

Integrated Assessment of Regional Stream-Sediment Geochemistry for Metallic Deposits in Northwestern British Columbia (Parts of NTS 093, 094, 103, 104)

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Introduction

Regional stream-sediment geochemistry is important to mineral exploration companies, governments and First Nations communities because it helps inform mineral exploration potential in suitable geographical terranes. From 2002 to 2017, Geoscience BC undertook projects involving the reanalysis of archived stream-sediment sample material by inductively coupled plasma–mass spectrometry (ICP-MS) and inductively coupled plasma–atomic emission spectrometry (ICP-AES), increasing the number of elements reported and lowering detection limits compared to historical analytical methods. These improvements allow for a more rigorous assessment of the variation in sediment composition and the filtering of effects related to lithological controls and secondary scavenging, which can mask signals related to metallic metal deposits. Some of these new data covering southern and central British Columbia (BC) have been evaluated using catchment basin analysis and a variety of multivariate statistical approaches (e.g., Arne and Bluemel, 2011; Arne and Brown, 2015); however, data from much of northern BC have not yet been assessed.

Several factors should be considered when interpreting regional stream-sediment geochemical data, including the effects of dilution in catchment basins of differing sizes; the influence of variable bedrock types on geochemical background values; the potential effects of scavenging metals onto secondary Fe and Mn oxides or organic matter; as well as the influence of streamwater pH and Eh, which control the solubilities of most metals (e.g., Hawkes, 1976; Bonham-Carter and Goodfellow, 1986; Carranza, 2009; Arne and Brown, 2015; Mackie et al., 2015). A major conclusion from previous studies is the importance of bedrock geology as a control on stream-sediment geochemistry, although this will depend to a certain extent on the elements

under consideration. For example, when using conventional aqua-regia digestion, elevated Cu values would be expected in catchment basins draining areas dominated by basalt, making it difficult to distinguish elevated background from slightly elevated Cu values associated with sulphide mineralization. Black shales are also often elevated in a variety of metals, including those commonly used for geochemical targeting of mineral deposits. Their extent may be poorly mapped and/or their influence on stream-sediment composition may be disproportionate to their surface expression. The effects of scavenging by secondary Fe or Mn oxides or organics will vary by geographical setting. Streamwater pH is largely bedrock controlled but will influence the distribution of important commodity pathfinder elements such as Zn, As, Sb, Cu and Hg. Using the newly available multi-element geochemistry in conjunction with catchment information, the influence of these effects can be assessed and filtered for more accurate exploration targeting using commodity and pathfinder elements.

This project is a regional assessment of stream-sediment geochemical data from various Geoscience BC reanalysis programs encompassing parts of twenty 1:250 000 scale NTS map areas, as shown in Figure 1. The limits of the project were generally based on the following criteria:

- areas where samples have been reanalyzed by ICP-MS
- areas with an absence of regionally extensive Quaternary cover
- areas with a lack of previous geochemical interpretations of stream-sediment data
- areas with a high degree of interest from mineral exploration companies

The areas covered by the Spatsizi Plateau Wilderness Provincial Park and the Tatlatui Provincial Park have also been excluded from this study. The study area was further constrained to include only regions underlain by the Stikine, Quesnel and Cache Creek terranes. This geological filter was applied because the fringing terranes to the east and

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west will have distinctly different lithological background values for many elements, which could limit the ability to ‘isolate’ geochemical signals associated with mineralization within the targeted terranes. The adjacent terranes are also not significant hosts for base- or precious-metal mineralization and thus are of less immediate exploration interest.

Geological Setting and Mineral Deposits

The study area covers much of the northwestern Stikine terrane of central and northern BC (Figure 1), including important regions of mineral exploration and development. The Stikine terrane is part of the Intermontane Belt, which stretches through BC, Yukon and into Alaska (Colpron et al., 2006). It comprises a north- to northwest-trending allochthonous belt of dominantly Devonian to Jurassic sedimentary and volcanic rocks intruded by coeval Late Devonian, Triassic and Jurassic plutonic rocks (Gunning et al., 2006). Paleozoic volcanic and sedimentary rocks of the Stikine terrane include calcalkaline to tholeiitic sequences largely dominated by basalt, marine limestone and lime mudstone. Volcanism and continued deposition of marine sediments continued through the Mesozoic until the mid-Cretaceous, following a break during the late Permian. The Stikine terrane was accreted to the adjacent Cache Creek and Quesnel terranes by the Middle Jurassic, followed by the deposition of Middle Jurassic to Early Cretaceous fluvial to marine clastic sediments that lie unconformably over the Stikine terrane in the Bowser and Sustut basins (Ricketts et al., 1992). Marine sedimentation and subaerial volcanism resumed in the Late Cretaceous or Paleogene and Neogene.

Parts of the study area have previously been included in Geoscience BC projects that have focused on well-mineralized areas of the Stikine and Quesnel terranes (Figure 1). The informally named ‘Golden Triangle’, stretching from south of the Red Mountain Au-Ag deposit to the Red Chris Cu-Au mine, was included in the QUEST-Northwest project. This area contains volcanic-hosted massive sulphide (VHMS) deposits at Granduc and Eskay Creek, as well as porphyry Cu-Au and epithermal Au-Ag deposits such as Brucejack and KSM. The QUEST-Northwest project to the north of the Golden Triangle also encompassed the Thorn Au-Ag and Tulsequah Chief VHMS deposits. An area centred on the town of Smithers formed the basis of the QUEST-West project that includes porphyry Cu-Au and Mo deposits, including Endako. Porphyry Cu-Au deposits in the western portion of the original QUEST project area are also included within the study area. The northern portion of the TREK project area, which contains epithermal Au-Ag deposits such as Blackwater, occurs in the southeast corner of the study area. The majority of known mineral deposits in the study area are of magmatic hydrothermal origin, associated mainly with calcalkaline to alkaline Triassic

and Jurassic intrusive rocks, and to a lesser extent with Late Cretaceous–Paleogene calcalkaline intrusive rocks in the central and southern Stikine terrane (Nelson et al., 2013). The main deposit types that are the focus of the current investigation, therefore, are porphyry Cu-Ag-Au, epithermal Au-Ag and, less commonly, VHMS Zn-Cu-Ag-Au. Skarn deposits in the study area will also have a similar geochemical signature.

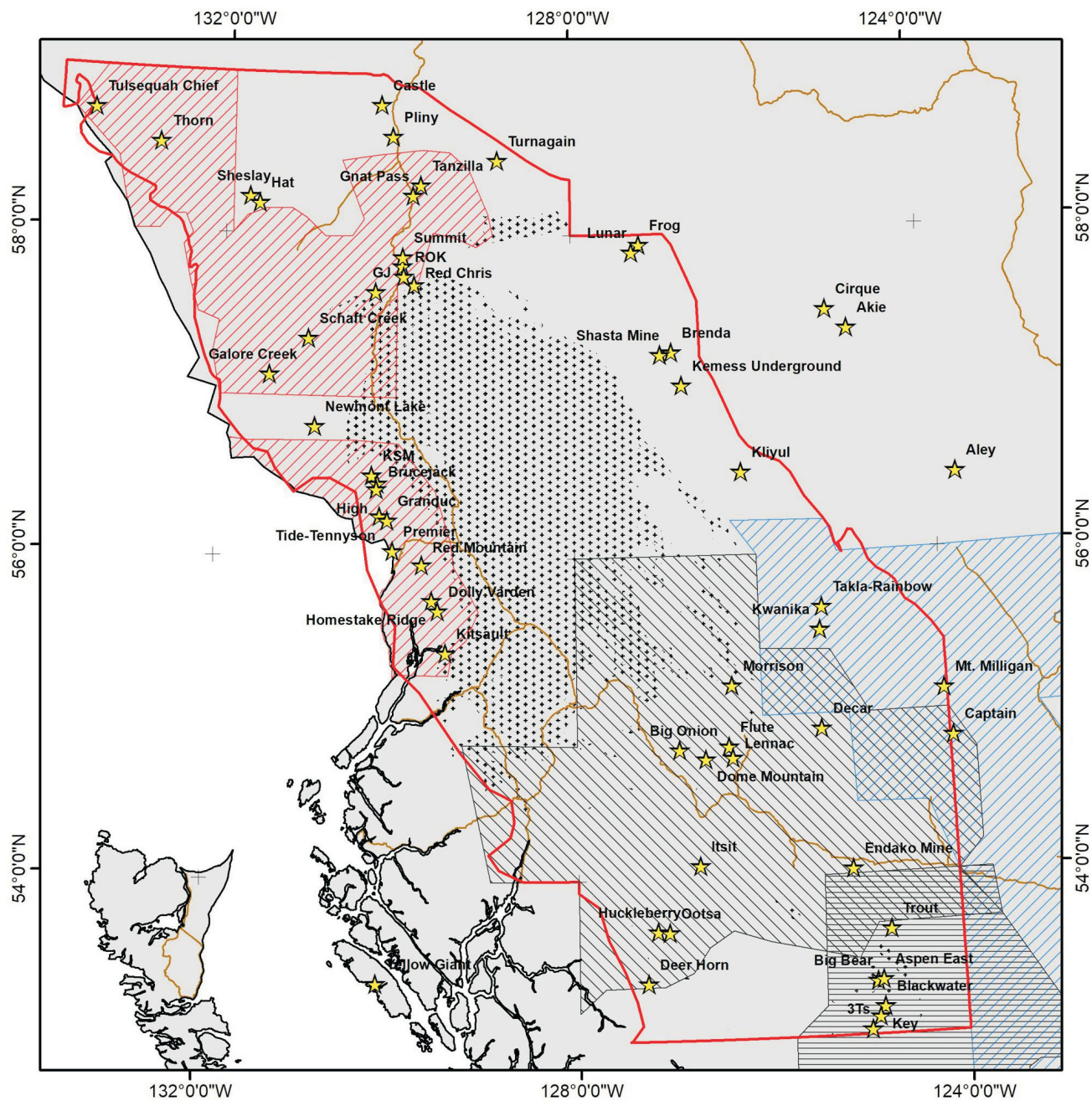
Methodology

Data Compilation and Conditioning

The data assembly for this project built on a previous compilation of historical regional geochemical data conducted by the BC Geological Survey (BCGS; Rukhlov and Naziri, 2015). This compilation was updated to include all the ICP-MS data generated through the various recent Geoscience BC projects. A summary of NTS map areas and public reports is provided in the form of a matrix in Table 1. Note that the reanalysis data were supplied from two separate laboratories. The bulk of the reanalyses were undertaken at Bureau Veritas Minerals (formerly Acme Analytical Laboratories Ltd.; Vancouver, BC), whereas reanalyses of samples from part of NTS map area 093F were undertaken by Eco-Tech Laboratories Ltd. (Kamloops, BC) in 2009. In addition, the reanalyses span 2002 to 2017, a period of 15 years. The use of two laboratories and the time span involved raises the possibility that some levelling of data to account for systematic variations within the compiled dataset may be required.

Table 1. Summary of NTS map areas in the study area and data sources.

NTS map area	Report							
	Jackaman (2008a)	Jackaman (2008b)	Jackaman (2012)	Jackaman (2011)	Jackaman (2009a)	Friske et al. (2003)	Jackaman (2017)	
093E					x			x
093F					x	x		
093K						x	x	
093L					x			
093M					x			
093N	x							
094C				x				
094D				x				
094E				x				
103I		x						
103J		x						
103O								x
103P								x
104A				x				
104B				x				
104F, G				x				
104H				x				
104I				x				
104J				x				
104K		x						



Legend

- ★ Projects and mines
 - Roads
 - ▭ Project area
 - Bowser Basin
- Geoscience BC projects**
- ▨ QUEST
 - ▨ QUEST Northwest
 - ▨ QUEST-South
 - ▨ QUEST-West
 - ▨ TREK

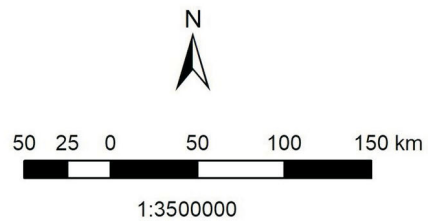


Figure 1. Location of study area, showing the areas covered by previous Geoscience BC initiatives, the locations of major mineral deposits and the area of bedrock covered by Bowser Basin sedimentary rocks that postdate some periods of mineralization.

An assessment of the database indicates that 36 elements have concentrations typically greater than the lower limits of detection while providing maximum spatial coverage. These include Au, Ag, Al, As, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Se, Sr, Te, Th, Ti, Tl, U, V, W and Zr. This process resulted in the selection of 14 877 samples, excluding quality-control samples but including those collected within the Bowser Basin, most of which will be excluded from catchment basin analysis. Data for values below the lower limits of detection were computed by the method of nearest neighbour replacement estimates. The adjusted data were then used for subsequent multivariate statistical analyses. Multivariate analyses of data for these elements, including principal and independent component analysis following a centred-log ratio transformation to remove the effects of closure (Aitchison, 1986), are consistent with a dominant spatial control that can be related to regional lithological and mineral deposit trends for most elements. Commodity and pathfinder elements show a general spatial correlation with major mineral deposits and districts. Raw-element and principal-component gridded maps show no abrupt variations that might be related to map area and/or survey boundaries, indicating that interpretation of the geochemical data can proceed without the necessity of levelling the data for analytical batch effects.

Sampling and Analysis

The original regional geochemical survey (RGS) stream-sediment samples were generally collected from first- and second-order streams under Canada's National Geochemical Reconnaissance (NGR) program at an approximate density of one sample per every 13 km² in BC (e.g., Friske et al., 2003). The samples were sieved to -80 mesh (<177 µm) prior to analysis, originally using either aqua-regia digestion followed by atomic absorption spectroscopy (AAS), instrumental neutron activation analysis (INAA) or, for Au only, lead-collection fire assay. Splits of the original sieved sample material were archived in Ottawa, Ontario at the Geological Survey of Canada (GSC). This material was sampled for reanalysis using a dilute aqua-regia digestion (1 HCl:1 HNO₃:1 H₂O) at Bureau Veritas or standard aqua-regia digestion at Eco-Tech Laboratories and analysis by combined ICP-MS and ICP-AES. The original quality-control samples (field duplicates, blind or pulp duplicates and reference materials) were also sampled for reanalysis.

As demonstrated by Arne and Bluemel (2011), Arne and MacFarlane (2014) and Arne and Brown (2015), the precision of the original RGS Au data is poor, even when using up to 10 g of sample material. The original data, however, are superior to Au analysis of the archived material by ICP-MS using a 0.25–0.5 g sample aliquot (Mackie et al., 2017; this paper). For this reason, the original Au data have been

used for the present compilation. Duplicate Au analyses have been averaged where available.

Data Quality

Quality-control data from the relevant Geoscience BC reanalysis projects have been provided by W. Jackaman (pers. comm., 2017). Data from a total of 1379 field duplicate pairs, 1394 pulp (blind) duplicate pairs, 1476 RGS reference materials and 2350 laboratory reference materials have been assessed for Au, As, Cu and Mo. These elements are representative of the types of mineral deposits found in the region of most interest (porphyry Cu-Mo, epithermal Au-Ag and VHMS Cu-Zn). Descriptions could not be obtained for all the reference materials submitted with the original stream-sediment batches, although data from them can still be assessed in terms of data consistency. The same reference materials were also not used throughout the original sampling programs, so it is difficult to assess continuity beyond a 10 year period, and is only possible for the Red Dog RGS reference material.

As expected, the precision and accuracy of the Au data are poor (Figure 2a, b), but improve for As, Cu and Mo. Neither the Acme DS7 (Acme Analytical Laboratories' in-house reference material; Natural Resources Canada, 2017) or Red Dog reference materials were designed for accurate and precise Au analyses, although they do demonstrate the amount of variability that might be observed in actual stream-sediment samples sieved to <177 µm. The control limits shown for the Red Dog reference material in Figure 2 were calculated from long-term averages, excluding outliers (R. Lett, pers. comm., 2017), and there are clearly numerous outliers that can be explained by inhomogeneity of the material and a nuggety distribution of Au particles in the reference material.

The accuracy of the Cu and As data is variable in Acme DS7 and Red Dog reference materials, respectively, but this is not surprising given that the reanalysis of the stream-sediment samples was completed between 2002 and 2017 (Figure 2c, d). Clear breaks in data for the reference materials occur where there is a break in the time sequence of the analyses; however, slight differences in the aqua-regia digestions used between labs, as well as variations over time at Bureau Veritas, are not considered to be significant for the interpretation of the data, although the Au ICP-MS data must be treated with caution.

Another important data-quality consideration is the reliability of original sample location information. The generation of catchment basins for individual samples uses modern 1:20 000 terrain resource information management (TRIM) topographical and hydrological data (Cui et al., 2009). Samples must, therefore, be accurately located within the modern topographical framework to ensure the correct catchment basin is allocated to each sample. In most

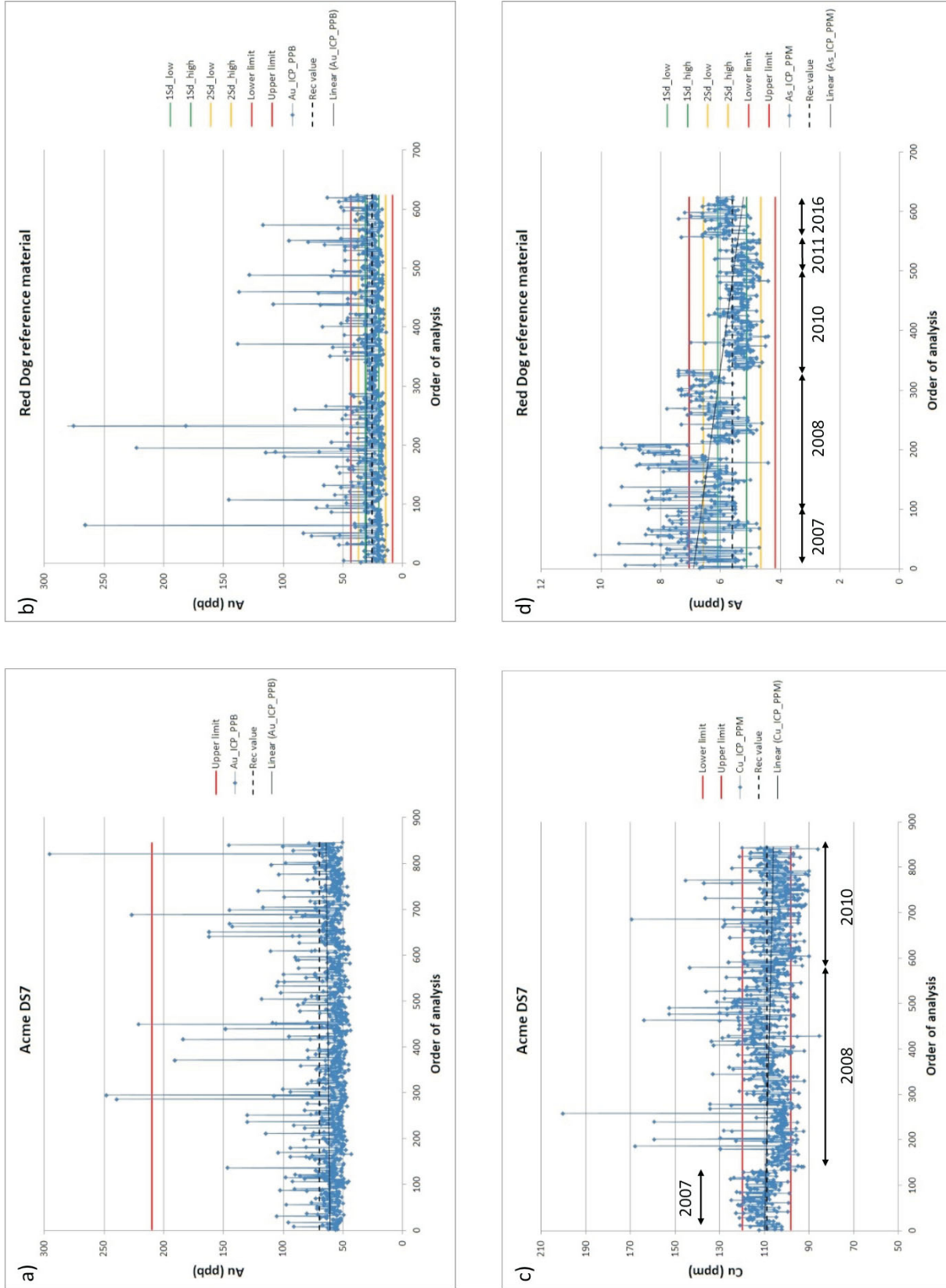


Figure 2. Summary of dilute aqua-regia inductively coupled plasma–mass spectrometry (ICP–MS) analyses of internal laboratory (Acme DS7) and RGS survey (Red Dog) reference materials: **a)** analysis of Acme DS7 for Au, **b)** analysis of Red Dog for Au, **c)** analysis of Red Dog for Cu and **d)** analysis of Red Dog for As. Analytical values (y-axis) are plotted in chronological order (x-axis).

cases, sample locations were manually marked onto 1:10 000 to 1:25 000 scale topographic map sheets and then the UTM grid reference locations measured off the map sheets in either NAD27 or NAD83 datums. In some cases, locations were recorded on sketch maps. In addition to the uncertainties associated with identifying sample locations prior to the availability of GPS receivers, the locations of streams have sometimes either physically shifted or vary by comparison to more precise topographical data. The result is that sample locations often do not plot on the correct drainage, and validation or correction of the locations is required (Cui, 2010). This process can be time consuming as not all location errors can be rectified using automated procedures within a GIS.

An example of a typical location validation issue is presented in Figure 3. In all three instances shown on this figure, sample points (shown by grey dots) plot up to 1 km from the locations plotted by hand using red circles shown on the georeferenced original sample location map. Samples 1391 and 1390 are good examples of a common loca-

tion error that would be partially fixed by using a ‘snap to’ tool in a GIS, although the location for sample 1390 could potentially snap to the wrong stream given its distance from the correct tributary. Sample 1388 is an example of a considerable plotting error that required a significant move to its correct sample point location based on the original map. Validated, or corrected, sample locations (shown by pink dots) are the preferred sample locations based on the original sample location map.

Preliminary Results

Analysis of the distribution of raw elements shows a strong spatial association of commodity and pathfinder elements such as Au, Ag, Cu, Mo, Sb, Bi, Hg and Pb with areas of known mineral deposits. These elements also define loadings on the main principal components that account for nearly 60% of the variation within the dataset. It is unusual to see such a strong influence of commodity and pathfinder elements in the main principal components from a regional dataset; this bodes well for defining anomalous catchment

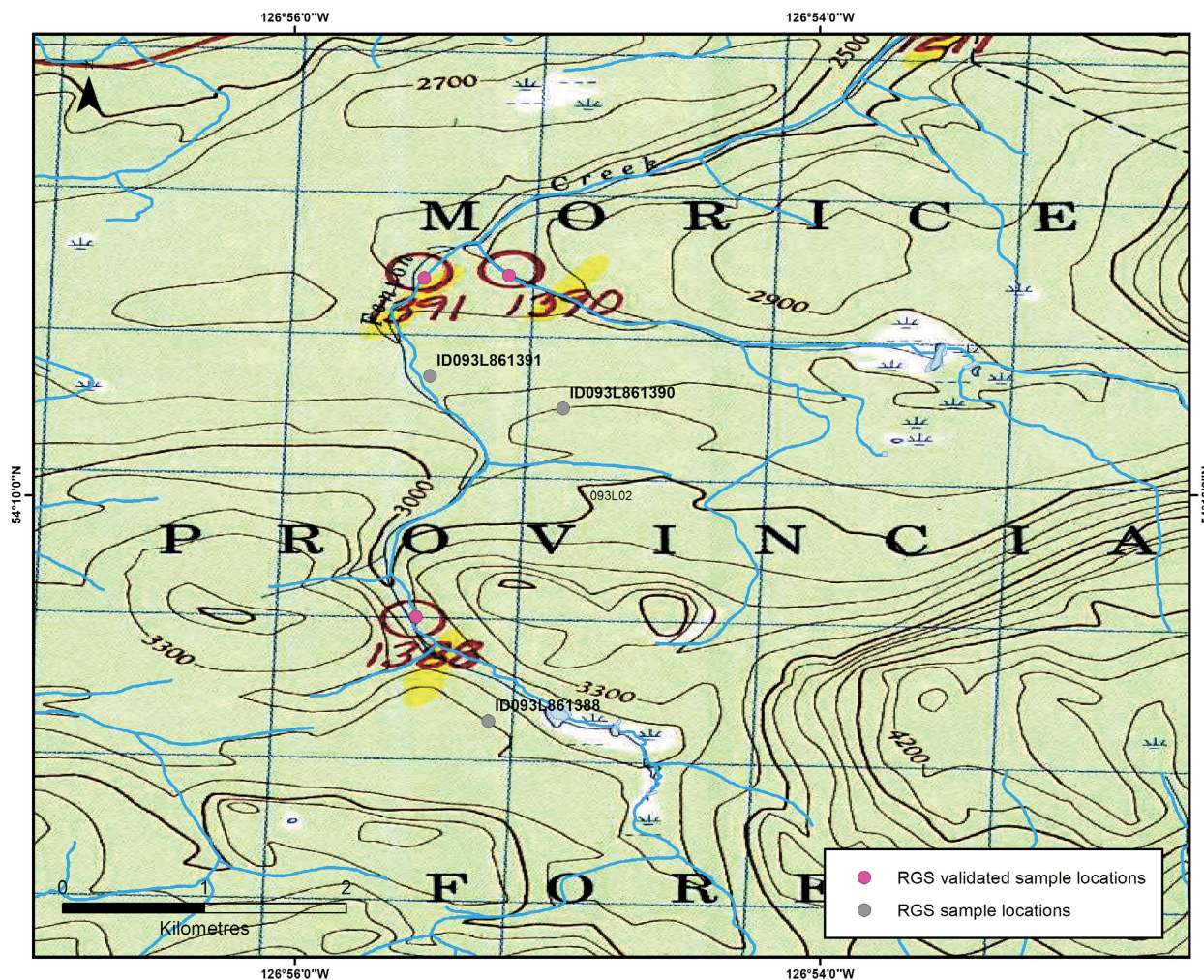


Figure 3. Example of regional geochemical survey (RGS) sample location validation problem (grey dots show the original sample location, red circles show the sampling locations marked on the original hard-copy map by the sampler and pink dots show the validated location).

basins with minimal processing of the data. Samples derived from sedimentary rocks of the Bowser Basin have a distinct geochemical signature defined largely by elements with a mafic affiliation (Co, Mg, Sc, Ni, Cr), as well as being elevated in elements that are often enriched in black shales (Cd, Sb, Ag, As, Se, Hg, Zn, Te). Triassic magmatic belts and batholiths of the Coast Plutonic Complex are characterized by elements having a felsic affinity (U, Bi, La, Mo, K).

Conclusions and Future Work

This project highlights the value of new ICP-MS geochemical data by assessing areas of known hydrothermal magmatic mineralization in the northern Stikine terrane in a single data compilation. Work remaining to be completed in this project includes validation and/or correction of sample locations prior to the generation of catchment basins by the BCGS for samples outside of the Bowser Basin. Catchment area and bedrock geology will be defined for each sample for comparison with inferred geology based on multi-element signatures for the main bedrock types. Geochemical data from individual samples will be levelled for the effects of variable bedrock geology in individual catchment basins. This will be followed by the generation of a series of exploration targeting catchment map products using a weighted sums modelling approach (Garrett and Grunsky, 2001) to optimize the geochemical fingerprint for different mineral deposit types using known mineral deposits and occurrences. These new products will identify specific basin catchments containing geochemical signatures consistent with the presence of mineralization, and thus provide new exploration targets for further investigation.

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