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Catchment Analysis of Re-analyzed Regional Stream Sediment Geochemical Data from the Yukon

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Introduction

CSA Global was contracted in 2015 and 2016 to generate a series of map products targeting different mineral deposit types using catchment analysis following the completion of an extensive re-analysis program by the Yukon Geological Survey (YGS) (Mackie *et al.* 2015). The re-analysis program resulted in new ICP-MS data for the <0.177 mm fraction of 24,279 archived regional stream sediment samples collected by the YGS and the Geological Survey of Canada (GSC) for the southern two-thirds of the Yukon (Fig. 1). Interpretation of the new geochemical data investigated two approaches to correct for the influence of variable bedrock lithology and metal scavenging on commodity and pathfinder elements of interest for mineral exploration. One was Z-score levelling of specific commodity and pathfinder elements by dominant bedrock lithology, and the second was a new approach – regression analysis of commodity and pathfinder elements against principal components that can be related to regional lithological variations and/or metal scavenging.

Digital copies of deposit-specific geochemical prospectivity maps and data packages are available for all maps sheets from the YGS web site (http://data.geology.gov.yk.ca/; see listing in Mackie *et al.* 2017). The results of both approaches are presented in the form of weighted sums models for specific mineral deposit types that were visually tested against known mineral deposits and occurrences on each map sheet. A subsequent review of data quality, including an assessment of geochemical data quality, sample locations, and geomorphological controls on dilution was provided by Mackie *et al.* (2017). A previous contribution to **EXPLORE** No. 176 demonstrated the wide variability of Au data from the re-analyses of archived stream sediment samples by modified aqua regia/ICP-MS using a small (0.5 g) sample aliquot (Arne 2017). This

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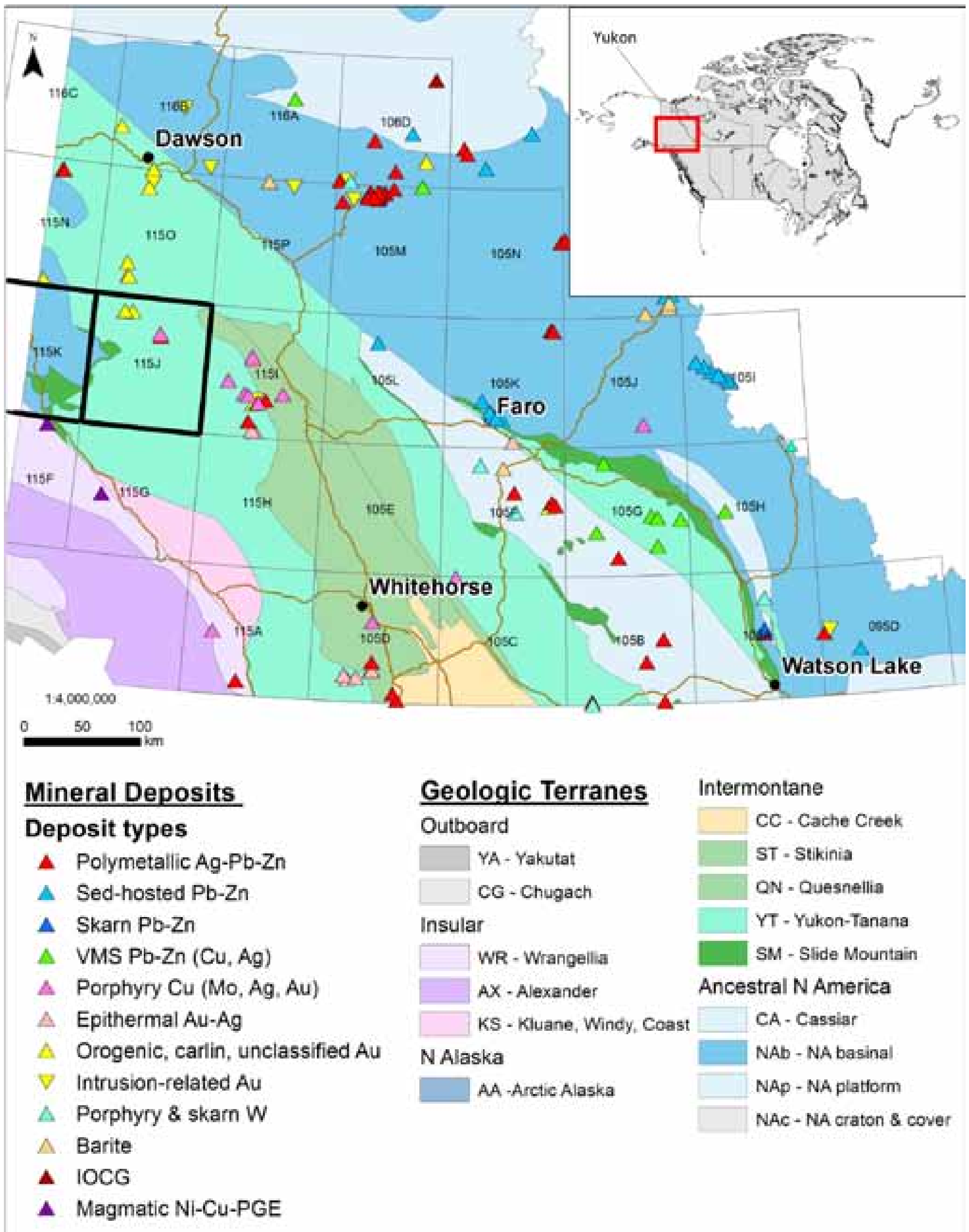

Figure 1 – NTS map sheets included in the YGS stream sediment re-analysis and interpretation project superimposed on geological terranes from http://www.geology.gov.yk.ca/bedrock_terrane.html. The distribution of mineral deposit types is also illustrated. The Stevenson Ridge area is shown by the heavy black map sheet outline.

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contribution introduces the concept of regressing commodity and pathfinder elements against principal components. A case study from the Stevenson Ridge area near the Coffee Au and Casino Cu deposits examines the removal of scavenging effects of Fe and Mn in the production of a weighted sums geochemical anomaly map.

Catchment Analysis Approach

The approach to catchment analysis used in this study is aligned with the concept of productivity described by Hawkes (1976) and further expanded on by Pan & Harris (1990) and Moon (1999). Bonham-Carter & Goodfellow (1986) demonstrated that catchment bedrock lithology was the main control on observed variation in stream sediment geochemical data from the Nahanni region of the Yukon Territory. Other effects, such as catchment area, possible adsorption of some elements onto secondary Fe or Mn hydroxides, or onto organic material, and water pH were considered minor by comparison. A similar conclusion was reached by Carranza & Hale (1997) in a study of the main controls on stream sediment geochemical dispersion in the Philippines. Bonham-Carter *et al.* (1987) applied a similar approach to the analysis of stream sediment data from the Cobequid Highlands of Nova Scotia and further concluded that use of the dominant lithology in the catchment basins was not as effective as including the areal extent of all lithological units in the catchment using multiple regression analysis, an approach further developed by Carranza (2009). An intermediate, computationally efficient option is to use the presence of a single lithological unit to assess catchment basins in a pass/fail approach, and this may be as effective as using the entire catchment geology (Bonham-Carter *et al.* 1987; Arne & Brown 2015).

The rationale for levelling stream sediment data for variable lithology and/or the effects of metal scavenging is to remove these effects on commodity and potential pathfinder elements to reveal subtle geochemical anomalies that might be associated with undiscovered mineral deposits. For example, Arne & Bluemel (2011) levelled re-analyzed stream sediment data from the Geoscience BC QUEST South project area using the dominant bedrock lithology identified in the catchments, as well as regression analysis against iron to correct for the effects of possible metal scavenging onto secondary iron hydroxides. Levelled geochemical data were then used to generate additive elemental indices associated with different mineral deposit types. Heberlein (2013) levelled newly acquired modified aqua regia/ICP-MS data for two map sheets in the Yukon using dominant bedrock lithology after demonstrating bedrock control on the dispersion of some elements, such as Cu. Weighted sums models (Garrett & Grunsky 2001) were generated for different mineral deposit types. The simplified approach used by Arne & Bluemel (2011) and Heberlein (2013) may not always be appropriate in large catchment basins where multiple lithological units are to be anticipated, as argued by Bonham-Carter *et al.* (1987), nor

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does it account for variable erosion rates within the catchment (Granger & Schaller 2014). 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 commodity or pathfinder elements, and this contribution is not easily modelled.

A more reliable approach to levelling stream sediment geochemical data for the effects of variable lithology would be to estimate a background value for each catchment and elements of interest using average values for individual lithological units weighted on the basis of the proportion of each unit exposed within the catchment. Such weightings assume a constant supply of sediment from each lithology and may require adjustment to account for local variations in relief and erosion. Topography and variable weathering effects because of slope aspect are no doubt important factors in controlling the geochemical input from each lithology in a catchment basin (e.g. Mackie *et al.* 2017) but are difficult to correct data for. Differences between calculated background metal values and those observed would indicate the presence of an anomalous metal source within a catchment basin relative to the expected metal concentrations based on known bedrock geology.

Methodology

One approach used by Mackie *et al.* (2015) levelled individual elements by the dominant bedrock lithology within the catchment basins using the approach described by Arne & Bluemel (2011) and Heberlein (2013), and as requested by the YGS. The catchment basins used were generated from a digital elevation model (DEM) by the YGS using the hydrology module in ESRI ArcMap™. Levelled data were then used to construct weighted sums models for specific mineral deposit types. This approach requires that the sample location be accurately located on the stream that was sampled, assumes constant sediment supply from all lithological units, and requires that the geology of the catchment basins is well constrained. The influence of geochemically distinct but geographically minor lithological units is under-estimated using this approach.

As noted by Bonham-Carter *et al.* (1987) and Arne & Brown (2015), levelling the geochemical data by the dominant lithology in the catchment basin does not necessarily provide the best interpretative outcome. Therefore, the second approach used by Mackie *et al.* (2015) involved exploratory data analysis of the geochemical data using principal component analysis to identify geochemical associations related to lithology, scavenging of metals by organics, clays or secondary Fe and/or Mn hydroxides, or (rarely) to mineral deposits. Principal component analysis was undertaken on centred-log transformed data to reduce the effects of closure on the data (Aitchison 1986). Individual commodity and pathfinder elements were regressed against one or more principal components in which they were prominent to normalize the data for the effects of variable lithological background geochemistry and/or the effects of metal scavenging. Weighted sums models were generated using residuals calculated for individual samples following least squares regression. Even though the catchments were not used to derive geology for the samples using this second approach, the usefulness of the resulting weighted sums models and correction of the data for the effects of dilution depends very much on identifying the correct catchments for further investigation. This approach relies on the main principal components clearly reflecting lithological or scavenging element associations. Regression against principal components also has the benefit of being applicable in areas where the bedrock geology is poorly known as no direct knowledge of bedrock geology is required for its application.

Processing of the geochemical data was carried out over 29 complete and partial NTS 1:250,000 map sheets covering the southern Yukon (Fig. 1). The study covered several different cordilleran terranes, and individual map sheets sometimes crossed significant terrane boundaries, thereby introducing substantial lithological variation within a single data set (Fig. 1). The southern Yukon includes a wide variety of mineral deposit types, including, but not restricted to: volcanic and sediment hosted base metal deposits, porphyry Cu-Au deposits, polymetallic epigenetic vein systems and skarn deposits, epithermal and orogenic Au deposits, and magmatic base metal and platinum group elements (PGE) deposits (Fig. 1).

Stevenson Ridge

The Stevenson Ridge region has variable relief, from elevations close to 3,500m to just over 300m, with large areas of subdued topography (Fig. 2). It lies in an area that was largely unglaciated during the late Wisconsin-McConnell glaciation (http://www.geology.gov.yk.ca/quarternary.html). The area hosts porphyry Cu-Au deposits at Casino, as well as the Coffee orogenic Au deposit (MacKenzie *et al.*, 2015). Both deposit types are known to be elevated in As associated with the mineralization. However, gridded percentile plot images indicate raw As data are also elevated in the low-lying regions (Fig. 3), where they correlate positively with Fe and Mn. They correlate, to a lesser degree, with loss on ignition (LOI) values (used as a surrogate measure for organic material, secondary hydroxides and clay in the samples), as well as a number of other elements, such as Ca, Sr, Cu, Co and Zn. Simple and multiple regression of As against Fe, Mn or LOI shows little significant variation from the distribution of raw As, and so proved inadequate to correct for the possible effects of metal scavenging onto secondary materials. This secondary, or scavenging, association of elements and LOI is evident in positive loadings on principal component 1 (PC1; Fig. 4), indicating a very strong influence of metal scavenging on the stream sediment geochemical data from this region.

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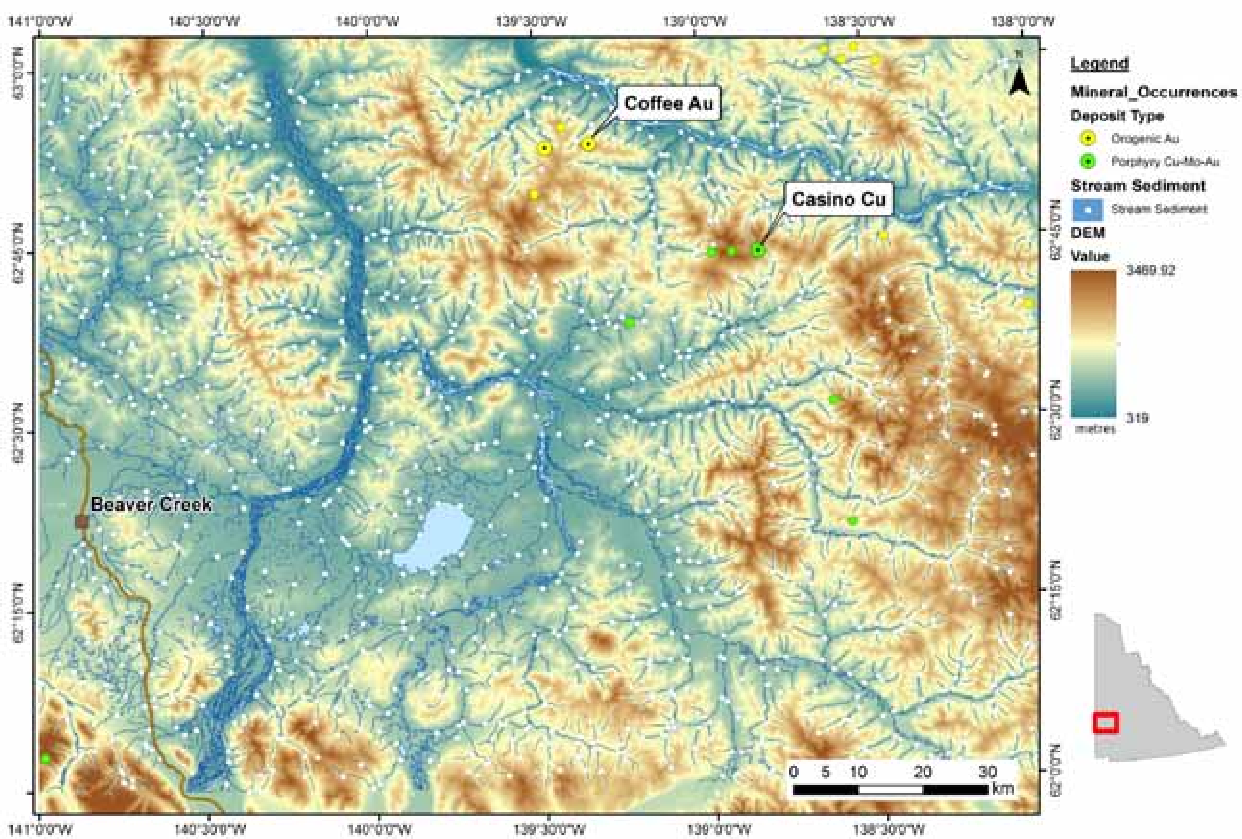

Figure 2 – Digital elevation model (DEM) of the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

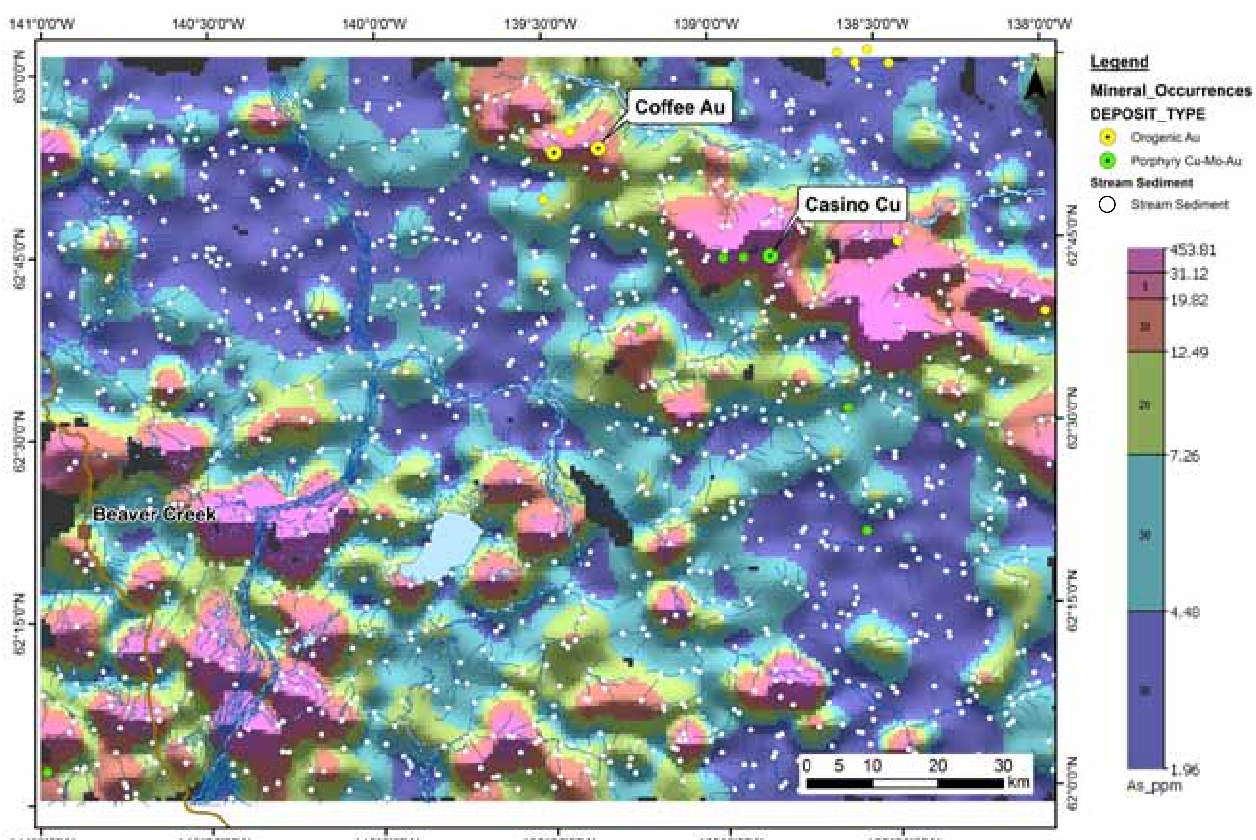

Figure 3 – Gridded percentile image of raw As data (aqua regia/ICP-MS <0.177 mm) from the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

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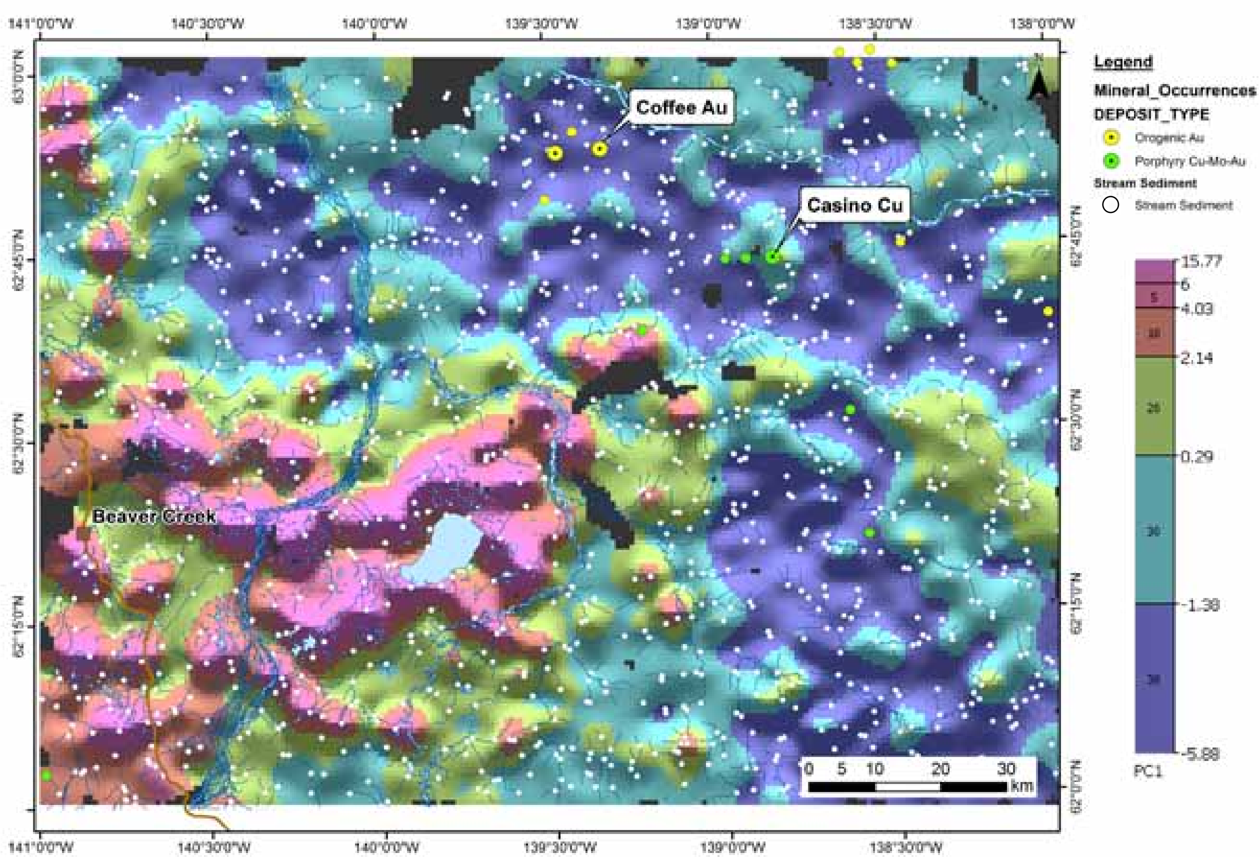

Figure 4 – Gridded percentile image of principal component 1 scores for individual stream sediment samples from the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

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Regressing As against PC1 and plotting residuals results in a reduction of the scavenging effects and emphasizes the association of As with both porphyry Cu-Au and orogenic Au deposits in the region along a distinct northwest trending belt (Fig. 5). Although the effects of possible metal scavenging in low-lying areas has not been entirely removed, the process has resulted in an incremental improvement in regional As anomaly contrast. The resulting As residuals (4) were combined with raw Au (3) and Te (1), as well as residuals for Sb (1) and Cu (-2) to generate an orogenic gold weighted sums model (importance rankings are shown in parentheses) for the region once the scavenging effects of secondary Fe and Mn hydroxides were reduced (Fig. 6). A negative weighting for Cu has been included in the weighted sums model to subdue the influence of porphyry Cu-Au mineralization on the orogenic model. Levelling of As data using catchment basin lithology was not successful in this area because one of the main controls on the distribution of As in stream sediment samples is the presence of secondary Fe and Mn hydroxides in the samples, rather than the lithology of the catchment basin bedrock geology.

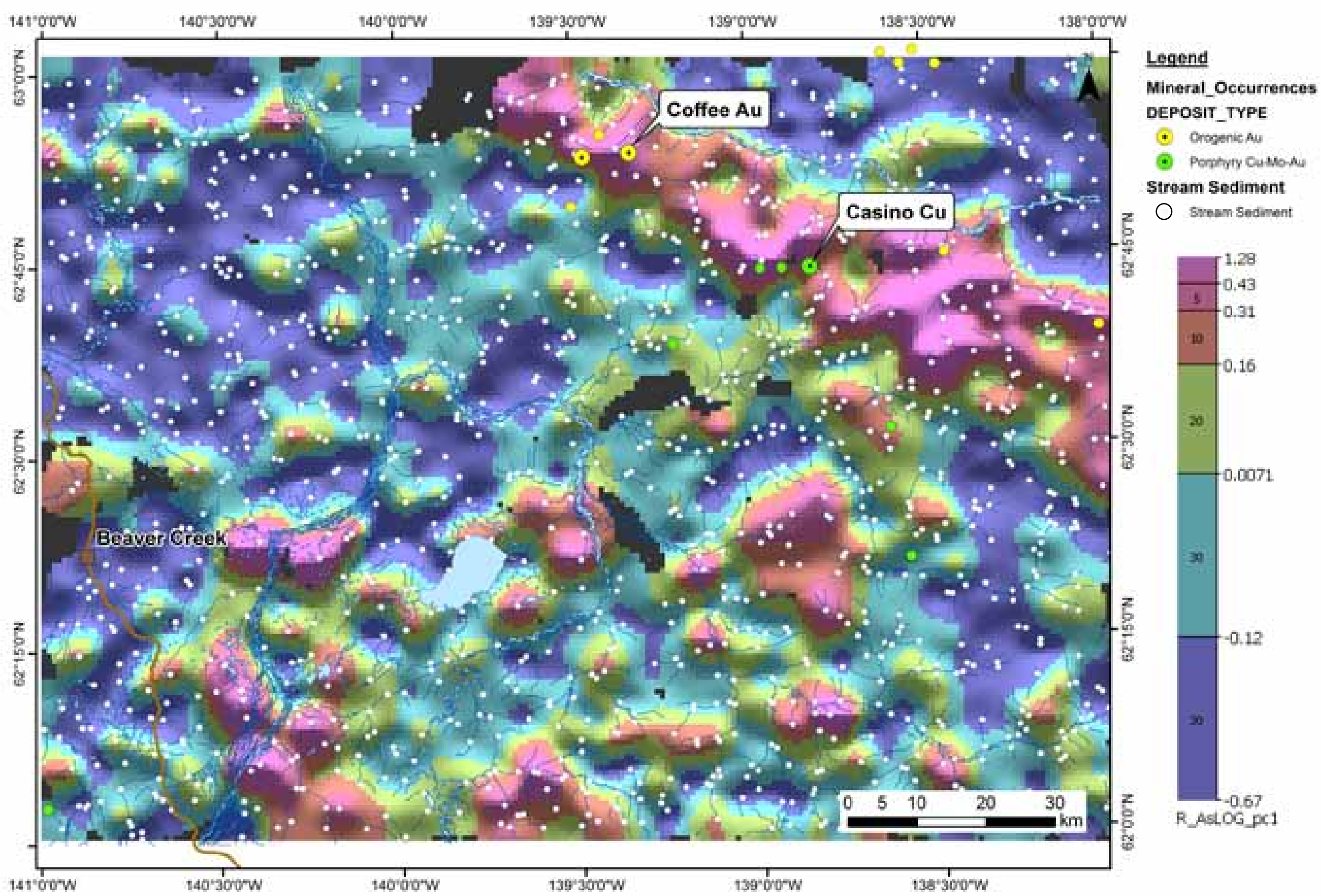

Figure 5 – Gridded percentile image of As residuals following regression against principal component 1 from the Stevenson Ridge area. Stream sediment sample locations are shown as white dots.

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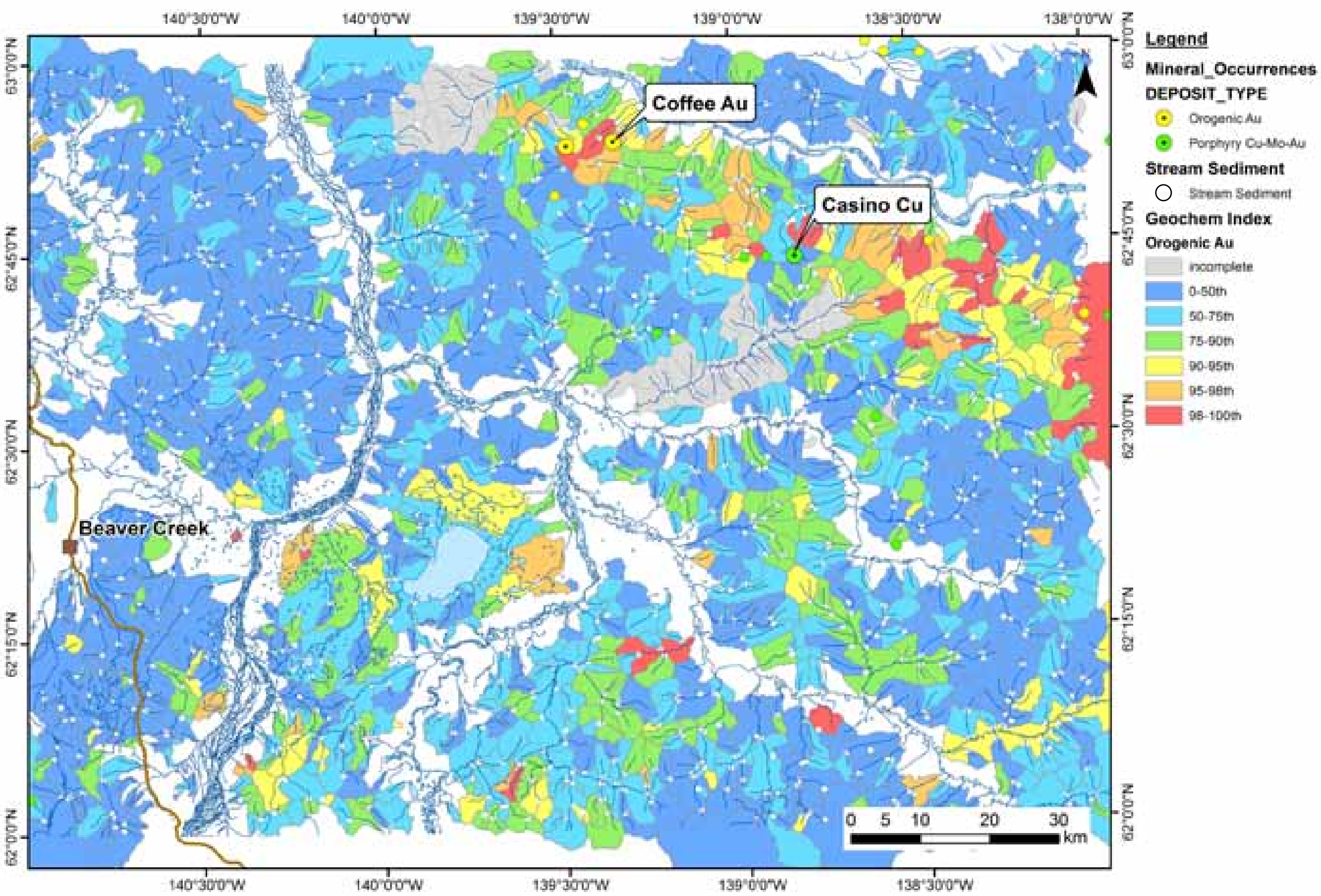

Figure 6 – Final orogenic Au weighted sums model for the Stevenson Ridge area constructed using Au, As residuals, Sb, Te and negative Cu. Catchment basins are thematically coloured based on percentile intervals of weighted sums scores.

Conclusions

A number of methods of varying sophistication have been proposed to level stream sediment geochemical data for the effects of variable catchment basin lithology so that geochemical anomalies potentially associated with mineral deposits are more apparent. Many of these approaches rely on the following assumptions:

1. The location of the sample is accurately known and the catchment from which sediment was sourced can be defined;
2. The bedrock and surficial geology of the catchment basin is known with confidence; and
3. Each lithological unit in the catchment basins contributes proportionally to the stream sediment sample collected at the basin outlet such that each unit's weighted contribution to background geochemical values can be estimated.

A qualitative review of catchment basin quality from the YGS southern Yukon re-analysis and enhanced interpretation of geochemical data suggests that the above requirements are not always honoured (Mackie *et al.* 2017; Fig. 7). For example, the low-lying region near Beaver Creek in the Stevenson Ridge area scored poorly in terms of over-all catchment basin quality in this review. Regression analysis of key commodity and pathfinder elements against principal components, where the latter can be readily attributed to either lithology or metal scavenging, provides a method to correct for these effects independent of the spatial location of the samples. These residuals can then be used in weighted sums models to develop mineral deposit-specific geochemical targeting maps for mineral exploration. The approach is internally consistent and entirely data-driven, although some subjectivity in the interpretation of principal components is involved.

Deciding whether regression analysis of individual elements against principal components is warranted or even desirable requires thorough exploratory analysis of the data. While removing the spatial aspect of levelling the geochemical data for background lithological or scavenging effects is certainly convenient, ultimately knowing where the stream sediment sample was collected is desirable. This approach may also be preferred to more classical data treatments in greenfields areas where the bedrock and/or surficial geology is poorly defined. This approach will also have application in other situations, such as lithogeochemistry or the interpretation of residual soil data.

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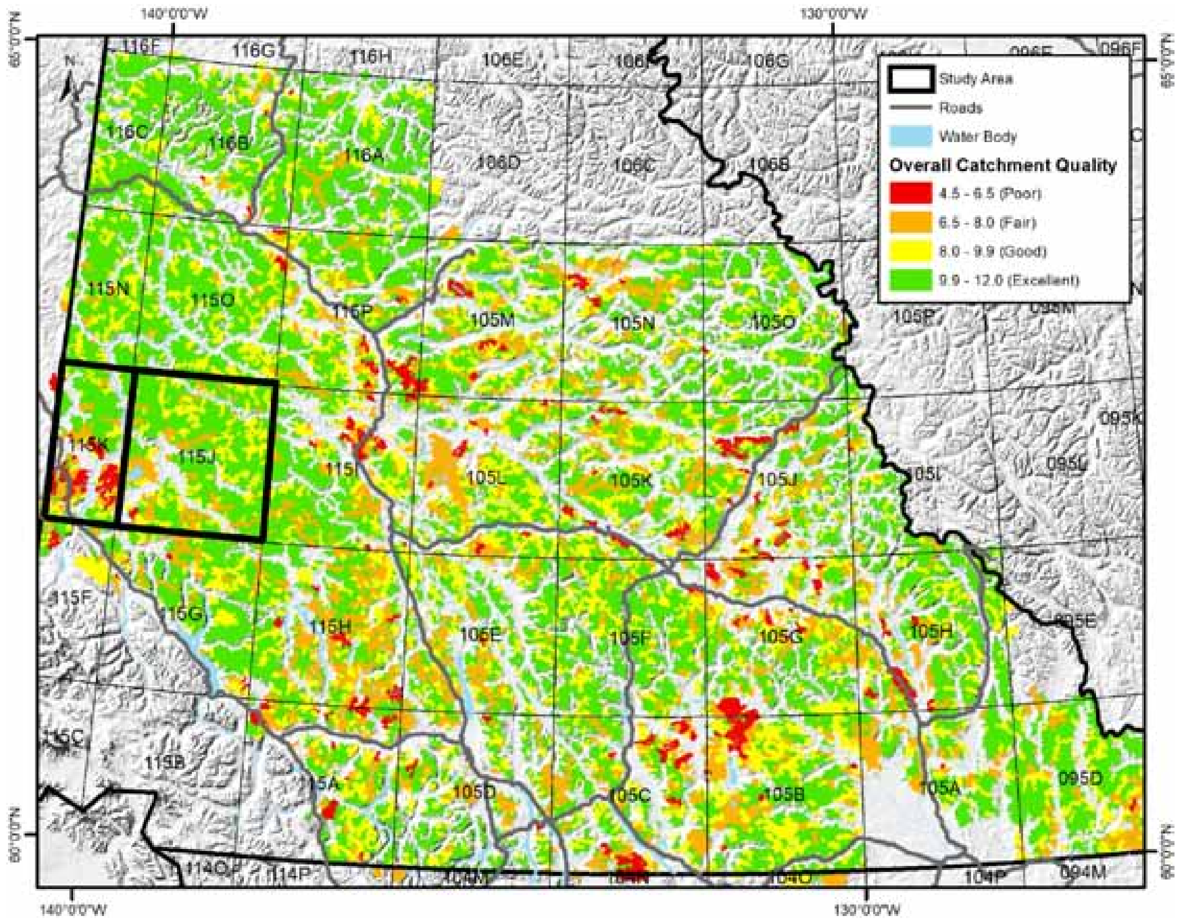

Figure 7 – Thematic summary of qualitative catchment basin quality from Mackie et al. (2017). The Stevenson Ridge area is shown by the heavy map sheet outlines.

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