BRITISH COLUMBIA REGIONAL GEOCHEMICAL CLUSTER ANOMALIES AND BEST MATCHES TO MINERAL DEPOSIT TYPES

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INTRODUCTION

The "Rocks to Riches" program was inaugurated and funded by the British Columbia government in June 2003 to rekindle mineral investment in the province of British Columbia. It is specifically designed to provide new data or ideas that will attract mineral exploration to BC.

The "MineMatch Geochemistry" project was one of 16 projects approved for funding by the "Rocks to Riches" program in July 2003.

The project's goal was the generation of Internet-accessible, easy-to-validate exploration targets based on a re-evaluation of all the province's 45000 regional geochemistry stream sediment sample (RGS) analyses.

All the project's results have been published on the Internet, and may be freely viewed at www.rockstorichesbc.com.

PROJECT BACKGROUND

Generating high quality exploration targets is a time-consuming and expensive task, particularly when information has to be obtained from multiple sources.

Even in the age of the Internet, integrating this information in a systematic way is a challenge. The MineMatch Geochemistry project seeks to make this integration easier in the context of target generation.

British Columbia's geology hosts many different mineral deposit types. It also has extensive, diverse, and high quality information records pertinent to minerals exploration and target generation - many of them available on the Internet. The MineMatch Geochemistry project capitalizes on these resources to generate a competitive advantage for companies looking for economic mineral deposits in B.C.

But primarily this project recognizes that, given a supportive permitting and fiscal environment, there can be no better way of encouraging exploration in an area than providing prospectors and companies with sound exploration targets which have not yet been tested. Government geological databases and modern software techniques can be combined to cost-effectively generate such new, easily validated, exploration targets for free distribution on the Internet to parties interested in exploring in BC.

PROJECT PURPOSE

The purpose of the project was therefore to provide new evidence of potentially economic mineralization in British Columbia in an easy-to-use format, obtained by applying new evaluation methods to the broad coverage of geochemical data existing for the province.

The Internet-accessible maps and supporting documentation delivered by the project are intended to be of immediate value to exploration licence-holders in BC, as well as those seeking to stake new claims in the province.

The project is therefore an example to explorers and potential explorers in BC of how, by investing in a province with an unsurpassed wealth of high-quality, well-maintained base geological data sets, they can gain maximum leverage on their exploration dollars.

PROJECT METHODS

Geochemical Analysis

The project has evaluated the majority of RGS stream sediment sample analyses in the British Columbia Geological Survey (BCGS) RGS database, in conjunction with the sample's primary-associated rock-types, as derived from the almost-complete integrated 1:250 000 geological map of British Columbia (Massey *et al*., 2003). Approximately 75% of BC is covered by RGS surveys, as shown in Figure 1. Moss-mat samples were excluded from the project on the basis of their being a different medium from conventional stream sediments.

Geochemical anomaly selection for the study was based on choosing values that exceed the 99th percentile for any specific lithology. Percentile-based threshold selection is widely recognized as the best automated anomaly-picking method in exploration geochemistry (Amor, 2000). A high percentile level was chosen to identify truly anomalous samples.

[1]*GeoReference Online Ltd, 301-850 West Hastings St. Vancouver, B.C. V6C 1E1*

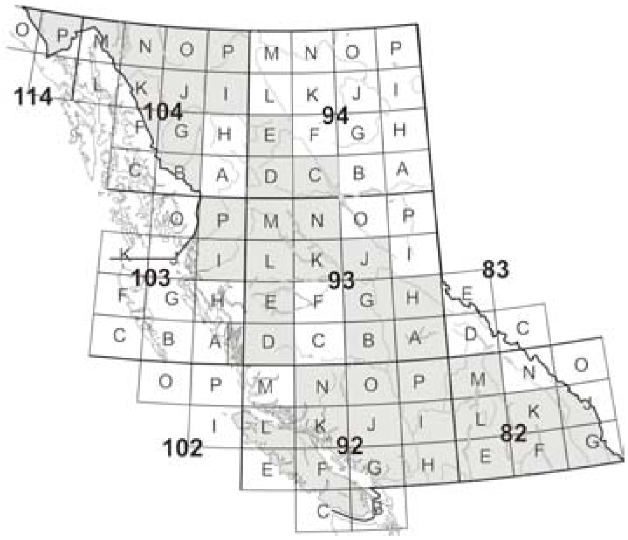

Figure 1. Regional Geochemical Sampling (RGS) coverage of British Columbia. Shaded map sheets have been sampled.

All thresholds have been published on the project web site, together with the number of samples in each lithology-specific population.

Despite its merits, minor problems can arise from this method of anomaly selection when the sample population is too small, or when the population contains no truly anomalous samples, even if it is large. In both cases, non-anomalous levels may be flagged as anomalous.

Since the project web site makes it easy to check the absolute elemental levels in anomalous samples, and the lithology over which the sample was taken, it is quick and easy to disregard anomalies that have arisen because of these effects.

Since large mineral deposits may display zoned anomalous geochemistry over more than 2 kilometres, anomalous samples within a two and a half kilometre radius of any "in-focus" sample site were combined to form an "anomaly cluster". The description of the anomaly cluster prepared for use in MineMatch (see next section) includes all the anomalous elements of all the samples in the cluster, as well as all the lithologies present at each of the included sample sites. Table 1 shows the MineMatch description for Anomaly Cluster 3191, which is derived from two samples. The original sample data, together with relevant statistics for the lithology types over which the samples were taken, are shown in Table 2.

If there are no additional anomalous samples within the search radius, we still call the site an anomaly cluster, but only if it is anomalous in more than one element. Sample sites anomalous in only one element, which are more than 2.5 km from any other anomalous sample, are ignored in this study. They are, however, plotted with a unique symbol (a blue dot) on the project's main output map, and can be included in any target characterization studies by working with MapPlace[5] tools.

Mineral Deposit Matching

MineMatch® is a Windows-based program which assists geologists to document and compare exploration prospects, mineral deposits and mineral deposit models. Built on internationally recognized standard geological vocabularies, it is able to provide similarity rankings between mineral deposits or geochemical anomalies and mineral deposit models. This is a fundamental aspect of target generation.

In this project the geochemical anomalies identified using the techniques described above are matched against a collection of 95 globally recognized mineral deposit types. These include most of the United States Geological Survey (USGS) deposit types (Cox *et al.*, 1986), and 15 deposit types described by the BCGS (Lefebure *et al.*, 1995; Lefebure *et al.*, 1996) in order to produce the following aids to minerals exploration in BC.

(1) Maps showing localities which display similarities with recognized mineral deposit types based on multi-element anomalies and lithologies present in the region sampled;

(2) Similarity rankings for each anomalous locality against each deposit type (Table 3);

(3) Detailed comparisons of the attributes of each locality with the attributes of the two mineral deposit types it most closely matches (example: Table 4). These comparisons provide powerful guidelines for the further exploration of each locality by highlighting what additional information is required to enhance the exploration potential of the site. This aspect of the proposed project caters explicitly for Recommendation 2 of the "Geochemistry and Geophysics" section of the 2001 BCGS "Five Year Plan" (BC Geological Survey, 2001).

The evaluations were carried out using a combination of ESRI's ArcView® 8.3 geographic information system[2] and GeoReference Online Ltd's MineMatch® software system[3].

ArcView® 8.3 was used to:

(1) Group samples according to lithology before determining anomaly thresholds;

(2) Identify and flag anomalous samples;

(3) Identify anomalous sample clusters comprised of closely spaced anomalous samples (using GIS buffering techniques); and

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[2] *As described at www.esri.com*

[3] *As described at www.minematch.com*

TABLE 1

MINEMATCH DESCRIPTION OF ANOMALY CLUSTER NO 3191

Cluster 3191's MineMatch Description	Comment
ElementEnhanced - Au	From Sample 93N831386
ElementEnhanced - Na	*From Sample 93N831385*
ElementEnhanced - Ta	*From Sample 93N831385*
ElementEnhanced - U	*From Sample 93N831385*
RockHost - alkali-feldspar-granite*	From Sample 93N831386
RockHost - granite*	From Sample 93N831386
RockHost - fine-grained-normal-crystalline-rock*	*From Sample 93N831385*
RockHost - volcaniclastic-igneous-rock*	*From Sample 93N831385*
* These are the standard rock names taken from the British Geological Survey Rock Classification Scheme (Gillespie *et al*., 1999) which most closely match the lithologies shown to be present at the sample sites on the BC 1: 250 000 geological map.	

TABLE 2

SAMPLE DATA FOR CLUSTER NO 3191, WITH SAMPLE POPULATION SIZE AND 99TH PERCENTILE VALUE FOR THE LITHOLOGY TYPES OVER WHICH ITS CONSTITUENT SAMPLES WERE TAKEN

ClusterNo	SampleID	ANOMS	U_INAA	AU1_INAA	NA_INAA	TA_INAA	LITHOLOGY_TYPE
3191	93N831386	1	10	**110**	2.9	2	granite, alkali feldspar granite intrusive rocks
99th Percentile for Lithology Type			200	94	3.9	20	
No of Samples for Lithology Type			1784	1784	1784	1784	
3191	93N831385	3	**18**	6	**3.7**	**2.7**	undivided volcanic rocks
99th Percentile for Lithology Type			18	164	3.4	2.7	
No of Samples for Lithology Type			1328	1328	1328	1328	

TABLE 3

SIMILARITY RANKING FOR ANOMALY CLUSTER 3191, SHOWING ONLY THE BEST SIX MATCHES

Deposit Type	Similarity Ranking
Subvolcanic Cu-Au-Ag (As-Sb)	1
Porphyry Cu + Mo + Au	2
Hot-spring Au-Ag	3
Porphyry Cu-Au Alkalic	4
Sn Greisen Deposits	5
Gold on flat faults	6
… etcetera	

TABLE 4
EXTRACT FROM THE DETAILED COMPARISON GENERATED BY MINEMATCH OF THE ATTRIBUTES OF ANOMALY CLUSTER 3191 TO THE ATTRIBUTES OF THE BCGS VERSION OF THE PORPHYRY CU/MO/AU DEPOSIT TYPE. THE UNMATCHED DEPOSIT TYPE ATTRIBUTES, MANY OF WHICH DO NOT APPEAR IN THIS EXTRACT, PROVIDE A CHECKLIST OF ATTRIBUTES TO LOOK FOR IN THE VICINITY OF THE ANOMALY CLUSTER

Cluster 3191: Attributes	Cluster 3191's Value	Cluster 3191: Present or Absent	Porphyry Cu + Mo + Au Deposit Type: Attribute	Porphyry Cu + Mo + Au Deposit Type's Value	Deposit Type: Expected Frequency of Attribute Value	Match Type	Porphyry Cu + Mo + Au's Comment
			Alteration	altAssemblage 1	sometimes		Na-Ca silicate alteration, dominated by albite. Sometimes classed as 'propylitic' alteration
ElementEnhanced	Ta	present					
ElementEnhanced	Au	present	ElementEnhancedToOre	Au	sometimes	maAKOca	Inherited
ElementEnhanced	U	present					
ElementEnhanced	Na	present					
			FormDepositHost	breccia	sometimes		Hydrothermal origin
			FormDepositHost	contact zone	sometimes		Intrusive contact
			FormDepositHost	pluton	usually		Commonly small, multiphase stocks. Deposits referred to as 'classic' or 'southwest U.S.A. type' porphyry coppers
			RockHost	quartz-monzonite	sometimes		Most common intrusive hostrock for mineralization in Canadian Cordillera
RockHost	granite	present	RockHost	granite, porphyritic	sometimes	maybeAKO	
RockHost	fine-grained-normal crystalline-rock	present	RockHost	porphyry	usually	maybeAKO	Commonly granitic plutonic rocks and dykes in intrusive-hydrothermal complex
			RockHost	quartz feldspar porphyry	sometimes		
			RockHost	granodiorite	sometimes		
			RockHost	hornfels	usually		
RockHost	volcaniclastic-igneous-rock	present	RockHost	volcaniclastic-igneous-rock	usually	exact	Commonly andesitic rocks, volcanic flow rocks are locally dominant
RockHost	alkali-feldspar-granite	present	RockHost	<any value>	always	exact	

(4) Combine lithological information with anomalous cluster characteristics (using spatial joins of sample points with the lithology of the geological polygons within which they lie),

MineMatch® was used to:

(1) Represent information characterizing 95 mineral deposit models;

(2) Compare anomaly clusters with deposit model descriptions, and publish their similarity rankings; and

(3) Publish referenced comparison reports (see "Referencing" below) for the best and second-best matching model for each anomaly cluster.

PROJECT OUTPUTS

All project maps, as well as the data used to generate them, are available from the www.rockstorichesbc.com web site.

Geochemical Anomaly Cluster Maps

Figure 2 illustrates the main map output from the project, in which all identified anomaly clusters are shown. These clusters are highly anomalous[4], as their values exceed 99% of the values for the lithology over which they occur. The clusters are plotted, together with 1:250 000 geology outlines, sample positions, mineral occurrences, and mineral claims boundaries, as they were portrayed on MapPlace in October 2003[6].

Approximately 85% of the anomaly clusters identified have centroids which lie over free ground, as determined from the mineral claims boundaries mentioned above.

A second way of viewing the project outputs is as maps of anomalous clusters matching different deposit types. Figure 3 shows the distribution of anomalous clusters best matching Copper Porphyry, Eskay Creek Gold, and Zinc-Lead Skarn deposit types.

Reports and References

For each anomaly cluster, the model similarity ranking, best, and second-best match reports are accessed by clicking in the map on the cluster of interest, and then clicking on the desired link in the link-list that appears below the map on the computer screen. See Tables 3 and 4 for examples of these reports.

The best and second-best matching models are hyperlinked to detailed Internet-accessible descriptions of the models on either USGS or BCGS web sites.

Documented mineral occurrences falling within the anomaly cluster boundaries are listed and hyperlinked to their entries in the BCGS MINFILE database.

All anomaly clusters are linked to the MapPlace web site[5], where custom maps of the samples comprising the anomaly clusters can be dynamically created in a web browser without the need for proprietary software.

Geochemical Sample Statistics

In the course of calculating anomaly thresholds, informative statistical plots were produced, which have value beyond the scope of this project.

For example, bedrock mappers will be interested in the extent to which the statistics validate lumping and splitting of rock types into different mappable lithological units at a scale of 1:250 000. The statistics are also important to environmental studies interested in the background values, and maximum and minimum expected values, of metals in streams in different geological settings. They may also be important to the selection of analytical techniques for future sampling programs.

Consequently all statistical plots produced by the project have been published on the project website, in the "Geochemical Statistics" area.

The statistical plots fall into three categories:

(a) Box and Whisker plots to summarize compositional distributions for each lithology type;

(b) Histograms to provide greater detail of compositional distributions for each lithology type; and

(c) Scatter plots of duplicate analyses.

Figure 4 shows box and whisker plots for cobalt in 31 of the 62 lithologies present on the BC 1:250 000 geology map. These results show how the mean and range of geochemical values change as a function of surrounding lithology-type.

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[4] *Bearing in mind the qualifications made in the section entitled "Geochemical Analysis" above*

[5] *A BCGS map portal, accessible at www.em.gov.bc.ca/Mining/Geolsurv/MapPlace/*

[6] *Some of these claim boundaries might have been up to one year out of date in October 2003. An online titles administration system, scheduled for release in 2004, will remove these backlogs. See the following web site for current titles information www.em.gov.bc.ca/Mining/Titles/TitlesSearch/mguideInfo.htm*

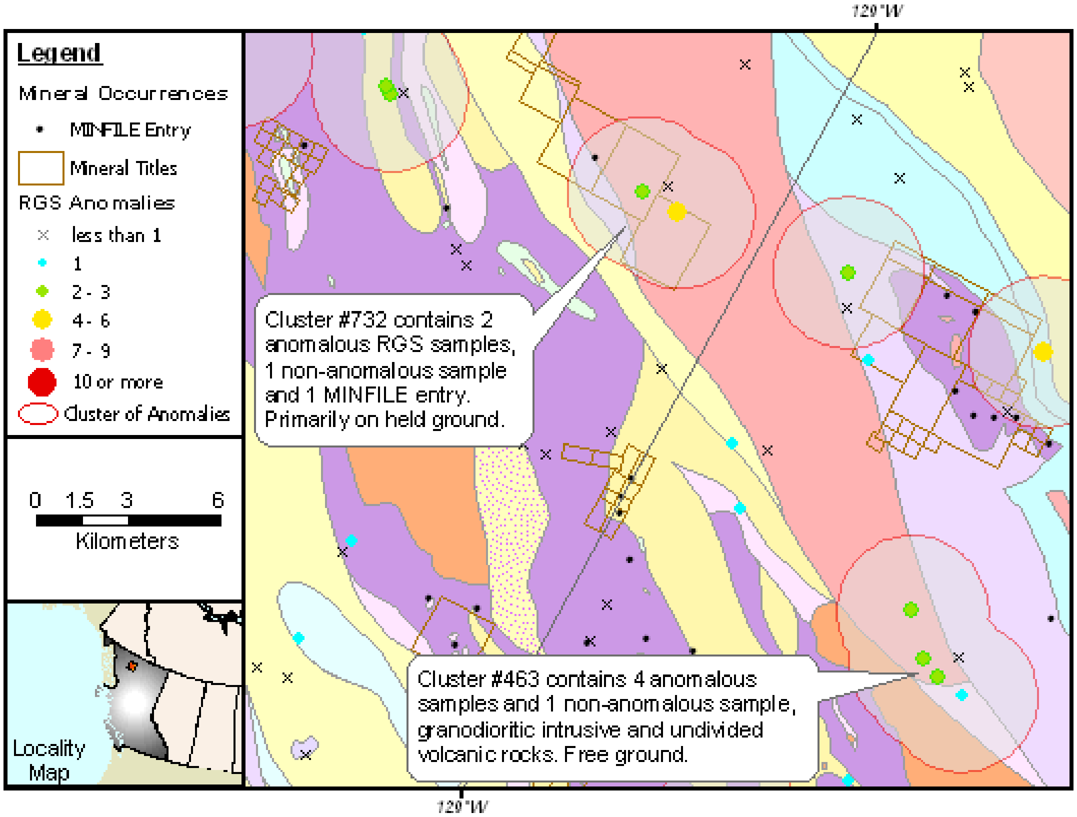

Figure 2. Detail from a MineMatch Geochemistry Anomaly Cluster map, showing 2.5 km buffers around anomaly clusters (some may be "clusters" of only one sample), geology polygons, non-anomalous RGS sample points, MINFILE mineral occurrences, and claim outlines. Note that only mineral occurrences within cluster boundaries are referenced in the MineMatch cluster reports.

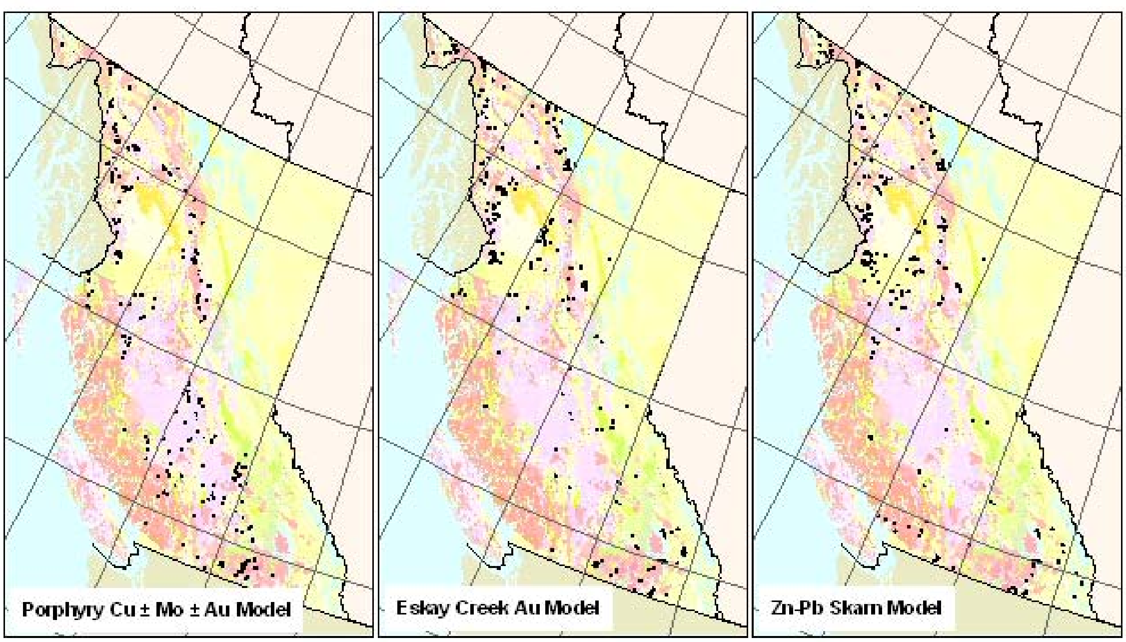

Figure 3. Distribution of anomaly cluster best-matches, according to deposit type. From left to right: Zn-Pb Skarn, Iron Oxide Copper Gold, and Polymetallic Replacement deposit types.

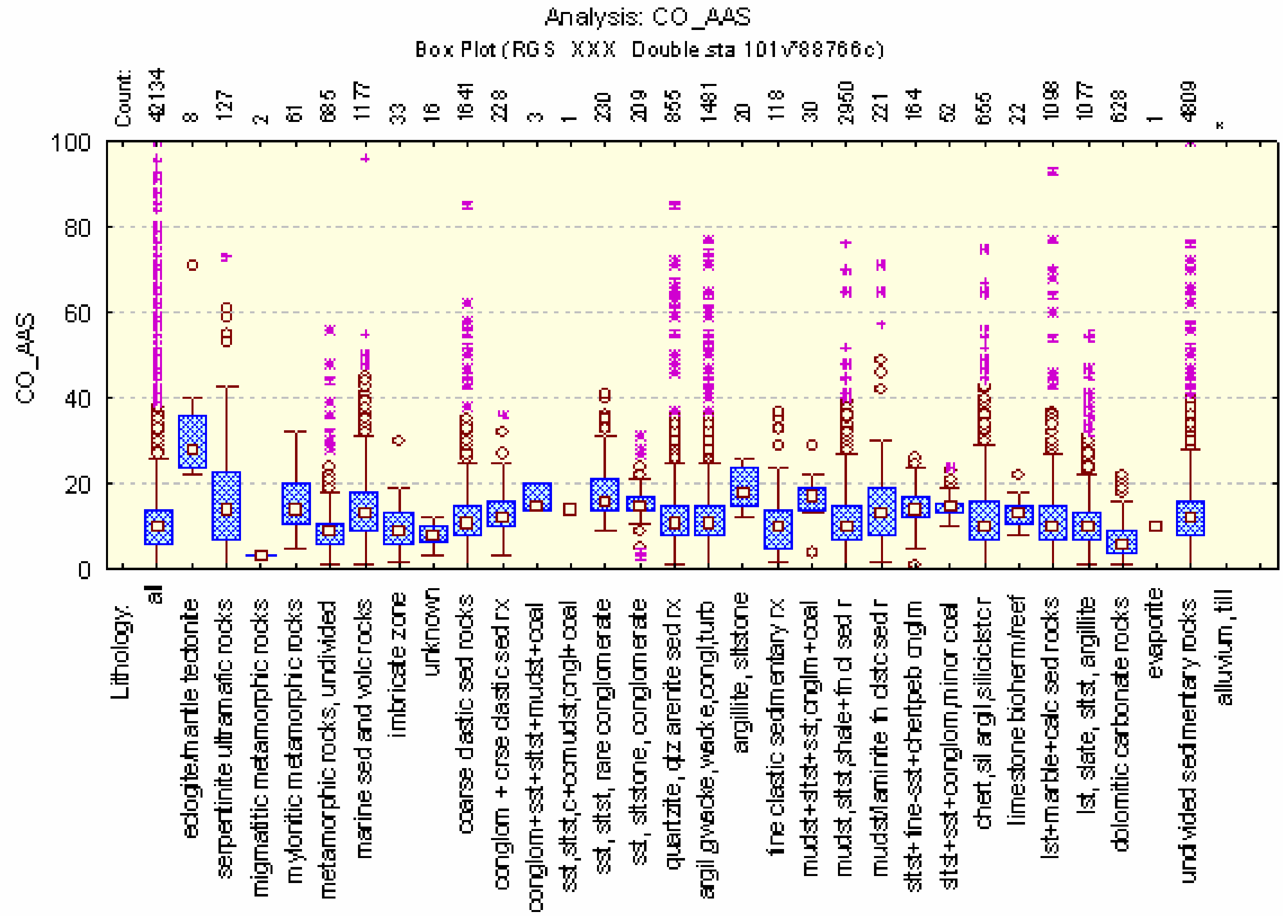

Figure 4. Box and whisker plots showing the distribution of cobalt levels, as determined by AAS, in 31 of the 62 lithology types appearing on the 1:250000 geology map of British Columbia.

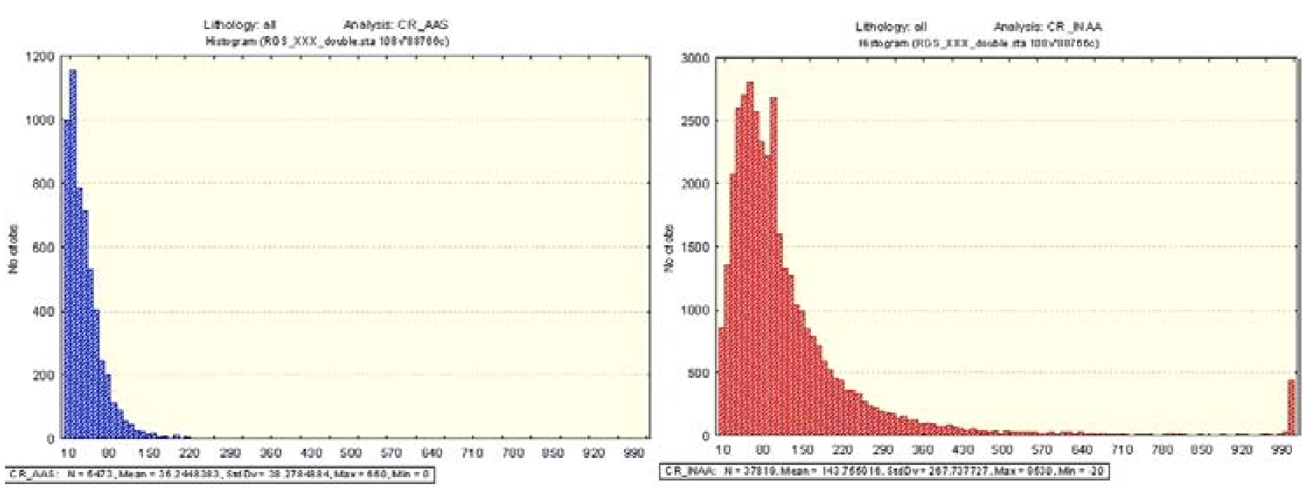

Figure 5. Histograms of chromium levels as determined by Atomic Absorption Spectrometry (left) and Neutron Activation Analysis (right)respectively. All available determinations from the RGS stream sediment database have been plotted. The lower levels in the AA results probably result from only partial extraction of chromium into the solution analysed in the AA spectrometer.

Figure 5 shows histograms of chromium levels as determined by Atomic Absorption Spectrometry and Neutron Activation Analysis respectively. The higher levels in the neutron activation results are almost certainly because of the method's ability to see all the chromium in the sample, while the atomic absorption technique is effectively a partial analysis for chromium.

In addition, scatter plots of all duplicate analyses were generated to assist in anomaly evaluation. A detailed discussion of anomaly evaluation techniques is beyond the scope of this report. However, the importance of these plots may be seen in the differences between the Au (INAA) and V (AAS) duplicates scatter plots in Figures 6a and 6b. Clearly, using the sample medium analysed in the British Columbia RGS program, the absence of an anomalous level of gold in the gold analytical result does not un-equivocally

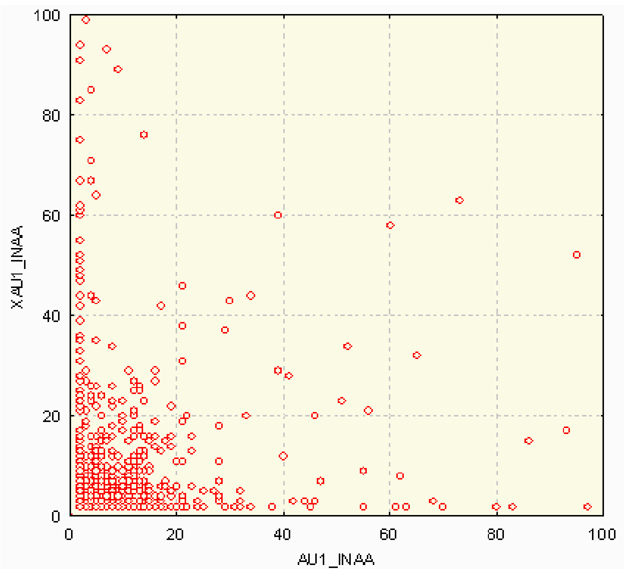

Figure 6a. Scatter plot of RGS sample duplicate analyses for gold by Neutron Activation.

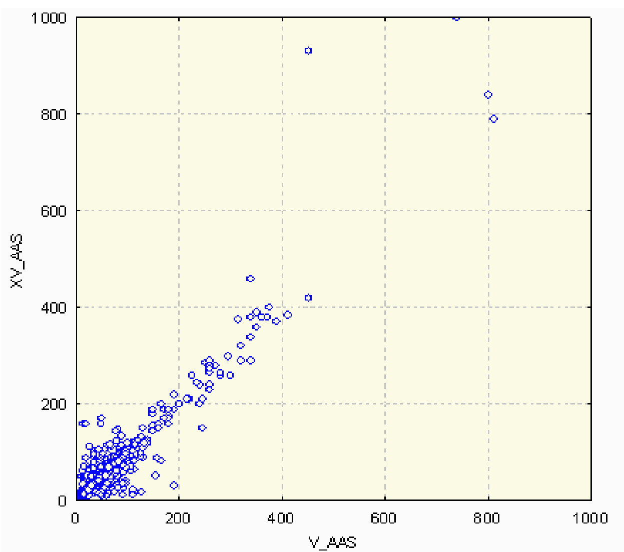

Figure 6b. Scatter plot of RGS sample duplicate analyses for vanadium by Atomic Absorption Spectrometry.

establish that elevated levels of gold are not present in the sampled stream. This issue has long been recognized in the BCGS, and as a result for many years the BCGS did not analyse for gold because the small samples available were known to be unreliable for gold analysis in many locations because of the nugget effect (Matysek *et al*., 1988). As with all geochemical surveys, prospectors and geologists should be aware that there can be numerous reasons why an RGS sample can be downstream of a major mineral occurrence, but not show anomalous values.

On the other hand, vanadium analysis of the stream sediments, as measured by AA, which may be reporting only a partial extraction, yields highly reproducible results, as shown in Figure 6b.

CONCLUSION

British Columbia's high quality geological databases and mineral exploration records have been combined with state-of-the-art computer technology to yield a large number of new exploration targets in the province.

These targets have been made available free-of-charge to the world's minerals exploration community, with the purpose of encouraging investment in exploration in British Columbia.

If only one of the new targets leads to an economic discovery, the "Rocks to Riches" program will have paid its sponsors, the taxpayers of British Columbia, a handsome dividend.

ACKNOWLEDGMENTS

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