INTRODUCTION

Drainage geochemical surveys utilize a combination of water and stream or lake sediment media collection and chemical analysis for rapid and effective evaluation of mineral resources within fluvial catchment areas. Low-density surveys (typically at a density of one sample site per ~10 km²) are a cost-effective method for regional mineral exploration covering thousands of square kilometres. Drainage geochemical surveys are based on the principal that the bedrock and surficial geology underlying the drainage catchment area upstream from a sample site will be reflected in the sediment chemistry. Background element variations in drainage sediment can characterize the source bedrock geochemistry and may outline metallogenic belts. Elevated metal contents may indicate mineralized bedrock or rock types that are the potential hosts of economic mineral deposits. However, low density (e.g., an average of one sample per 13 km² in British Columbia) sampling is not sufficient to detect all mineral deposits unless their surface exposure is substantial.

Regional surveys for geochemical mapping, metallogenic studies and mineral exploration have been carried out by governments and mining companies for over 30 years. Darnley (1990) reported on the beginning of an international geochemical mapping (IGM) project in 1988 that was sponsored by the International Union of Geological Sciences and UNESCO. Since then, there have been more examples of national mapping surveys from many countries, including the United Kingdom (Plant et al., 1989, 1997), Greenland (Steenfeld, 1993) and China (Xie and Ren, 1993). The results of national geochemical surveys are commonly displayed in the form of an atlas that shows the spatial distribution of elements as either symbol or contour maps. One of the first of these to be produced was the Wolfson Geochemical Atlas of England and Wales (Webb, 1978; since then, there have been several others, such as the Geochemical Atlas of Alaska (Weaver, 1983).

Advantages of the RGS for geochemical mapping are that:

- few changes have been made to analytical and sample preparation methods since the start of the survey, and
- strict quality control has been maintained during sample preparation and analysis.
Thus, the data from all survey areas can be combined into a relatively seamless geochemical database.

Geofile 2008-1 is comprehensive, province-wide, geochemical atlas created from this database using GIS spatial analysis. The Geochemical Atlas of British Columbia is an ongoing project, with updates anticipated as new data come available to augment the stream sediment, moss-mat sediment (moss sediment) and lake sediment results that are distributed over ~70% of the province (Figure 1).

**SOURCE DATA**

Information used to create the geochemical atlas has been extracted from the British Columbia Regional Geochemical Survey database; a Microsoft Access® database implemented in the late 1980’s and most recently revised in 2007 for the British Columbia Geological Survey MapPlace portal. Among database tables used for the atlas are:

**RGS Sample Location Information:** This table has a unique sample identification number combining NTS map sheet, year and sample number. It also contains a code for the sample type (e.g. 1 = stream sediment; 7 = moss-mat sediment; 9 = lake sediment) location coordinates (UTM; UTM Zone, latitude and longitude, datum used in NAD 83) and a quality control sample code identifying field replicate samples. There are presently 55873 sample locations in the atlas source database.

**RGS Field Stream Lake:** This table has all of the field information for stream sediment, lake sediment and surface water samples. It includes such criteria as water colour, stream depth, stream width, bank composition, sediment texture, etc.

**RGS Routine Water:** This table includes pH, F and U results from the analysis of surface stream and lake water. For recent surveys (since 2002) water conductivity was also recorded.

**RGS Stream Sediment AAS:** This table comprises analytical data for stream sediment, moss-mat sediment and lake sediment analysed by an aqua regia (HCl-NH₄OH) digestion followed by atomic absorption spectrophotometry (AAS). The table also has the results for samples analysed for Au by lead collection fire assay and AAS and for loss on ignition at 500°C.

**RGS Stream Sediment ICPMS:** This table comprises analytical data for stream sediment, moss-mat sediment and lake sediment analysed by an aqua regia (HCl-NH₄OH) digestion followed by inductively coupled plasma mass spectrometry (ICP-MS).

**RGS Stream Sediment INAA:** This table comprises analytical data for stream sediment, moss-mat sediment and lake sediment determined by instrumental neutron activation analysis (INAA).

### Data Merging – Analytical Methods Comparison

The RGS database comprises analytical results for over 70 elements determined by a combination of aqua regia-AAS, aqua regia-ICP-MS and INAA. However, province-wide coverage exists for only 40 of these and the data can be used to create maps showing their regional variation. Thirty of the elements are not considered because they are determined by a variety of methods that produce incompatible results. In addition the data may be limited by high instrumental detection limit, inter-element inferences or only a small number of samples were analysed for a particular element (e.g. Sn).

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<th>IC/MS</th>
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<tr>
<td>Zn</td>
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Table 1. Detection limits for aqua regia-ICPMS and aqua regia-AAS determined elements (*Fire assay-AAS for Au).

All of the samples (< 0.180 mm fraction) have been analysed for a core group of ore indicator elements (e.g. Cu, Co, Fe, Mo, Mn, Ni, Pb, Zn) with a
aqua regia digestion, but there exists differences in the detection limits for aqua regia-AAS and aqua regia-ICP-MS as shown in Table 1. Samples from earlier surveys prior to 1999 were analysed by aqua regia-AAS whereas samples from more recent surveys were analysed by aqua regia-ICP-MS and there are few examples where drainage samples were analysed by both methods. As a basis for comparison between these two main analytical techniques, 1152 stream sediments from the McLeod Lake regional survey that were initially analysed by aqua regia-AAS were later reanalysed by aqua regia-ICP-MS for up to 37 elements including Cu (Lett, & Bluemel, 2006). Near perfect correlation between the two methods is shown for Cu in Figure 2 where the scatter plot shows a strong linear relationship with a correlation coefficient of + 0.957. A second example (Figure 3) shows the correlation between Cu by aqua regia-AAS compared to Cu by aqua regia-ICP-MS for 945 archive reanalyzed RGS samples from the Iskut River region (NTS 104B & G) of NE BC (Lett, 2003). Similar correlation between the original and re-analysed results for other elements of the McLeod Lake survey, especially those having essentially the same digestion method used since the start of the RGS program, justify the merger of AAS and ICP-MS analyses into data sets for production of Provincial atlas maps. A modified form of exploration data analysis has been used to compare populations of data produced by different analytical techniques because few samples from the broader RGS database have been re-analysed by aqua regia-ICP-MS.

**EXPLORATION DATA ANALYSIS**

Exploration data analysis (EDA) is designed to detect trends or structures in geochemical data. It involves graphical and numerical techniques that are independent of assumptions about element distributions. In this way EDA resolves problems of the common failure that statistical assumptions have in describing real data and the overwhelming influence that large populations have on smaller, but often significant distributions (Kurzl, 1988). Box plots and Q-Q plots can also be used to compare geochemical data such as subsets from the RGS database generated by different analytical methods and from different sample media. Pseudo-box plot divisions have been constructed using the following statistical ranges to compare data sets. The divisions are:

- Lower fence (Q1-1.5*(Q3-Q1)) – Also known as interquartile range/whisker
- First Quartile 1
- Median
- Third Quartile 3
- Upper fence (Q3+1.5*(Q3-Q1)) – Also known as interquartile range/whisker

Values above or below the fences are considered outliers.

Based on the techniques described by Kunzle (1988) and Grunsky (2007) a pseudo box plot approach has been applied to statistically examine the relationship between the results produced by the different analytical methods. An example of a pseudo box-plot for Cu by AAS and ICP-MS is shown in Figure 4.
The graphs can be used to determine if the data needs to be levelled with a correction factor so that misleading trends in plotted data are avoided. The first stage of the statistical analysis has been to calculate median, 1st quartile, 3rd quartile, and “fence” values from Co, Cu, Fe, Mn, Mo, Ni, Pb and Zn by AAS and ICP-MS. An example of a plot for Cu is shown in Figure 4. These statistics are plotted as a function of concentration on a simple line graph to produce a pseudo box plot. In the same fashion, U by delayed neutron counting (NADNC) is compared to U by INAA and Au by INAA compared to the data produced by Pb collection fire assay-AAS. Arsenic by AAS, ICP-MS and INAA are also compared and the similarity between results produced by all three methods justified merging AAS, ICP-MS and INAA data. This is the only case where INAA results have been merged with aqua regia ICP-MS/AAS analyses.

Comparison of pseudo box plots reveals most RGS elements have almost identical median and quartile values for AAS, ICP-MS and INAA methods indicating that no levelling is needed. Consequently, data from the following methods can be merged into a single file for map plotting:

As – AAS with ICP-MS or INAA
Au – Fire Assay AAS with INAA
Co – AAS with ICP-MS
Cu – AAS with ICPMS
Fe – AAS with ICP-MS
Mn – AAS with ICP-MS
Mo – AAS with ICP-MS
Ni – AAS with ICP-MS
Pb – AAS with ICP-MS
U – NADNC with INAA
Zn – AAS with ICP-MS

DATA MERGING – SAMPLE MEDIA COMPARISON

Element data for stream sediment, moss-mat sediment and lake sediment were compared using pseudo box-plots in the same way that different analytical methods were treated. Data from the same analytical technique (e.g. aqua regia-AAS) was used to compare two different samples types such as stream sediment and moss-mat sediment. An example of a pseudo box-plot for Cu in stream sediment compared to lake sediment and moss sediment is shown in Figure 5. Levelling of moss-mat sediment and or lake sediment data to stream sediment data was carried out with Q-Q graphs where the 1st quartile, 3rd quartile, median, lower fence and upper fence for each sample media data set was plotted on a scatter graph (Figure 6). Least squares best-fit regression lines are generated (in the simple form, \( y = mx + b \) where \( m \) is the slope and \( b \) is the intercept) and a common intercept (“\( b' \)”) is used to level the moss-mat sediment or lake sediment element values with stream sediment data. Substituting the analyzed moss-mat and lake sediment values (“\( x' \)”) into the equation for stream sediment results in transformed data distributions with a least squared best fit regression line having a slope (“\( m' \)”) and intercept (“\( b' \)”) like that of stream sediment data distribution for the element of interest. The resultant pseudo box plot for Cu after leveling has been applied and statistics or moss and lake sediment recalculated is shown in Figure 7. The data leveling process is summarized in Figure 8. Unlevelled and levelled data pseudo box-plot for Au, As, Co, Fe, Mn, Ni, Mo, Pb, U, and Zn are shown in Figure 9 to 27.

![Figure 4. Pseudo box-plot comparing median, quartile and fence values for Cu by AAS and ICPMS. The graph was prepared from 46 379 AAS Cu and 12 132 ICP-MS determinations. Q 1 and Q 3 are the 1st and 3rd quartiles respectively.](image)

![Figure 5. Pseudo box plot comparing Cu in stream sediment with Cu in moss and lake sediment before levelling.](image)
Figure 6. Scatter plot from median, upper and lower fence values to calculate correction factor for adjusting moss sediment Cu values.

Figure 7. Pseudo box plot comparing Cu in stream sediment with Cu in moss and lake sediment after levelling moss and lake sediment values to match sediment Cu.

Figure 8. Flow diagram summarizing levelling process.

Figure 9. Pseudo box plot comparing As in stream sediment with Cu in moss and lake sediment before levelling.
Figure 10. Pseudo box plot comparing As in stream sediment with As in moss and lake sediment after levelling moss and lake sediment values to match sediment As.

Figure 11. Pseudo box plot comparing Au in stream sediment with Au in moss and lake sediment before levelling.

Figure 12. Pseudo box plot comparing Au in stream sediment with Au in moss and lake sediment after levelling moss and lake sediment values to match sediment Au.

Figure 13. Pseudo box plot comparing Co in stream sediment with Co in moss and lake sediment before levelling.

Figure 14. Pseudo box plot comparing Co in stream sediment with Co in moss and lake sediment after levelling moss and lake sediment values to match sediment Co.

Figure 15. Pseudo box plot comparing Fe in stream sediment with Fe in moss and lake sediment before levelling.
Figure 16. Pseudo box plot comparing Fe in stream sediment with Fe in moss and lake sediment after levelling moss and lake sediment values to match sediment Fe.

Figure 17. Pseudo box plot comparing Mn in stream sediment with Mn in moss and lake sediment before levelling.

Figure 18. Pseudo box plot comparing Mn in stream sediment with Mn in moss and lake sediment after levelling moss and lake sediment values to match sediment Mn.

Figure 19. Pseudo box plot comparing Ni in stream sediment with Ni in moss and lake sediment before levelling.

Figure 20. Pseudo box plot comparing Ni in stream sediment with Ni in moss and lake sediment after levelling moss and lake sediment values to match sediment Ni.

Figure 21. Pseudo box plot comparing Mo in stream sediment with Mo in moss and lake sediment before levelling.
Figure 22. Pseudo box plot comparing Mo in stream sediment with Mo in moss and lake sediment after levelling moss and lake sediment values to match sediment Mo.

Figure 23. Pseudo box plot comparing Pb in stream sediment with Pb in moss and lake sediment before levelling.

Figure 24. Pseudo box plot comparing Pb in stream sediment with Pb in moss and lake sediment after levelling moss and lake sediment values to match sediment Pb.

Figure 25. Pseudo box plot comparing U in stream sediment with U in moss and lake sediment before levelling.

Figure 26. Pseudo box plot comparing U in stream sediment with U in moss and lake sediment after levelling moss and lake sediment values to match sediment U.

Figure 27. Pseudo box plot comparing Zn in stream sediment with Zn in moss and lake sediment before levelling.
Figure 28. Pseudo box plot comparing Zn in stream sediment with Zn in moss and lake sediment after levelling moss and lake sediment values to match sediment Zn.

MAP PLOTTING

Of the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 85th, 90th, 95th, 98th, 99th percentile values calculated from the raw and levelled data for each element only those above the 50th percentile were used for plotting the atlas maps. The levelled and unlevelled and levelled element values that correspond to the percentiles shown on the maps are listed in Table 2. Percentiles for the levelled data were used as intervals for contours on the atlas maps. The maps were prepared using both ESRI ArcMap® 9.2 and with Manifold® System 8. Each program produces slightly different representations but the same trends and patterns are maintained. Attribute tables of each element were queried and imported from Microsoft Access. Contours were created by kriging using the spatial analysis tool in each program. Output cell size was set to 0.05 of a degree, the search radius was set to “program determined” and the number of neighbour points to base the prediction on was set to 10. The resultant raster surface was combined with data from the digital geographic base map of British Columbia. Contoured maps plotted from levelled element data are shown as PDF and Manifold project maps. The source and levelled Au, As, Cu, Co, Fe, Mn, Ni, Pb, U and Zn data used to plot the maps is an Microsoft Excel file.

DATA FILE

Appendix B has the accompanying Excel data file used to plot the atlas maps. The fields in this file are:

- MASTER_ID - Unique sample identification number combining NTS map sheet, year and sample number.
- MAP – NTS Map sheet number
- YEAR – Year survey was carried out.
- ID – Sample ID number
- UTMZ – UTM Zone
- UTME_83. UTM East coordinates, NAD 83.
- UTMN_83. UTN East coordinates, NAD 83.
- LAT – Latitude
- LONG – Longitude
- MAT – Material code 1 or 6 = stream sediment; 7 = moss-mat sediment; 9 = lake sediment.
- REP = First field replicate 10 and 20
- Cu_source. E.g. of source data for Cu
- Cu_for atlas. E.g of Cu data that has been levelled for lake and moss mat sediments.

ACKNOWLEDGEMENTS

Encouragement from Brian Grant during the early stages of this project and advice from Eric Grunsky on procedures for data levelling were very much appreciated by the authors.
REFERENCES


Acknowledgements

The sediment surface was created using the method of kriging to predict spatial patterns of iron across BC. The Geochemistry data was produced as part of the Regional Geochemical Survey (RGS) program, a cooperative project between BC Geological Survey (BCGS) and Geological Survey of Canada (GSC). Recent data has also been contributed by Geoscience BC.

Output Grid Size: 0.005
Search Radius: Variable
Number of neighbour points: 10

*Data for the digital base map obtained from the Land and Resource Data Warehouse (LRDW).
*Geochemistry data obtained from the BCGS RGS Program.