg, As, Sb, and W. The gold content was measured by fire assay. Ag and Hg were determined by atomic absorption spectrophotometry. The As and W analyses were obtained by colorimetric methods. No information regarding analytical method was available for Sb.

Soil data. Four hundred and eighty-six soil samples were taken more-or-less regularly over the Cinola property, mainly along claim lines. Most were B-horizon samples that were analyzed for Au, Ag, Hg, Mo, Cu, Pb, Zn, Ni, and Co. A-horizon samples were analyzed only for Hg. A second B-horizon soil survey over the mineralized zone added 158 more samples that were analyzed only for gold. The -80 mesh fraction was used for all the analyses. Determination of all elements was by atomic absorption spectrophotometry.

Silt. Fifty-eight silt samples were collected from three creeks and a river in the vicinity of the mineralized area. The -80 mesh components of the samples were analyzed for all or some of Au, Ag, Mo, Cu, Pb, Zn, Ni, Co, and As, with the same analytical procedures as were used for the soil samples. The As content was measured by a colorimetric method.

DATA EVALUATION PROCEDURE

Our general procedure (Fig. 2) for creating each of the forgoing data groups involved: (1) coding and editing; (2) production of correlation matrixes for raw and log-transformed data; (3) construction of a correlation diagram; (4) threshold selection from probability plots of individual elements; (5) drawing of machine-constructed maps showing distributions of various sub-populations for each element in each data group; and (6) integration of results for the three separate data sets, and interpretation in a geological context.

The method of threshold selection is that described by Sinclair (1974, 1976), in which multi-modal distributions are partitioned on probability graphs into two or more components, which in general appear to be lognormal in form.

LITHOGEOCHEMISTRY

A summary of means and standard deviations for raw and log transformed lithogeochemical data is given in Table 1, and a correlation matrix for log-transformed variables is given in Table 2. The critical features of the correlation matrix are summarized in the correlation diagram of Fig. 3. These results are of interest because they demonstrate clearly that among the elements studied a simple, direct relationship involving Au exists with Ag,

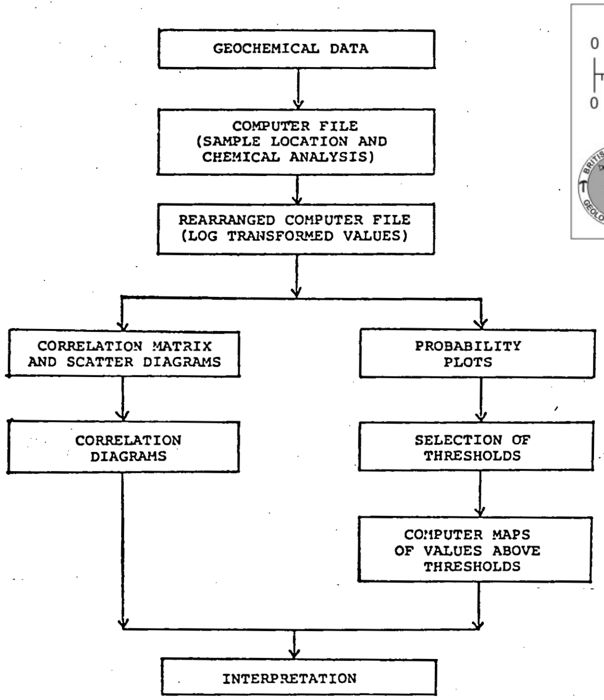

Fig. 2. Procedural path in evaluating Cinola geochemical data.

As, and Sb. Mercury and tungsten have significant inter-correlations, but do not correlate significantly with gold at the 0.01 level.

Probability graphs of all variables were examined in detail. Ag, Hg, Sb, and W can be interpreted without difficulty as combinations of two, and in the case of gold, three lognormal populations. Two of these graphs are reproduced in Fig. 4 and Fig. 5. Both illustrate the ease with which thresholds can be selected using the method of Sinclair (1974). Such thresholds have been used as a basis for contouring the data to separate geographic areas

Table 1. Summary of means and standard deviations for raw and log-transformed (base 10) lithogeochemical data, Cinola deposit. Arithmetic values are all in ppm except Hg which is in ppb.

Name	*No. of Values*	*Arithmetic*		*Logarithmic*	
		Mean	*Std. Dev.*	*Mean*	*Std. Dev.*
Au	59	0.2954	0.6060	−1.362	0.9675
Hg	48	2158.	2572.	2.944	0.7064
Ag	45	1.509	1.307	−0.01243	0.3971
As	45	127.8	200.0	1.508	0.9118
Sb	45	63.91	61.84	1.499	0.6151
W	45	40.02	37.10	1.280	0.6817

Table 2. Correlation matrix for log-transformed (base 10) lithogeochemical data, Cinola deposit.

	Au	*Hg*	*Ag*	*As*	*Sb*
Hg	.31				
Ag	.50	.32			
As	.56	.63	.30		
Sb	.50	.34	.36	.12	
W	.40	.49	.07	.36	.49

The correlation coefficients are based on from 29 to 45 paired observations.

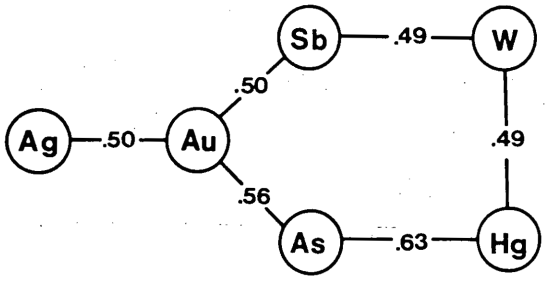

Fig. 3. Most significant correlations (at the 0.01 level) of logarithmically transformed (base 10) lithogeochemical data.

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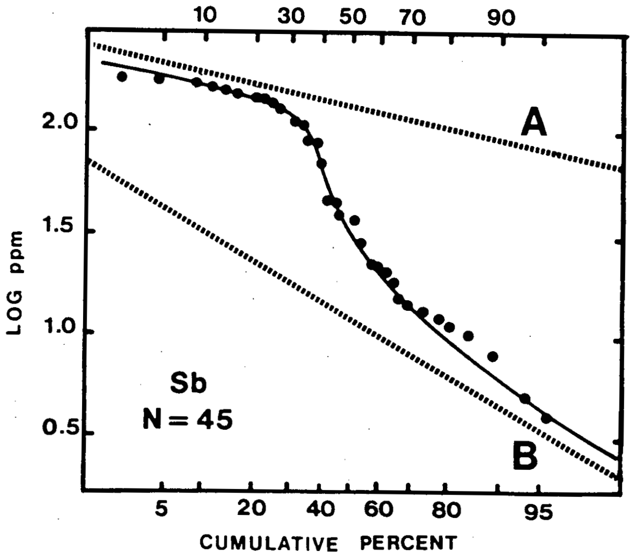

Fig. 4. Lognormal probability plot for Sb lithogeochemical data partitioned into upper (A) and lower (B) populations. Black dots are original data.

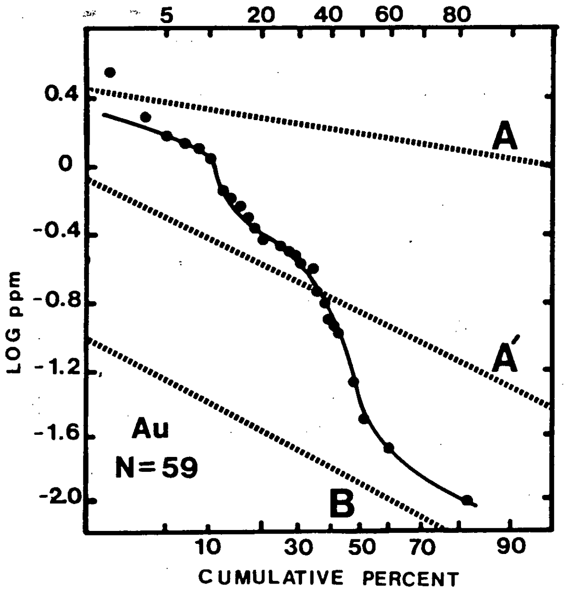

Fig. 5. Lognormal probability plot for Au lithogeochemical data partitioned into upper (A), median (A^1), and lower (B) populations. Black dots are original data.

underlain by "high" and "low" valued populations so that their distributions could be examined in relation to the mineral deposit as outlined by extensive diamond drilling. Representative examples are shown in Fig. 6 and 7, and indicate:

1. the close spatial correlation of areas of certain "high" element concentrations and their relationship to the gold deposit;
2. a high silver population that clearly defines the centre of the gold deposit.

Parameters of partitioned populations are given in Table 3. The geographic distribution of gold values above threshold is not surprising (Fig. 6). Diamond drilling has indicated that gold mineralization decreases progressively to the north and east. Sporadic occurrences of Au highs probably arise from the widespread nature of mineralization combined with its local variability, a variability that would be enhanced by the small size of the lithogeochemical samples. Silver is about as abundant as gold at Cinola, and is known to be present in solid solution in gold particles (Champigny and Sinclair, 1980b, 1981). A low silver content in the bedrock produces a much lower geochemical contrast of silver relative to gold and, therefore, a smaller area of silver "high" (Fig. 7).

Cinnabar and tiemmanite (HgSe) occur in the Cinola ore and are the obvious sources for mercury. Sphalerite, rarely observed, is also a possible source of Hg. Fracture systems through the poorly lithified Skonun sedi-

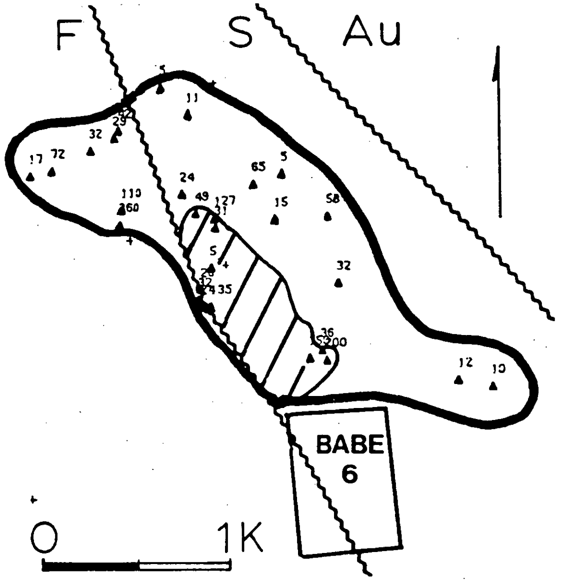

Fig. 6. Au (ppb x 100) in rock. Triangles are high population; plus signs are low population. Heavy black line encloses high population values. Hachured area represents extent of relatively high gold grades of the Cinola deposit as determined from diamond drilling. Babe 6 mineral claim, the footwall fault trace (F) and the Sandspit fault trace (S) are shown for geographic reference.

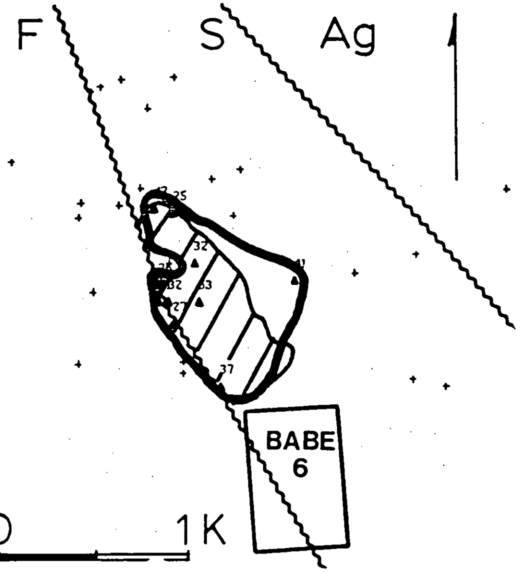

Fig. 7. Ag (ppm x 10) in rock. See Fig. 6 for explanation of symbols.

Table 3. Means and standard deviations determined graphically for partitioned metal populations of lithogeochemical data, Cinola deposit.

Element	Conc. Unit	A population %	A population b	A population $b+s_L$	A population $b-s_L$	B population %	B population b	B population $b+s_L$	B population $b-s_L$	Threshold(s)
Au	ppm	11	1.6	2.0	1.2	55	0.01	0.03	0.006	0.05 and
		34	0.13	0.30	0.06					0.85 ppm
Ag	ppm	29	3.3	4.2	2.5	71	0.7	1.35	0.36	2.5
Hg	ppb	58	3630	5750	1950	42	178	355	85	800
As	ppm	100	36	260	4.8					
Sb	ppm	45	129	170	98	55	13	26	5.8	70
W	ppm	56	61	110	36	44	7.5	13.5	4.3	23

Graphs based on 59 values for Au, 49 values for Hg and 45 values for Ag, As, Sb and W cumulated individually.

b = antilog of mean of log transformed data

$b+s_L$ = antilog of mean plus one std. dev. of log transformed data

$b-s_L$ = antilog of mean minus one std. dev. of log transformed data

ments east of the ore body probably contributed to the diffusion of mercury (Fig. 8).

Disseminated pyrite occurs outside the limit of economic mineralization and electron microprobe analysis has shown locally a high As content (1.1%) in pyrite (Champigny and Sinclair, 1981). No arsenic and antimony minerals have been identified in the deposit. As and Sb (Fig. 9) lithogeochemical highs can probably be attributed to solid solution of arsenic and antimony in pyrite and/or marcasite, as reported in other gold deposits by Boyle (1979, p. 144-145).

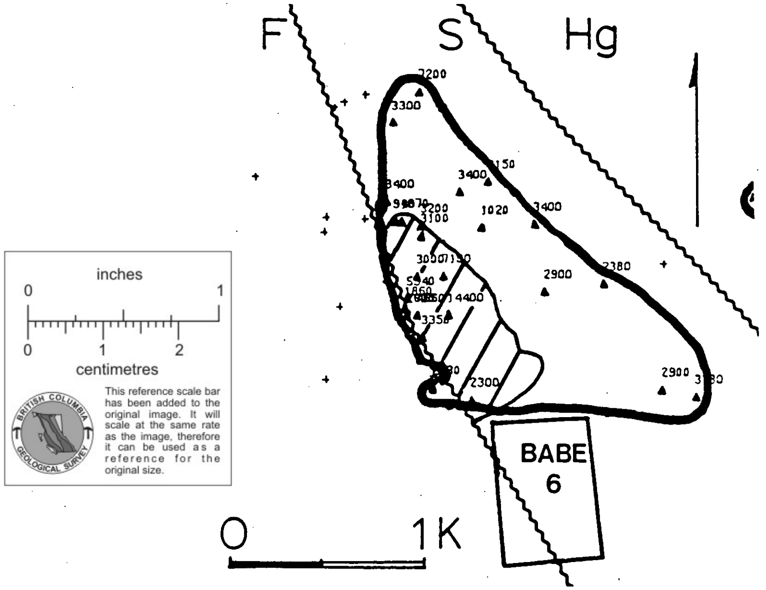

Fig. 8. Hg in rock (ppb). See Fig. 6 for explanation of symbols.

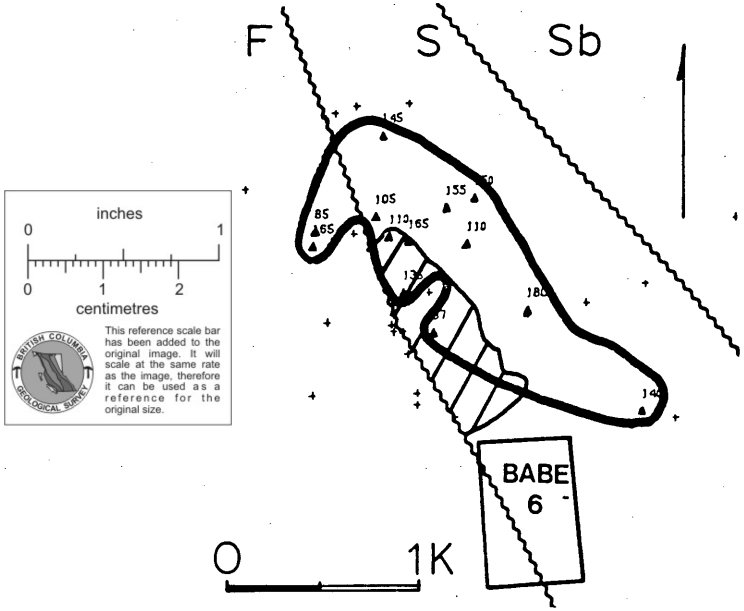

Fig. 9. Sb in rock (ppm). See Fig. 6 for explanation of symbols.

The tungsten anomaly pattern (Fig. 10) is about the same as for gold and may be caused by the presence of trace amounts of scheelite, which is not reported at Cinola but is a common trace mineral in gold deposits (Boyle, 1979, p. 195).

SOIL GEOCHEMISTRY

A similar method of data analysis was used for soil data as for lithogeochemical data. A summary of means and standard deviations is given in Table 4 and a correlation matrix of log-transformed values is provided in Table 5. The correlation matrix indicates the presence of three groups of elements. Group I (Au, Hg, Hg in peat, Ag) would appear to relate most directly to the mineralization process. Group II elements (Cu, Ni, Co, Zn, Pb) have high intragroup correlations, but correlate only in a limited manner with Group I elements. It would appear that these two groups are fundamentally different. Group III consists only of Mo, about which little can be said, because of the narrow range of values and poor analytical precision.

Probability graphs of all elements in groups I and II can be partitioned into two or three lognormal sub-populations and thresholds chosen with ease (Fig. 11 and Table 6). As with lithogeochemical data, we produced contoured plots, using thresholds as the only contour values. Four examples are shown in Figs. 12, 13, 14 and 15 for Au, Hg, Hg in peat, and Cu respectively. The example for copper clearly illustrates the sporadic distribution of high values throughout the property, a result that we found to be characteristic of all elements of Group II. These erratic soil geochemical highs are easily explained in the cases of zinc, copper, and lead, because of small amounts of sphalerite, chalcopyrite, and galena occuring very sporadically in the Cinola deposit.

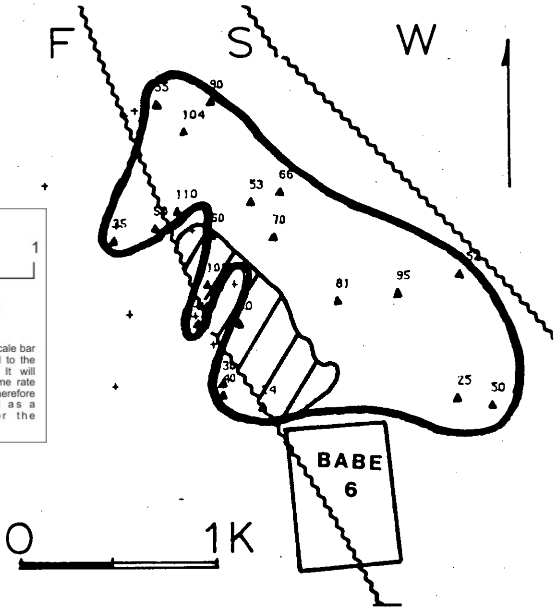

Fig. 10. W in rock (ppm). See Fig. 6 for explanation of symbols.

Table 4. Summary of means and standard deviations for raw and log-transformed (base 10) soil geochemical data, Cinola deposit. Arithmetic values are all in ppm except Hg and Hg in peat (HgP) which are in ppb.

	No. of	*Arithmetic*		*Logarithmic*	
Name	*Values*	*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*
Au	644	0.03781	0.08178	−1.729	0.4126
Hg	474	590.0	1227.	2.519	0.4034
Ag	486	0.6926	0.5865	−0.2677	0.3262
Mo	480	1.077	0.3484	−0.01945	0.09844
Cu	483	10.22	5.578	0.9285	0.2892
Pb	484	10.18	3.629	0.9723	0.1958
Zn	483	29.74	19.46	1.358	0.3504
Ni	483	9.673	18.66	0.8245	0.3496
Co	483	7.077	5.184	0.6898	0.4212
HgP	457	675.3	1248.	2.621	0.3458

Table 5. Correlation matrix for log-transformed (base 10) soil geochemical data, Cinola deposit. Dash lines represent correlation coefficients that are not significant at the 1% level.

Group	*Element*	*Au*	*Hg peat*	*Hg*	*Ag*	*Cu*	*Ni*	*Co*	*Zn*	*Pb*
I	Hg peat	.30								
	Hg	.24	.63							
	Ag	.19	—	.23						
II	Cu	—	—	.29	.71					
	Ni	—	—	.14	.63	.72				
	Co	—	—	.17	.73	.78	.79			
	Zn	—	—	—	.69	.78	.82	.86		
	Pb	—	—	—	.38	.26	.35	.30	.38	
III	Mo	—	—	.15	.16	—	.15	—		

The correlation coefficients are based on about 480 paired observations between all elements excepting pairs with Au and Hg in peat which are based on 438 and 340 paired observations respectively.

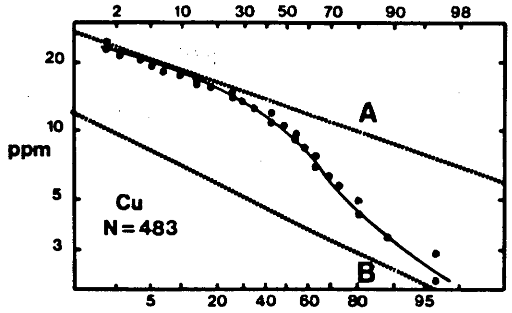

Fig. 11. Probability plot for Cu in soils, partitioned into upper (A) and lower (B) populations.

On the other hand, Group I elements (Table 5) excepting silver, have appreciably more regular distribution patterns. Most regular are the comparable patterns shown by Hg in B-horizon and Hg in A-horizon soils. The pattern is pronouncedly arcuate, concave to the west but dramatically removed to the east of the Cinola deposit, in a manner suggestive of secondary easterly dispersion (Figs. 13 and 14). This dispersion was probably chemical rather than physical, because gold which is intimately related in the deposit has soil highs in part directly over the Cinola deposit (Fig. 12), suggesting relatively little secondary dispersion.

The erratic spatial distribution of silver highs probably results from the low abundance level in soils in combination with poor analytical precision. It is also possible that no background correction was applied during spectrophotometric analysis.

Table 6. Means and standard deviations determined graphically for partitioned metal populations of soil geochemical data, Cinola deposit.

	Conc.	*A population*				*B population*				Thresh-
Element	*Unit*	%	*b*	$b+s_L$	$b-s_L$	%	*b*	$b+s_L$	$b-s_L$	*old(s)*
Au	ppm	4	0.26	0.29	0.23	91	0.015	0.030	0.008	0.20 and 0.07
		5	0.11	0.15	0.09					
Ag	ppm	5	1.6	2.0	1.3	80	0.78	1.1	0.56	1.3 and 0.3
						15	0.05	0.18	0.02	
Hg	ppb	10	2100	3500	1300	90	240	500	120	1000
Hg peat	ppb	7	3200	4700	2200	93	350	620	195	1350
Mo	ppm	100	1.1	1.5	0.8					
Cu	ppm	65	13	17	9.4	35	4.2	6.4	2.8	8
Pb	ppm	96	10	13	8.0	4	2.1	3.0	1.4	5
Zn	ppm	70	35	54	23	30	8.8	15	5.0	23
Ni	ppm	15	14	17	12	85	7.0	11	4.2	35 and 16
Co	ppm	70	8.4	13	5.4	30	1.5	2.3	1.0	3.5

Graphs based on 644 values for Au, 486 values for Ag, 484 values for Pb, 483 values for Zn, Ni and Co. 480 values for Mo, 474 values for Hg and 457 values for Hg in peat.

Symbols used are the same as Table 3.

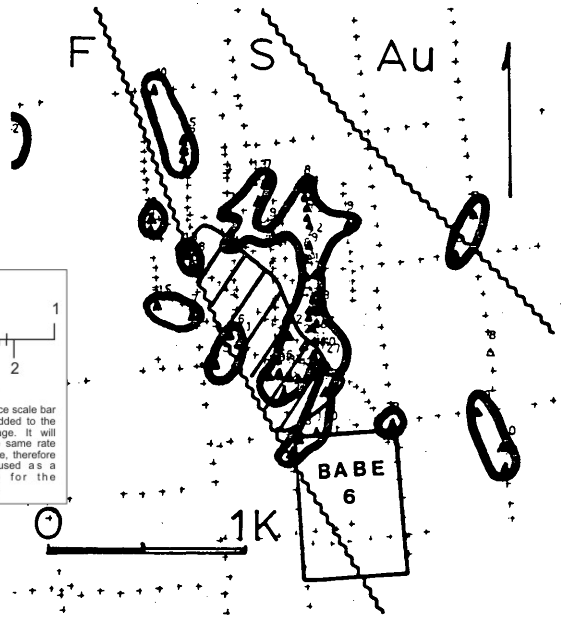

Fig. 12. Au (ppm x 100) in soil. Symbols as in Fig. 6. Sampling grid mostly follows claim boundaries.

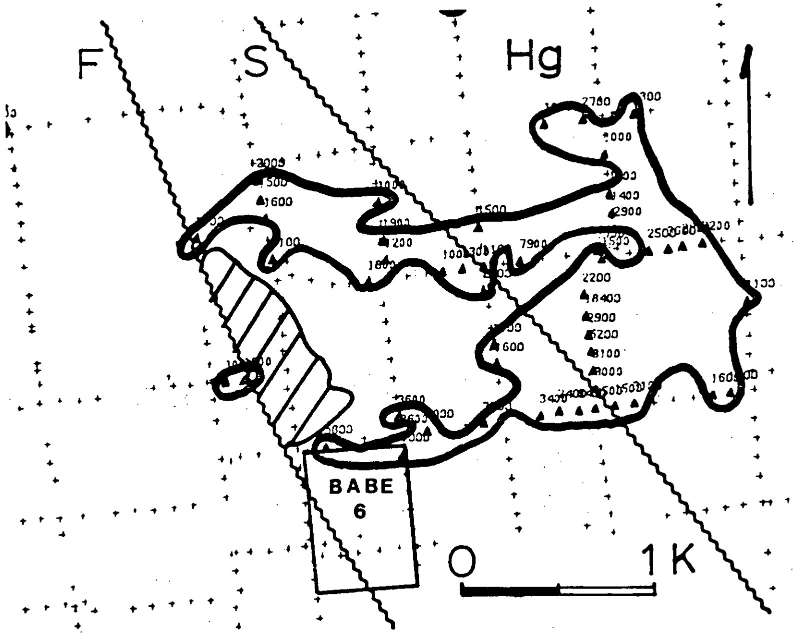

Fig. 13. Hg in B horizon (ppb). Symbols as in Fig. 6.

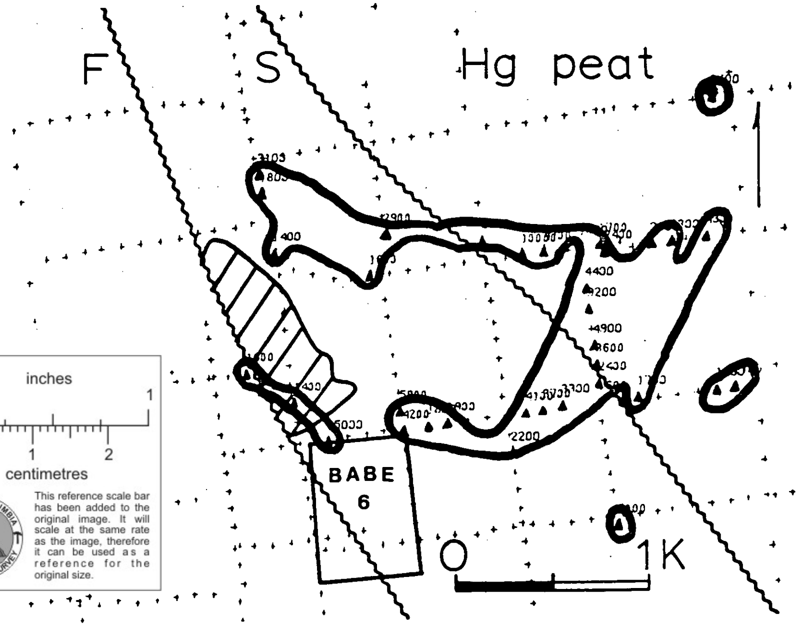

Fig. 14. Hg in peat (A horizon) (ppb). Symbols as in Fig. 6.

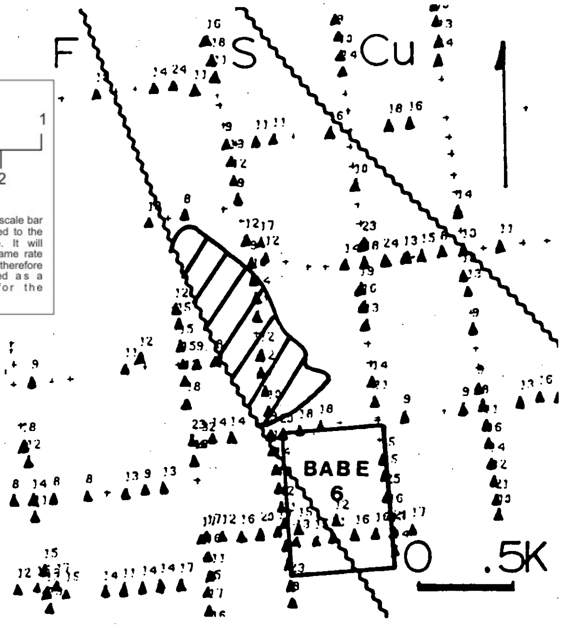

Fig. 15. Cu in soil (ppm). Symbols as in Fig. 6.

SILT GEOCHEMISTRY

An identical statistical analysis was done for stream sediment data as for the rock and soil data. Plotting and contouring of the data were not done in this case because the silt survey covered only a very small portion of the property. Table 7 contains the means and standard deviations of the nine elements that were analyzed. Groupings of elements from the correlation matrix for silt data (Table 8) are very similar to groups defined from the correlation matrix for soil data. Group I for silt samples include Au, As, and Ag. Group II elements (Cu, Ni, Co, Zn, and Pb) elements are highly intercorrelated, especially Zn, Ni, and Co, which have correlation coefficients higher than 0.8. Correlations of Group II to Group I elements are restricted to Ag and As; no significant correlation of Group II elements exists with gold. Mo has a very narrow range of values, and is the only variable included in Group III.

For both soil and silt correlation matrixes, Group I and Group II are easily distinguished. Group I is certainly related to mineralization, but such a relationship is not apparent for Group II.

Bimodal lognormal distributions were observed for most variables of Groups I and II of the silt data. Selection of thresholds was done without difficulty. Partitioning of upper and lower populations is summarized for all variables in Table 9. Arsenic and copper data seem to represent single lognormal distributions.

Table 7. Summary of means and standard deviations for raw and log-transformed (base 10) silt geochemical data, Cinola deposit. Arithmetic values are all in ppm.

	No. of	*Arithmetic*		*Logarithmic*	
Name	*Values*	*Mean*	*Std.Dev.*	*Mean*	*Std. Dev.*
Au	58	0.01845	0.01412	−1.838	0.33059
Ag	58	0.7293	0.2728	−0.1813	0.2214
Mo	58	0.7241	1.121	−0.3443	0.4656
Cu	58	9.138	3.390	0.9339	0.1556
Zn	58	70.90	48.98	1.744	0.3279
Pb	58	10.48	3.803	0.9900	0.1690
Ni	58	14.53	5.823	1.120	0.2046
Co	58	35.50	60.55	1.220	0.5782
As	57	141.9	191.3	1.855	0.5050

Table 8. Correlation matrix for log-transformed (base 10) silt geochemical data, Cinola deposit. Dash lines represent correlation coefficients that are not significant at the 1% level.

Group	*Element*	*Au*	*Ag*	*As*	*Cu*	*Ni*	*Co*	*Zn*	*Pb*
I	Ag	.57							
	As	.45	.43						
II	Cu	–	.38	–					
	Ni	–	.65	.60	.57				
	Co	–	.60	.52	.57	.89			
	Zn	–	.54	.54	.54	.94	.84		
	Pb	–	.48	–	.63	.63	.61	.54	
III	Mo	–	–	.50	–	.45	–	.45	–

Correlation coefficients based on .58 paired observations.

Table 9. Means and standard deviations determined graphically for partitioned metal populations of silt geochemical data, Cinola deposit.

	Conc.	*A population*				*B population*				*Thresh-*
Element	*Unit*	*%*	*b*	*$b+s_L$*	*$b-s_L$*	*%*	*b*	*$b+s_L$*	*$b-s_L$*	*old(s)*
Au	ppm	30	.037	.048	.029	70	.007	.011	.005	0.02
Ag	ppm	83	0.80	1.00	0.66	17	0.25	0.32	0.17	0.48
As	ppm	100	63	250	15					
Cu	ppm	100	8.4	11.6	6.2					
Zn	ppm	20	125	180	88	51	83	112	62	110 and 40
						29	20	27	15	
Pb	ppm	30	16	17	15	70	8.2	10.5	6.5	14
Ni	ppm	71	18	24	14	29	6.8	8.4	5.5	11
Co	ppm	6	133	174	108	94	23	39	12	83
Mo	ppm	100	0.72	1.84	0					

Graphs based on 58 values for all elements apart from As which is based on 57 values. Symbols used are the same as Table 3.

CONCLUSIONS

This simple statistical evaluation of geochemical data from the Cinola deposit has led to the following conclusions.

1. Significant but moderate correlation coefficients between Au on the one hand, and Hg, Ag, As, Sb, and W on the other hand, in rock samples indicate that these elements were all part of the primary mineralizing process at Cinola.
2. Spatial correlation of sub-populations determined by partitioning probability graphs of each variable is a more useful method for evaluating lithogeochemical data than is a matrix of simple linear correlation coefficients.
3. A high silver lithogeochemical population defines the Cinola deposit better than does a high gold population because silver is less dispersed. High populations of Hg, Sb, and W in rocks are as much dispersed as is gold. Consequently, Ag data is of little practical use in regional surveys but may be useful in detailed studies in locallizing the centre of a mineralized system.
4. A correlation matrix for multi-element soil data leads to recognition of two groups of elements. Group I elements (Au, Hg, and Ag) are shown to have more-or-less systematic dispersion patterns in soils relative to the Cinola ore body. Group II (Cu, Ni, Co, Zn, and Pb) are very erratically dispersed in soils with relatively low abundance levels, and the absence of systematic patterns makes them less useful in an exploration sense.
5. Groups of elements from the correlation matrix for silt data are very similar to the groups for the soil data. This suggests that Group I elements in Silt (Au, Ag, As) can be considered as good indicators of the proximity of Cinola-type gold concentrations.
6. Significant correlations between (a) Au and (b) Ag, Hg, and As and comparable distributions of these elements in rock, soil, and silt are a feature of the Cinola data. Thus, Au, Ag, Hg, and As are potential elements to be analyzed for in geochemical exploration for similar large tonnage, low grade Carlin-type gold deposits. Insufficient data were available to fully evaluate the exploration potential for Sb and W, although high lithogeochemical populations of each of these two elements showed systematic distribution patters.

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