Catchment Analysis Applied to the Interpretation of New Stream Sediment Data from Northern Vancouver Island, British Columbia (NTS 102I, 092L)

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Introduction

For many years, Geoscience BC has been engaged in the reanalysis of archived Regional Geochemical Survey (RGS) sample material, as well as in the collection of new samples to cover areas where historical sample coverage was not adequate. A number of projects in the past have examined ways to add value to these new regional geochemistry datasets, including the use of catchment analysis to level the geochemical data for dominant bedrock types in the catchments, and to assess whether the catchment areas used for sampling were appropriate. Arne and Bluemel (2011) is an example of a project using a catchment analysis approach previously sponsored by Geoscience BC with the then newly acquired QUEST-South stream sediment geochemical data. A summary of the approach used can be found in that paper. Such approaches are designed to identify second- and third-order geochemical anomalies often overlooked during a routine analysis of the data by accounting for the effects of metal scavenging by secondary Fe and Mn oxides, as well as variable background levels for important pathfinder elements due to the exposure of different bedrock types in catchment basins. In this way, the analysis adds value to the existing datasets by providing additional information not readily available to most prospectors and geologists working for small exploration companies.

The approach to catchment analysis proposed herein is aligned with the concept of productivity described by Hawkes (1976) and further expanded on by Pan and Harris (1990) and Moon (1999). Bonham-Carter and Goodfellow (1986) demonstrated that catchment lithology was the main control on observed variation in stream sediment data from the Nahanni region, Yukon. Other effects, such as catchment area, possible adsorption of some elements onto secondary Fe or Mn oxides, or onto organic material, and water pH were considered to be minor by comparison. A similar conclusion was reached by Carranza and Hale (1997) in a study of the main controls on stream sediment geochemistry in the Philippines. Bonham-Carter et al. (1987) applied a similar approach to stream sediment data from the Cobequid Highlands of Nova Scotia and further concluded that use of the dominant rock type in the catchment basins was not as effective as taking into account the areal extent of all rock types in the catchment. One of the fundamental assumptions of these approaches is that similar erosion rates affect all lithological units, although this is unlikely to be the case in many instances, particularly in areas of variable relief.

The moss-mat stream sediment dataset selected for evaluation was assembled as part of the Northern Vancouver Island Exploration Geoscience project by Geoscience BC in co-operation with the Island Coastal Economic Trust. This project consisted of collecting new samples (Jackaman, 2013a) and reanalyzing historical RGS samples from the same area (Jackaman, 2011, 2014). The location of the study area, along with the distribution of sample points, is illustrated in Figure 1. Data from this terrain should be ideal for the automated generation of catchment basins. Raw Cu in the historical RGS dataset from Vancouver Island has previously been demonstrated to be a poor predictor of Cu mineralization within individual catchment basins due to the widespread distribution of mafic volcanic rocks in the region contributing to high background Cu levels (Sibbick, 1994).

This project will assess the impact of various approaches to estimating background geochemical levels for stream sediment (moss mat) samples from the northern Vancouver Island study area. New Cu anomalies should be apparent in the map products to be generated for this study once the effects of elevated background Cu have been addressed. Data for other elements important for mineral exploration that also show variable backgrounds levels related to bedrock geology (e.g., Ni and Ba), or tend to be easily adsorbed onto the surfaces of secondary Fe and Mn oxides in the stream sediments (e.g., Zn and As), will also be easier to interpret in terms of anomalies that might be related to unrecognized mineralization within the catchment basins. It is hoped that the release of these new map products will stimulate further mineral exploration in the study area.

Keywords: *geochemistry, regional geochemical survey, RGS, catchment analysis*

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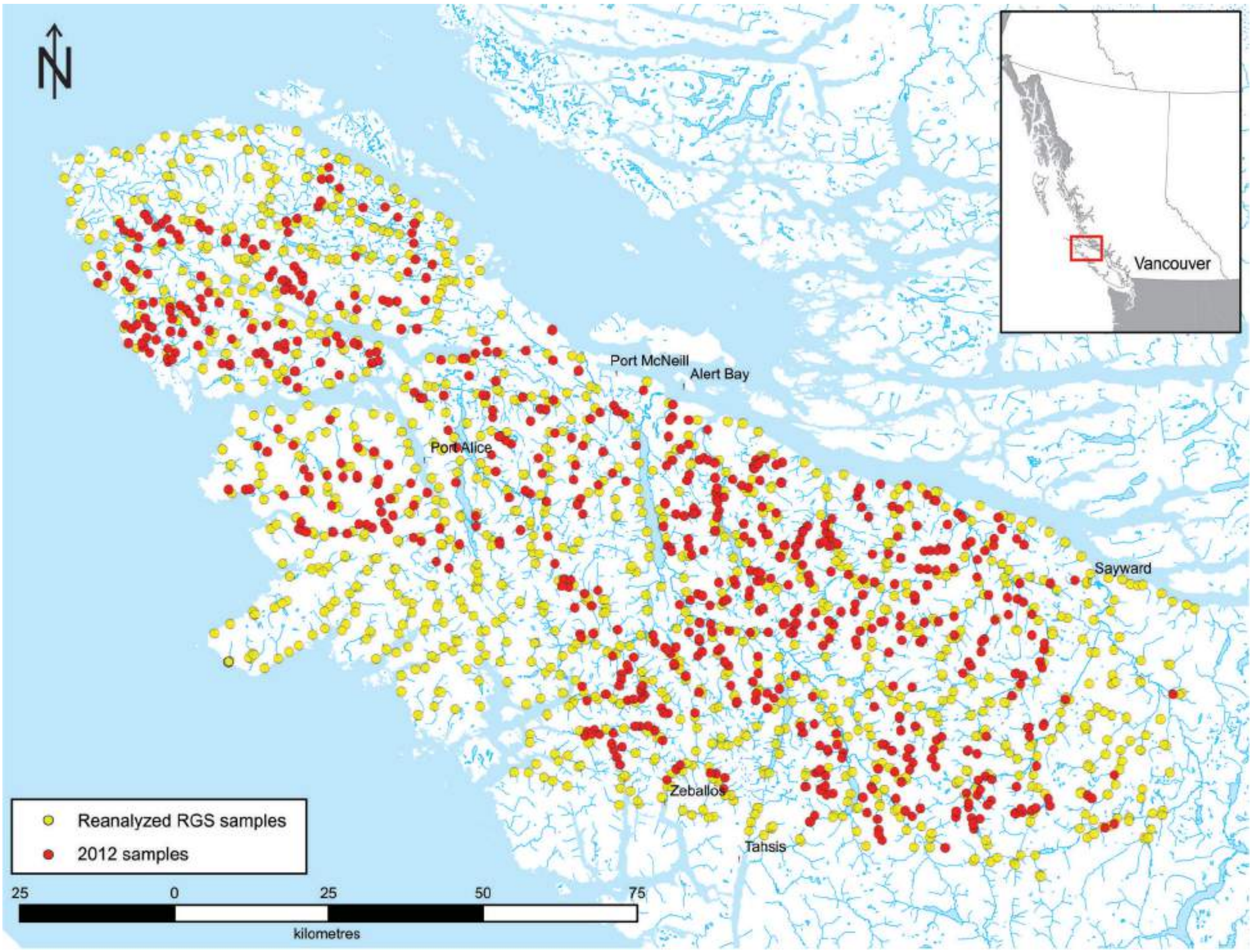

Figure 1. Location of study area showing the distribution of moss-mat stream sediment samples reanalyzed and collected as part of the Northern Vancouver Island Exploration Geoscience project.

Validation of historical RGS sample location points against the terrain resource information management (TRIM) hydrology for the area is nearly completed. Catchment basins will be defined for these samples shortly, followed by attribution with bedrock geology and interpretation of the geochemical data by the end of the year. The catchment basins will be made available as digital geographic information system (GIS) files along with the compiled geochemical data and the bedrock geology for each catchment. A series of map products in both portable document format (PDF) and as GIS data files will also be supplied. Completion of this project is anticipated in early 2015.

Method

Historical and recent moss-mat sediment geochemical data and sample location metadata were obtained from previous Geoscience BC papers. Original field and analytical data obtained by Gravel and Matysek (1989) were taken from Jackaman (2013a). Data from the reanalyses of the original samples by inductively coupled plasma–mass spectrometry (ICP-MS) following an aqua-regia digestion at ALS Minerals (North Vancouver, British Columbia) were also obtained from Jackaman (2013a). These data were supplemented by the addition of Pt and Pd data by lead-collection fire assay from the reanalysis of the original RGS samples in Jackaman (2011). A total of 721 new moss-mat samples were collected for the Northern Vancouver Island Exploration Geoscience project area in 2012 (Jackaman, 2013). These samples were analyzed using both ICP-MS following an aqua-regia digestion at ALS Minerals and by instrumental neutron activation analysis (INAA) at Becquerel Laboratories Ltd. (Mississauga, Ontario). Data on water F contents, pH and conductivity, as well as sediment loss-on-ignition (LOI) and F were also obtained for these new samples. The archived RGS samples were also reanalyzed by INAA at Becquerel Laboratories Ltd. and the results are reported in Jackaman (2014). The sources of data compiled for this study are summarized in Table 1.

The stream sediment samples from the northern Vancouver Island study area were obtained from moss mats. The high flow velocities of many streams in this region meant that very little fine-grained material could be recovered through

Table 1. Summary of data sources and type compiled for this project, northern Vancouver Island. Abbreviations: ICP-MS, inductively coupled plasma–mass spectrometry; INAA, instrumental neutron activation analysis; LOI, loss-on-ignition.

Source	Data type	Number	Data
Geoscience BC Report 2013-11 Appendix B (MEMPR RGS 21-25)	Original analyses	1120	original field metadata; Au by fire assay with charge weights; LOI, F in sediment and water, U in water, pH
Geoscience BC Report 2011-04	Reanalyses	1120	aqua-regia ICP-MS; Pt and Pd by fire assay with charge weights
Geoscience BC Report 2013-11 Appendix A	New samples	721	aqua-regia ICP-MS; INAA with charge weights; LOI, F in sediment and water, pH, conductivity
Geoscience BC Report 2014-03	Reanalyses	1107	INAA with charge weights
		1841	Total number of samples

the collection of traditional stream sediment samples from local traps (Gravel and Matysek, 1989). Moss mats, however, contained abundant fine-grained sediment and preferentially trapped heavy minerals, and so were the preferred sampling material for both the 1988 and 2012 surveys. The samples were disaggregated after drying to remove the organic material and then the sediment was sieved to –177 µm.

Cui (2010) emphasized the necessity of validating the historical RGS sample locations, which were manually located on NTS 1:50 000 topographic map sheets, against the hydrology layer using the current 1:20 000 scale TRIM topographic and hydrological data available in British Columbia, as the entire approach is predicated on the attribution of sample data to the correct watershed. Catchment basins for the validated sample locations are provided by Y. Cui of the British Columbia Geological Survey using the automated methodology described in Cui et al. (2009). This approach involves a three-stage computation:

1) identify the root watershed for each stream sediment sample site
2) retrieve all watersheds upstream of the root watershed
3) dissolve the upstream watershed boundaries to yield a single catchment for each sample

This approach differs from that used by Sibbick (1994). The catchments defined for that analysis were digitized manually from NTS 1:50 000 topographic maps; however, the catchment basins for samples with nested catchments were truncated at the next upstream sample, meaning that the catchment area for some RGS samples in that study will be underestimated compared to this study's approach. In addition, the contribution of bedrock types to the geochemistry of the stream sediment samples from areas located upstream from other samples on the same drainage system would not be taken into account using these root catchments only. A previous comparison of catchment areas derived using the two methods indicates good agreement for the bulk of the catchments, but reveals considerable scatter between a significant number of catchments determined manually and those derived using the automated procedure described by Cui et al. (2009). In some instances, the differences are on the order of several orders of magnitude. These differences either reflect the different approaches to evaluating nested catchments or differences in placement of the samples on the different hydrology layers (NTS 1:50 000 versus TRIM).

The investigation by Arne and Bluemel (2011) used a simple approach to leveling stream sediment data for catchment geology by using the dominant bedrock type. The dominant bedrock type was identified in a GIS query of published bedrock geology and catchments derived using an automated analysis of TRIM terrain data by the British Columbia Geological Survey, as previously described. Considerable effort on the QUEST-South project was expended in manually validating the locations of 8536 historical RGS samples using archived field maps. In the case of the 721 newly acquired northern Vancouver Island stream sediment samples available for this study, the locations are assumed to have been well positioned using modern satellite technology. The locations of 1120 historical samples collected in 1988, however, need to be validated against the TRIM hydrology layer.

The approach used by Arne and Bluemel (2011) will not always be appropriate in large catchment basins where multiple rock types are to be anticipated, nor does it account for variable erosion rates within the catchment. A spatially insignificant rock unit may contribute disproportionately to the geochemistry of a stream sediment sample from the catchment if it is relatively enriched in a particular element. A more accurate approach would be to estimate a background value for each catchment and element of interest using background values for individual lithological units and then apply a weighting to these values based on the proportion of each unit exposed within the catchment. Such weightings assume a constant supply of sediment from each rock type and may require adjustment to account for local variations in relief and erosion weights. Topography and variable weathering effects for different rock types are no doubt important factors in controlling the geochemical input from each rock type in a catchment basin, but such a detailed study is beyond the scope of this investigation. An intermediate approach that is computationally efficient is to use the presence of a particular lithological unit or units to assess catchment basins in a pass/fail approach. This may be as effective as using the entire catchment geology (Bonham-Carter et al., 1987).

The approach used in this study is to estimate background stream sediment values for as many lithological units in the study area as possible in catchments underlain by a single lithological unit but not known to contain mineralization enriched in the elements of interest. Where insufficient catchments meet these criteria, it may be necessary to include catchment basins outside the study area to obtain sufficient data or to statistically filter anomalous data from mineralized catchments from the entire dataset. Geochemical values from till in the study area (Jackaman, 2013b) may also be used where a significant amount of till occurs within the catchment. A theoretical background value for key elements will be calculated for each catchment using the estimated proportion of various lithological units and a weighted average calculated from the background geochemical values for the units (weighted background value, WBV; or catchment background values), a procedure that inherently assumes constant sediment supply from all areas of the catchment.

Observed stream sediment data will be compared to the WBV and the differences recorded in terms of the number of standard deviations above the WBV in order to level the data and define anomalous catchments. In practice, these calculations can be performed using robust multiple regression following the approach recommended by Rose et al. (1970), Bonham-Carter and Goodfellow (1986), and Carranza and Hale (1997). Unlike the traditional approach to productivity, there will be no attempt to estimate the size or element enrichment associated with a theoretical mineral deposit within the catchment, as this approach is also influenced by the position of the deposit within the catchment relative to the stream sediment sample location. The approach will be validated by comparing the results to known mineral occurrences and deposits to see if there is an improvement in predictive capability compared to more traditional and less computationally intensive approaches.

An additional factor to be considered is the possibility of scavenging cations by secondary iron oxides in the samples. This is known to be an important influence on stream sediment data in areas of low relief (Bonham-Carter and Goodfellow, 1986) and is suggested by a positive association of Fe and elements such as V in the original 1988 moss-mat dataset from northern Vancouver Island. Elements affected by suspected scavenging effects will have to be treated through principal component analysis that includes the variables Fe and/or Mn, or by the generation of residuals to indicate the presence of anomalous metals within particular catchments.

Principal component analysis will be used to assess a variety of influences on the raw geochemical data (lithological control, possible scavenging effects by secondary Fe and Mn oxides or organic matter, commodity element associations related to mineral deposits). Regression analysis of the data against the most important principal components will highlight samples that are anomalous and allow an independent validation of the weighted background values.

The effectiveness of current sampling coverage will be assessed through the evaluation of plots of metal concentration versus catchment area sampled to identify the catchment area at which the effects of dilution appear to reduce most stream sediment samples to regional background levels. This represents the maximum catchment area that should be sampled. Samples that capture sediment from larger catchments than this value can be considered to have been undersampled and these areas provide opportunities for follow-up sampling at a higher density to assess mineral potential. Regional background values for individual elements can also be compared to catchment background values to assess the influence of particular lithological units on the stream sediment data.

Comments on Data Quality

The issue of data precision for the original RGS Au data has previously been noted, most recently by Arne and MacFarlane (2014). Gold was originally determined on the RGS samples from northern Vancouver Island using a lead collection fire assay with a 10 g (and occasionally a 5 g) charge. Data for 656 duplicate pairs were obtained from all RGS samples collected on Vancouver Island in 1988 and 1989. The data for 383 duplicate pairs having average values in excess of 10 ppb (i.e., an order of magnitude above the 1 ppb lower limit of detection for a 10 g charge) are presented in Figure 2. The data clearly suffer from poor reproducibility with an indication of a negative bias in the duplicate analyses. The average coefficient of variation for these duplicate pairs is 102%, calculated using the root-mean-squared (RMS) method described by Stanley and Lawrie (2007).

Gold data obtained from the more recent ICP-MS reanalyses are likely to have even greater variance given the 0.5 g aliquot analyzed. The INAA Au analyses are based on an average charge weight of 37.3 g for the new sample analyses and 27.41 for the reanalyses by INAA. The latter includes a wide range of aliquot weights, from just over 50 g to less than 1 g, so the precision of individual values will be variable. The INAA Au data are assumed to be superior to the original RGS Au data given average aliquots three times what was originally analyzed. Only 8% of the archived samples analyzed by INAA had sample weights less than 10 g; therefore, the INAA data will be used to provide the Au values for this study.

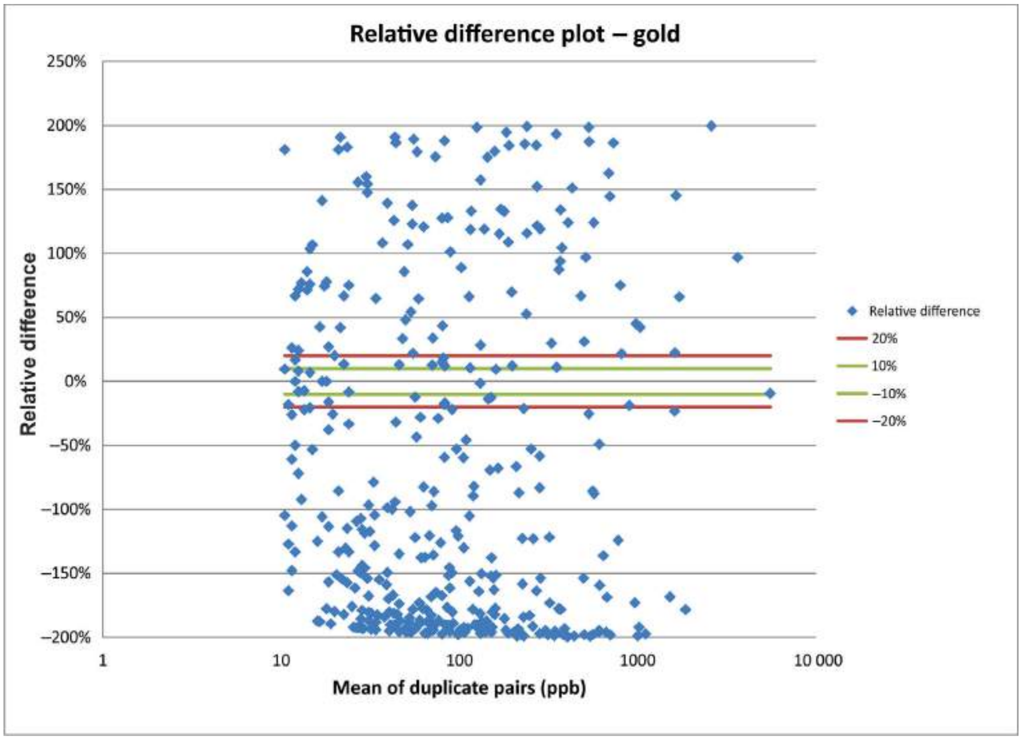

Figure 2. Comparison of historical RGS Au data from analytical duplicates analyzed by fire assay in 1988 and 1989, Vancouver Island.

The quality of the PGE data is also variable depending on which dataset is examined. The archived RGS samples for all of Vancouver Island were analyzed for Pt and Pd by fire assay using an average charge weight of 22.7 g and lower limits of detection for Pd and Pt of 0.5 and 0.1 ppb, respectively. The PGE data for the new samples collected on northern Vancouver Island in 2012 have been analyzed by ICP-MS using a 0.5 g aliquot with lower limits of detection for Pd and Pt of 1 and 2 ppb, respectively. The fire assay PGE data from the archived samples are therefore considered to be superior. Equal weighting should not be given to all Pd and Pt results from the project area given the possible physical transport of PGE grains in the streams sampled due to their high velocities and therefore it is likely the data were obtained from nonrepresentative samples.

Although data quality for the reanalysis of historical RGS samples and the analysis of new samples collected in 2012 have previously been assessed, the quality-control data were not made publicly available. The final report on this project will include a brief assessment of the quality-control samples associated with the new data acquired by Geoscience BC.

Acknowledgments

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