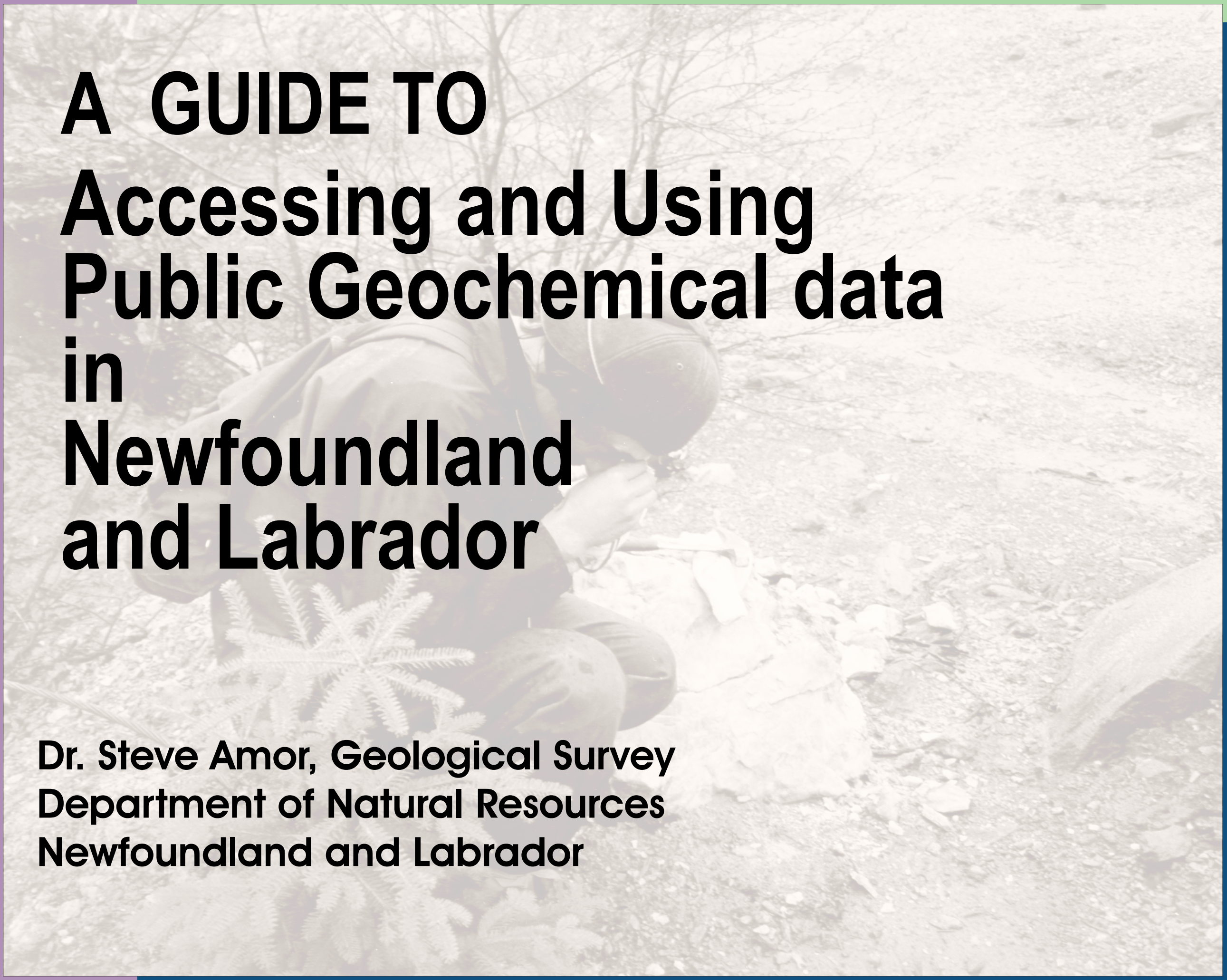

A GUIDE TO Accessing and Using Public Geochemical data in Newfoundland and Labrador

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Prospector’s Guide to Accessing and Using Geochemical Data In Newfoundland and Labrador

Introduction – Accessing Geochemical Data

Geochemical data are freely available to the public and can be accessed from the ***Geoscience Resource Atlas***, on the Department of Natural Resources’ website. Browsers Firefox, Google Chrome or a recent version of Microsoft Internet Explorer (10 or 11) are recommended, as the Geoscience Atlas may not display correctly with other browsers.

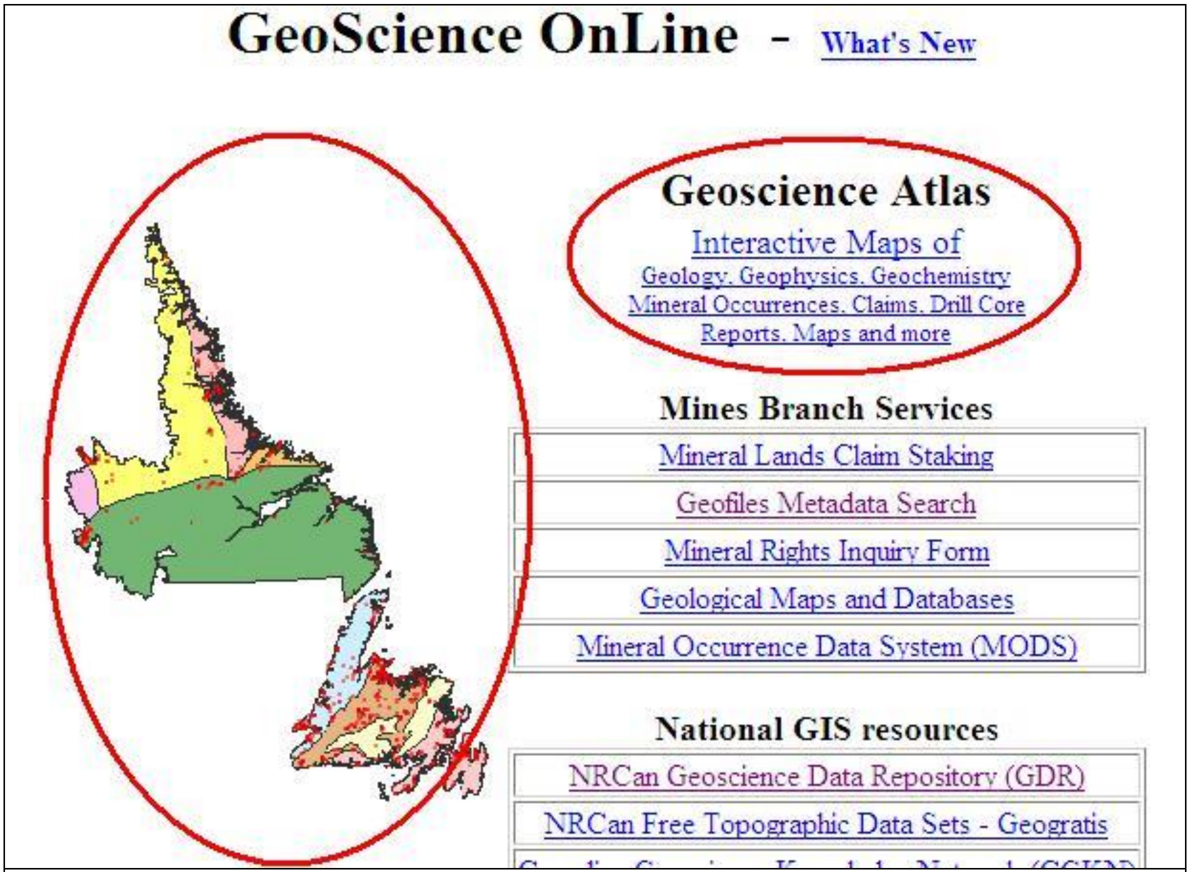
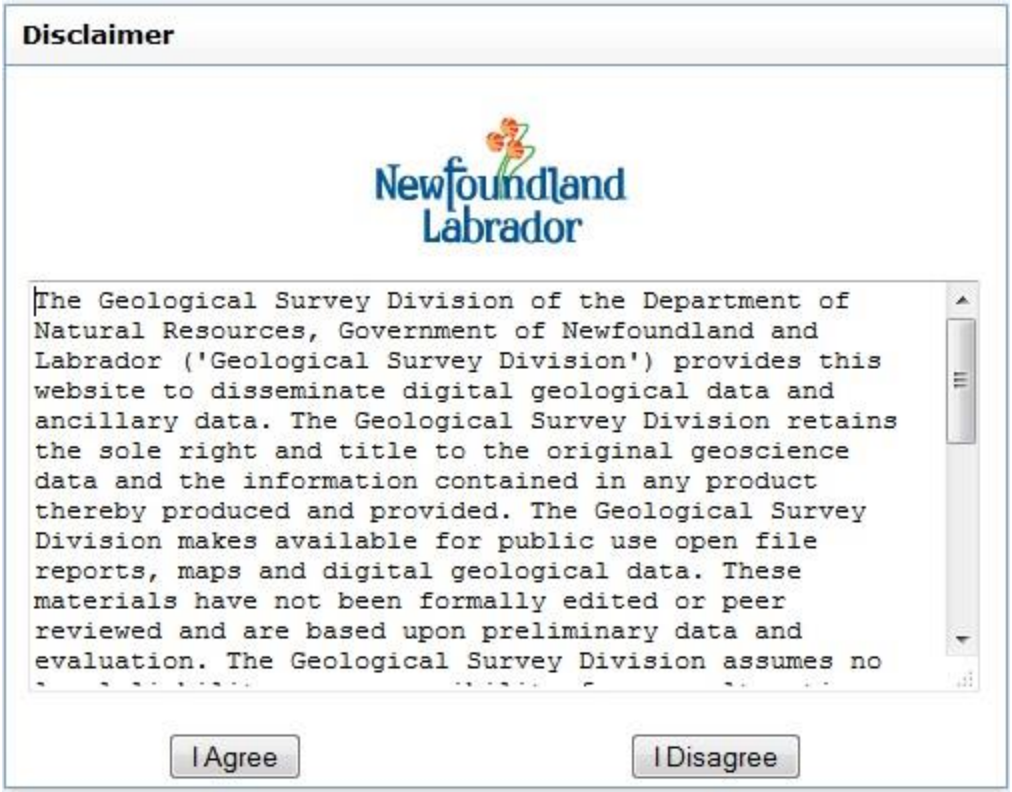


Figure 1: Introductory page to Geoscience Atlas. Clicking on either of the circled links will open the Geoscience Atlas in a new window.

All data retrieval exercises begin with opening the Geoscience Online page at http://gis.geosurv.gov.nl.ca/ (Figure 1).

The Geoscience Atlas is opened either by clicking on the map, or the link entitled “Interactive Maps of Geology, Geophysics, Geochemistry, Mineral Occurrences, Claims, Drill Core Reports, Maps and more”. It can also be opened directly via http://geoatlas.gov.nl.ca/Default.htm.

The first page to appear at this point is the disclaimer (Figure 2), to which the user must agree:



The Geological Survey Division of the Department of Natural Resources, Government of Newfoundland and Labrador ('Geological Survey Division') provides this website to disseminate digital geological data and ancillary data. The Geological Survey Division retains the sole right and title to the original geoscience data and the information contained in any product thereby produced and provided. The Geological Survey Division makes available for public use open file reports, maps and digital geological data. These materials have not been formally edited or peer reviewed and are based upon preliminary data and evaluation. The Geological Survey Division assumes no

Figure 2: Disclaimer

When the Atlas opens, the whole of Newfoundland and Labrador will be shown (Figure 3). However, on subsequent use the user's previous zoom level and other settings on his/her computer will be restored.

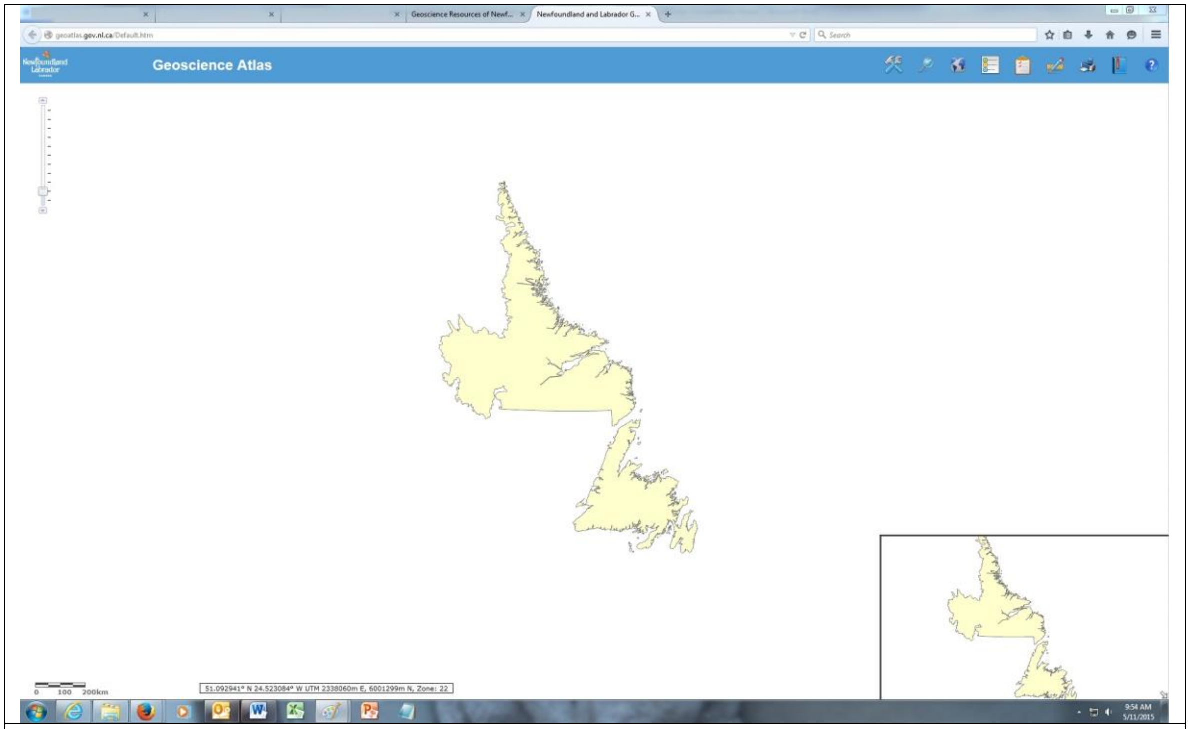


Figure 3: The Geoscience Atlas when first opened. The controls are located in the upper right-hand corner.

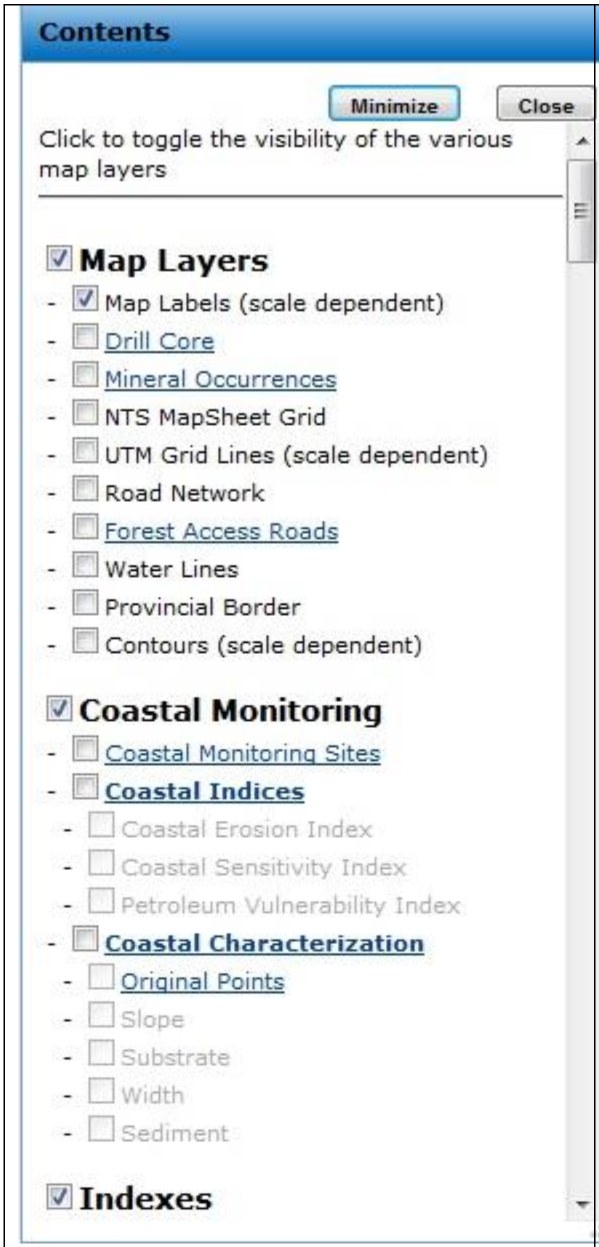
This guide will concentrate on accessing, viewing, downloading and interpreting geochemical data only. Note, however, that it is a good idea to have the Mineral Occurrences Layer (see below) loaded/selected so that you can view the known mineral occurrences in an area as you view or analyse the geochemical data for that same area.

A detailed guide to using the atlas is available at http://gis.geosurv.gov.nl.ca/resourceatlas/help/help.html

Viewing Lake Sediment Geochemical Data

When the Geoscience Atlas page is opened, various data layers, such as geochemistry, can be turned on in the contents menu, which is activated by clicking on the 📋 icon in the upper right-hand corner of the screen.

The menu (Figure 4a) includes the following sections, each of which contains many layers that can be turned on and off:



Contents

Minimize Close

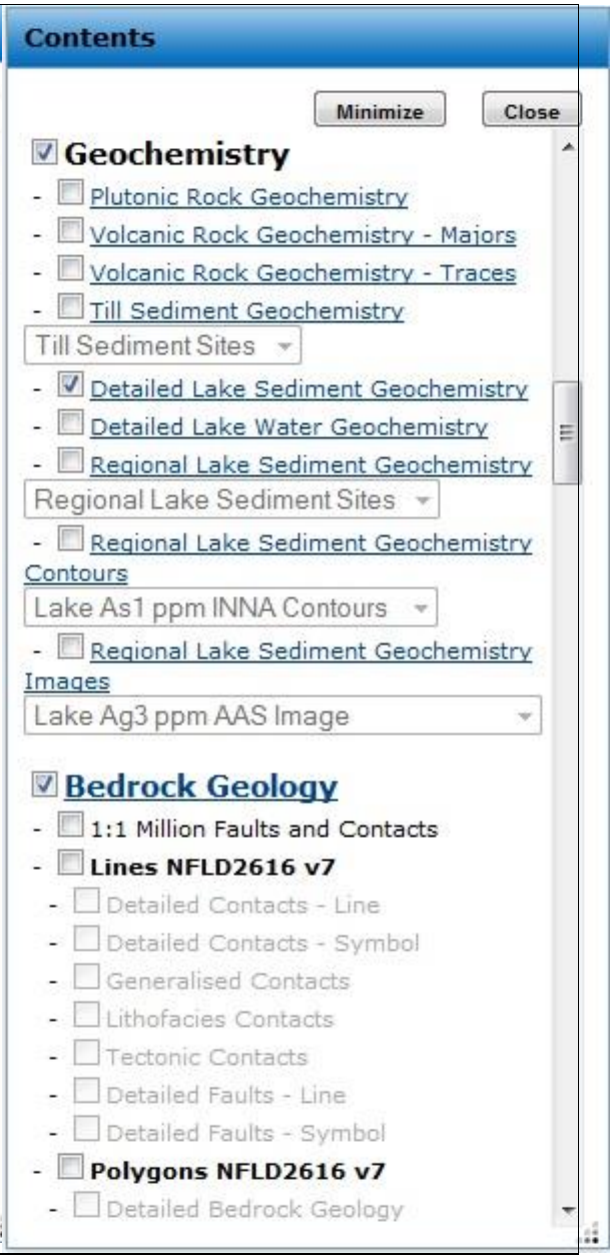
Click to toggle the visibility of the various map layers

☑ **Map Layers**
- ☑ Map Labels (scale dependent)
- ☐ Drill Core
- ☐ Mineral Occurrences
- ☐ NTS MapSheet Grid
- ☐ UTM Grid Lines (scale dependent)
- ☐ Road Network
- ☐ Forest Access Roads
- ☐ Water Lines
- ☐ Provincial Border
- ☐ Contours (scale dependent)

☑ **Coastal Monitoring**
- ☐ Coastal Monitoring Sites
- ☐ **Coastal Indices**
  - ☐ Coastal Erosion Index
  - ☐ Coastal Sensitivity Index
  - ☐ Petroleum Vulnerability Index
- ☐ **Coastal Characterization**
  - ☐ Original Points
  - ☐ Slope
  - ☐ Substrate
  - ☐ Width
  - ☐ Sediment

☑ **Indexes**

Figure 4a: Geoscience Atlas Contents menu, when first opened.



Contents

Minimize Close

☑ **Geochemistry**
- ☐ Plutonic Rock Geochemistry
- ☐ Volcanic Rock Geochemistry - Majors
- ☐ Volcanic Rock Geochemistry - Traces
- ☐ Till Sediment Geochemistry

Till Sediment Sites ▾
- ☑ Detailed Lake Sediment Geochemistry
- ☐ Detailed Lake Water Geochemistry
- ☐ Regional Lake Sediment Geochemistry

Regional Lake Sediment Sites ▾
- ☐ Regional Lake Sediment Geochemistry Contours

Lake As1 ppm INNA Contours ▾
- ☐ Regional Lake Sediment Geochemistry Images

Lake Ag3 ppm AAS Image ▾

☑ **Bedrock Geology**
- ☐ 1:1 Million Faults and Contacts
- ☐ **Lines NFLD2616 v7**
  - ☐ Detailed Contacts - Line
  - ☐ Detailed Contacts - Symbol
  - ☐ Generalised Contacts
  - ☐ Lithofacies Contacts
  - ☐ Tectonic Contacts
  - ☐ Detailed Faults - Line
  - ☐ Detailed Faults - Symbol
- ☐ **Polygons NFLD2616 v7**
  - ☐ Detailed Bedrock Geology

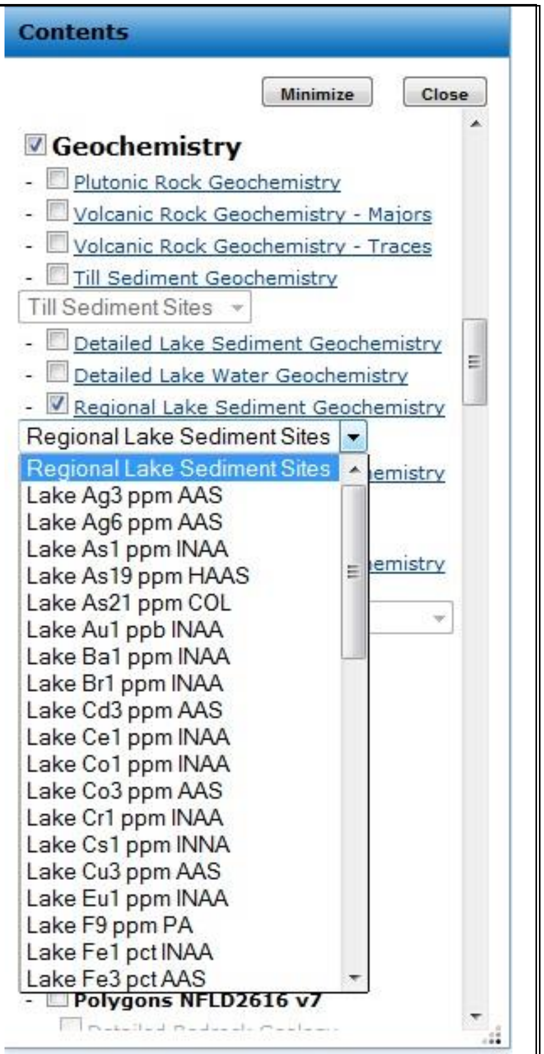
Figure 4b: "Geochemistry" section of Geoscience Atlas Contents menu.

- Map Layers (this includes the Mineral Occurrences layer)
- Coastal Monitoring
- Indexes
- Land Use
- Mineral Lands (this includes current and historic claims)
- Geochemistry (this is described in detail below)
- Bedrock Geology
- Surficial Geology
- Geophysics

The “Geochemistry” section of the menu (Figure 4b) contains the following layers:

- Plutonic Rock Geochemistry Layer
- Volcanic Rock Geochemistry – Majors
- Volcanic Rock Geochemistry – Traces
- Till Sediment Geochemistry
- Detailed Lake Sediment Geochemistry
- Detailed Lake Water Geochemistry
- Regional Lake Sediment Geochemistry
- Regional Lake Sediment Geochemistry Contours

Lake Sediment Layer



This layer consists of lake sediment analyses for 48 elements, from all of Newfoundland and Labrador, collected at an average density of one sample per 16 square kilometres in Labrador, or one per 7 square kilometres in Newfoundland.

These data are the result of two programs: the National Geochemical Reconnaissance (NGR) program, carried out under the direction of the Geological Survey of Canada, over Labrador; and a similar program carried out over the island of Newfoundland by the provincial Geological Survey. With few exceptions, the elements and analytical methods in the Labrador and Newfoundland data sets are the same.

Figure 5: Sublayers of the Geochemistry Sites layer

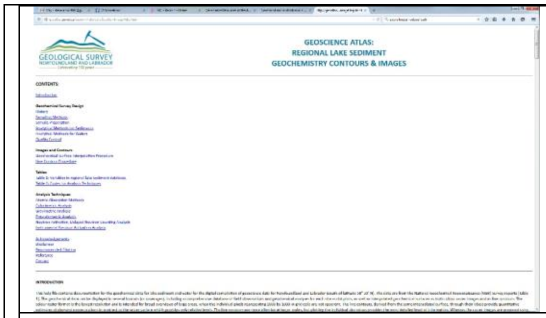
Historically, data in the Lake Sediment Geochemistry Layer have been of great value to prospectors. Many claims have been staked based on anomalous levels of various elements in this database and subsequent option deals have been of financial value to many prospectors. In this respect, the Lake Sediment Database has been and continues to be one of the most important sources of information for generating prospective mineral properties.

There are three ways of viewing lake-sediment or lake-water geochemical data:

- by creating geochemical symbol maps
- by creating line-contour maps
- by creating colour-contour maps

How to view the data – Symbol/Dot Plots

Selecting one of the elements in the pull-down menu (Figure 5) will result in the creation of a symbol map where the size of a dot at each sample point represents the concentration of the element chosen. Seven different concentration ranges are represented by symbols of increasing size for most elements (there are only six ranges for As21, Au1, Eu1, Se1). The value ranges represented by the symbol sizes are shown in a separate pop-up box when the ☰ (legend) icon is clicked.

 GEOLOGICAL SURVEY NEWFOUNDLAND AND LABRADOR GEOSCIENCE ATLAS: REGIONAL LAKE SEDIMENT GEOCHEMISTRY CONTOURS & IMAGES CONTENTS INTRODUCTION **Figure 6:** Detailed lake sediment geochemistry information	Fluoride and uranium analyses of lake waters, for Labrador lakes only, are also included as a separate layer. The analyses are accompanied by UTM coordinates and certain field observations.

Clicking on the layer name in the Contents Menu (which appears as a link) opens a page of detailed information about the survey design, elements analyzed, and methods of preparation, analysis and map creation (Figure 6). In particular, there is an explanation of the numerical suffixes (e.g., Ag3 and Ag6) that accompany each element symbol; these refer to the analytical method (AAS or INAA, etc.) and will be described in detail later.

When a geochemical map is being compiled (or when any layer is being loaded), a progress monitor (three grey squares) can be viewed in the lower left-hand corner of the screen next to the scale bar.

Some of the geochemical maps in the Atlas (generally, those in which most element values are very low, with a small proportion of much higher values) are very effective in highlighting zones of enrichment, even at a very small scale, e.g., 1:1,000,000 (see Glossary for explanation of large scale vs small scale); an example is Mo1, that is, molybdenum analyzed by neutron activation (see Figure 7). Others, like sodium (Na1; Figure 8), have a more even spread of values, with the result that areas of enrichment are not distinguishable.

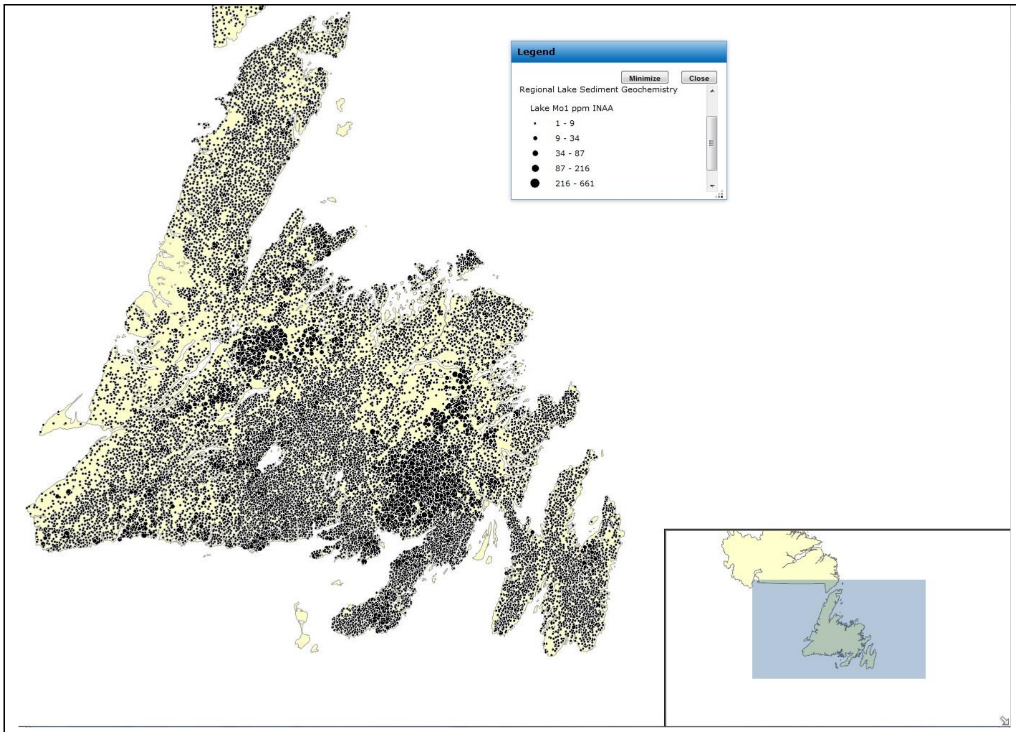


Figure 7: Geoscience Atlas showing Mo1 in lake sediments. The relatively large proportion of low values throws the areas of enrichment, such as the Topsails and Ackley granites, into sharp relief.

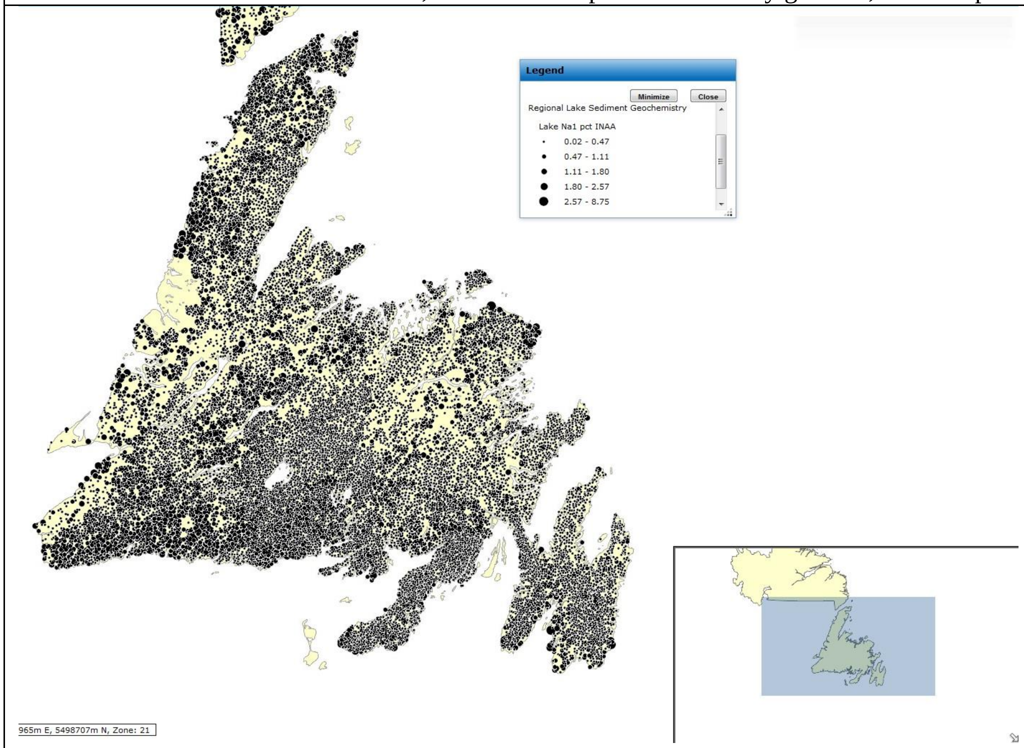
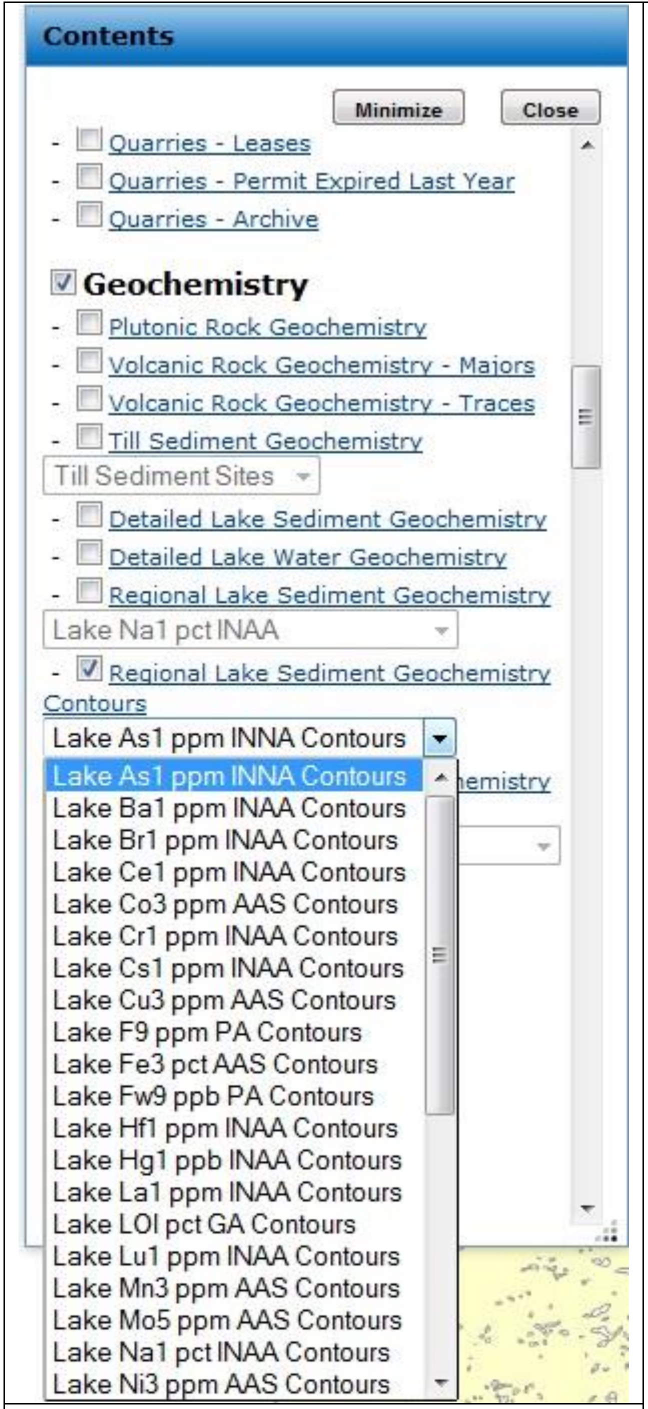


Figure 8: Geoscience Atlas showing Na1 in lake sediments. Values are evenly distributed over the element's range, making areas of enrichment harder to distinguish.

How to view the Data – Line Contour Maps



Line-contour maps of most of the elements analyzed can be created by checking the box for “Regional Lake Sediment Geochemistry Contours” and selecting an element to plot in the pull-down menu (Figure 9).

Line contours maps are generally best viewed as a large-scale map of a small area. Figure 9a shows a line-contour map of arsenic values in lake sediments in an area of central Newfoundland.

With the ready availability of colour monitors and printers, most geologists and prospectors prefer to create colour contour images (see below).

Figure 9: Pulldown menu for creating a line-contour plot.

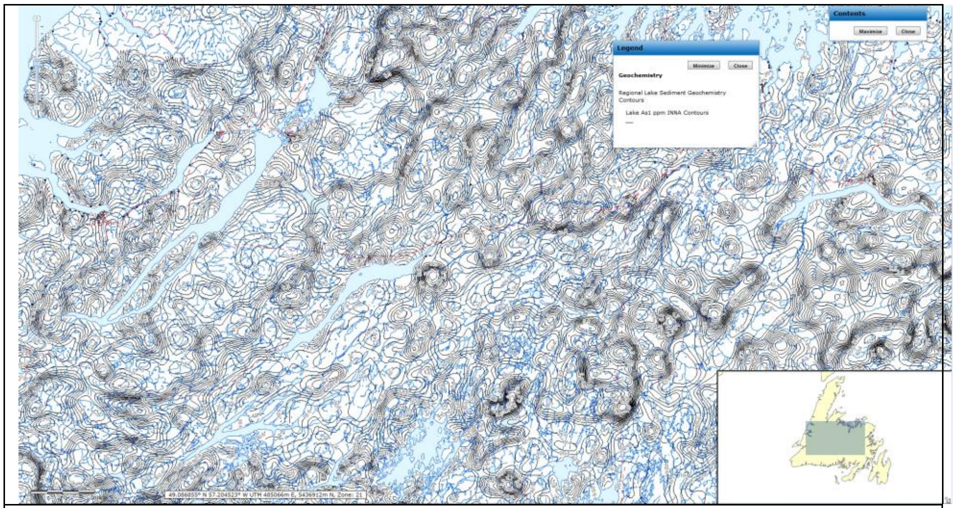
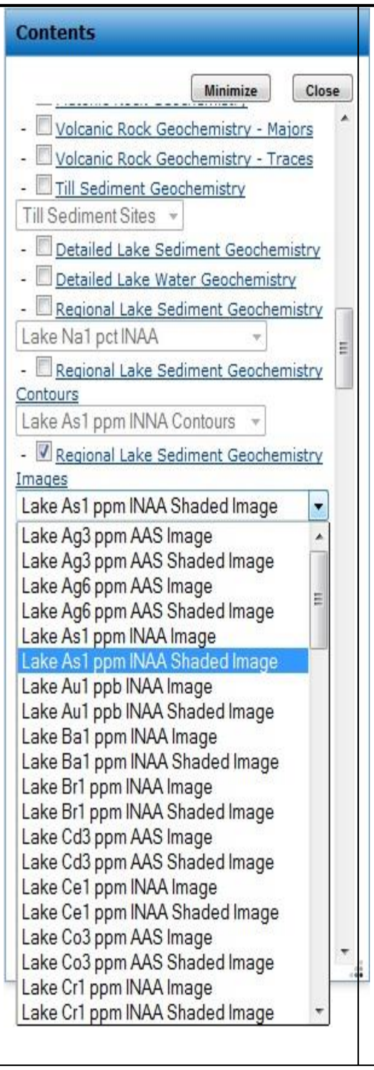


Figure 9a: Line-contour map of arsenic (As1) in lake-sediment samples in central Newfoundland.

How to View the Data – Colour Contour Images



Colour-contour images of most of the elements analyzed can be created by checking the box and opening the "Regional Lake Sediment Images" pulldown menu (Figure 10). On doing so, a default contour image map of silver (Ag3) is generated (Figures 10a and b) because this is the first, alphabetically. The suffix "3" indicates that the silver was analyzed by atomic absorption (AAS) after *aqua regia* digestion and because this method was only applied to lake-sediment samples from Labrador, the Newfoundland part of the map may appear blank.

The image for another element can be selected from the pulldown menu. Figures 10a and 10b show an unshaded colour-contour map of Ag3 (with no coverage for Newfoundland) and a shaded colour-contour image for As1 (that is, arsenic analyzed by neutron activation) for all of Newfoundland and most of Labrador. The extreme north of Labrador is too mountainous for lake sampling to be effective.

Figure 10: Pull-down menu of detailed lake sediment geochemistry information

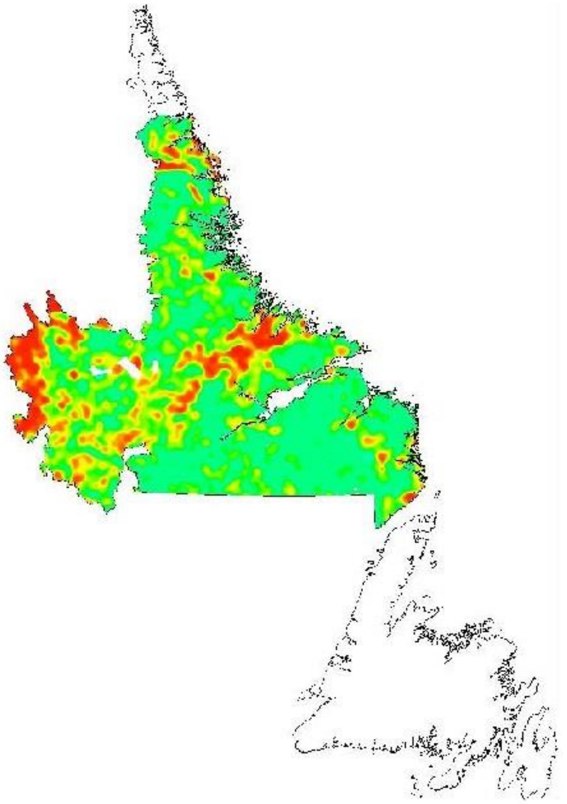
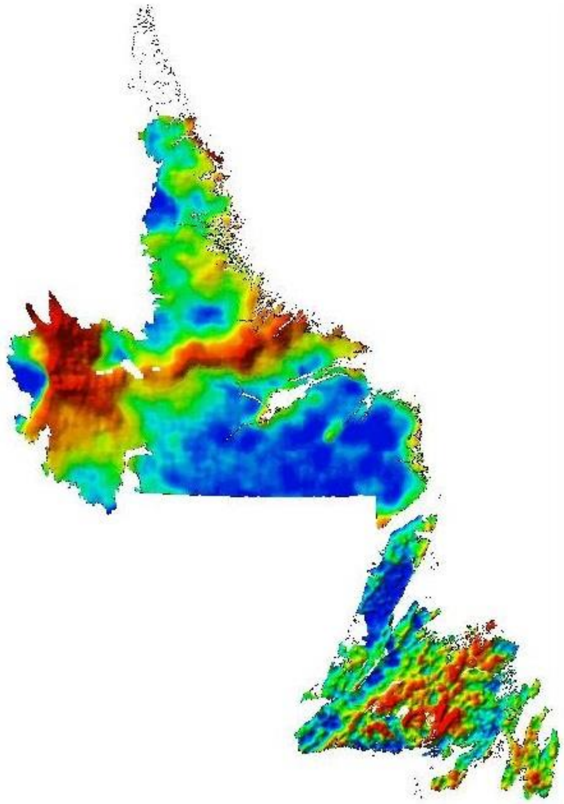
	

Figure 10a: Colour-contour map of silver (AAS, *aqua-regia* digestion) for Labrador.	Figure 10b: Shaded colour-contour map of arsenic (INAA) for Newfoundland and Labrador.

In general, higher values are indicated by red, which most people consider to be a "warm" colour, through orange, yellow and green to blue, a "cold" colour that denotes low values.

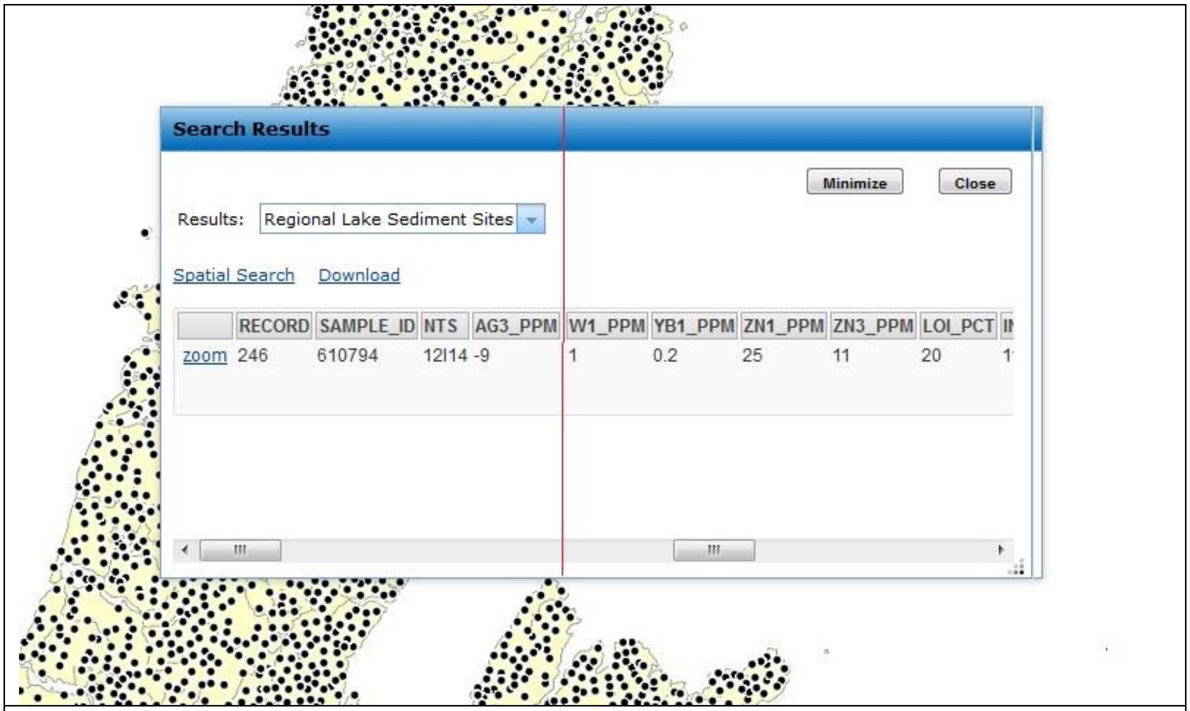
The colour contours are best utilized at small scale (for example, at 1:1,000,000), to identify zones of regional enrichment. Although it is possible to examine these maps at any scale, after zooming in to an area of interest it is preferable to examine results for individual samples, either:

1) as a symbol plot,
2) by looking at individual analyses, or
3) by downloading the data and subjecting it to customized plotting and data-analysis procedures (see below).

Note that it is possible to display a geochemical contour map with a geochemical dot plot, of the same element or another one, superimposed.

Clicking on an individual sample point will normally return all of the field and analytical characteristics for that sample. These will be displayed in a window in the middle of the screen (Figure 11).

Reading the characteristics of individual samples in the Geoscience Atlas



Results: Regional Lake Sediment Sites

	RECORD	SAMPLE_ID	NTS	AG3_PPM	W1_PPM	YB1_PPM	ZN1_PPM	ZN3_PPM	LOI_PCT
zoom	246	610794	12I14	-9	1	0.2	25	11	20

Figure 11: Sample information displayed after clicking on a sample point. All analytical data between AG3_PPM and W1_PPM have been omitted to facilitate display.

Downloading Geochemical Data from the Geoscience Atlas

In some cases it may be preferable to download geochemical data (lake sediment, till or rock data) from the Geoscience Atlas for processing and display on a home/private computer. Clicking on the "Tools" provides a number of options, including one to download data for all of the samples displayed on the screen

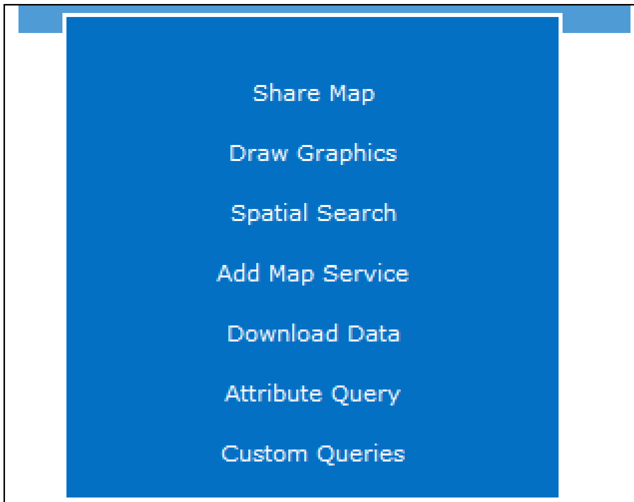
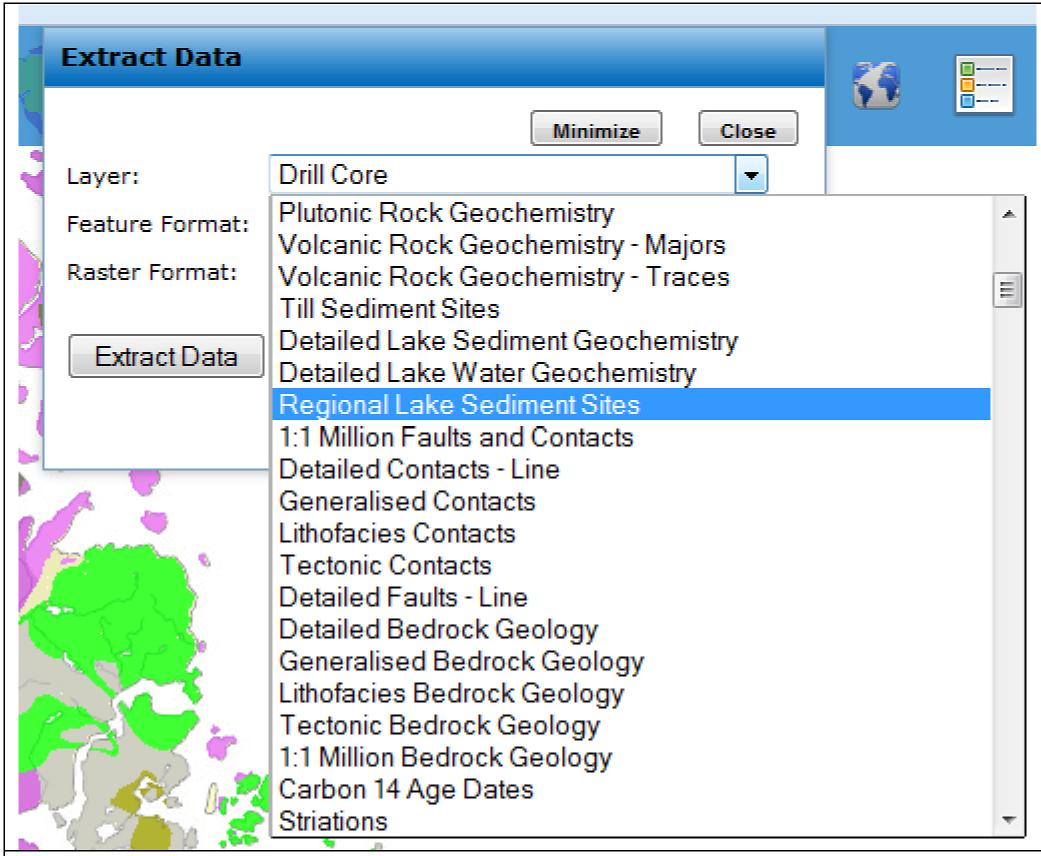


Figure 12: The Tools menu

The "Download Data" option is chosen (Figure 12).

In the pulldown menu that appears (Figure 13), it is necessary to specify the data layer from which you are downloading. The layer that is offered (by default because it is at the top of the list) is “Drill Core”.



Layer: Drill Core

Figure 13: The pulldown menu for selecting a layer to download.

The “Extract Data” button is clicked (Figure 14), followed by clicking the download instruction “Output File (right click and save as)” (this may take a few seconds if the map area is large): the data are then saved to a location of your choice. The downloaded files comprise a zipped shapefile (.SHP) and supporting files, one of which is in dBase (.DBF) format that can be read, edited and resaved in MS-Excel and various other applications for simple or specialized processing and display. However, all four files (Figure 15) are required if the data are to be reloaded into a Geographic Information System (GIS) software package like MapInfo or ArcMap.

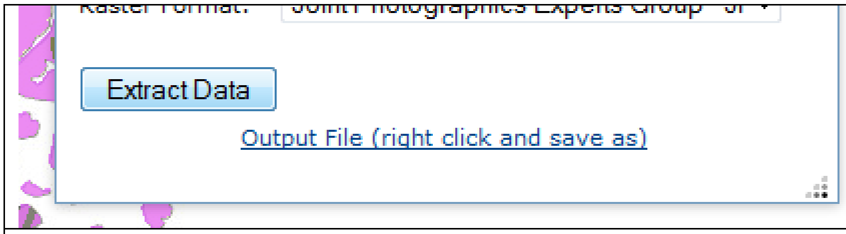
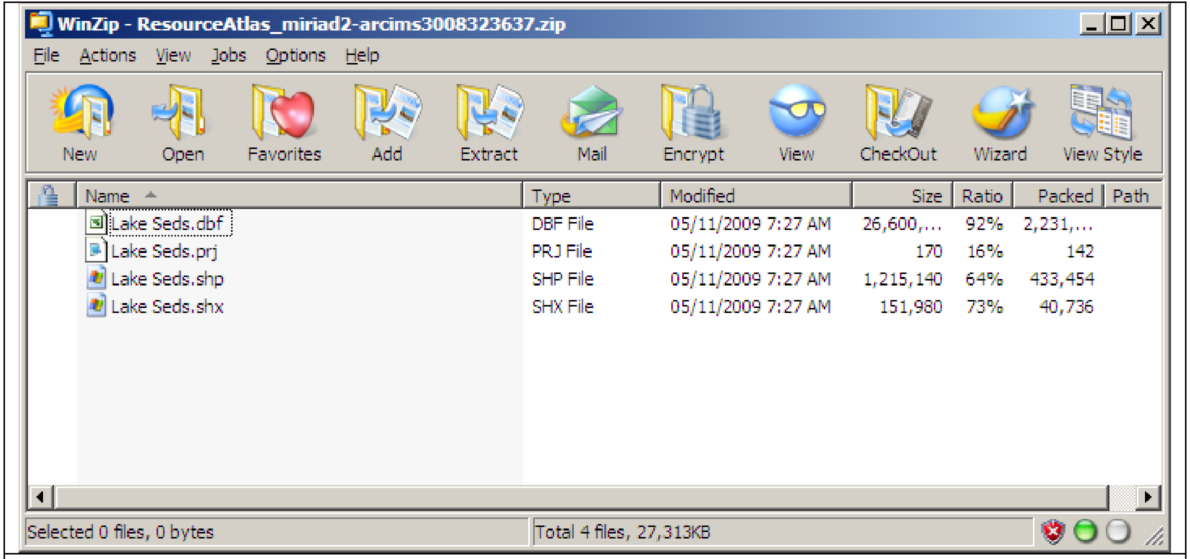


Figure 14: Instruction to save.

The downloaded data set will probably include some unwanted material, which can be edited out once the data are displayed in Excel.



Name	Type	Modified	Size	Ratio	Packed	Path
Lake Seds.dbf	DBF File	05/11/2009 7:27 AM	26,600,...	92%	2,231,...	
Lake Seds.prj	PRJ File	05/11/2009 7:27 AM	170	16%	142	
Lake Seds.shp	SHP File	05/11/2009 7:27 AM	1,215,140	64%	433,454	
Lake Seds.shx	SHX File	05/11/2009 7:27 AM	151,980	73%	40,736	

Selected 0 files, 0 bytes

Total 4 files, 27,313KB

Figure 15: Zipped files downloaded from the lake-sediment database in the Geoscience Atlas.

A separate article on data processing is available from the Matty Mitchell Room or from Steve Amor of the Geological Survey of Newfoundland and Labrador at 709-729-1161 or stephenamor@gov.nl.ca.

Accessing Till Geochemical Data

Till data can be accessed and downloaded from the Geoscience Atlas in the same way as lake sediment and water data. Till sampling is continuing in Newfoundland, with priority assigned to the most prospective areas of the Province. Coverage in Labrador is restricted to an area west of Port Hope Simpson, the Central Mineral Belt and the Schefferville and Strange Lake areas.

The suite of elements for which most till samples have been analyzed is more extensive than for the lake sediments, with symbol plots available for 70 different element/method combinations. However, till data are only available as point plots; colour-contour images and line-contour maps are not available. The Help window, accessible by clicking on the layer title in the table of contents, includes a listing of the original reports for the till surveys from which the data were derived.
Both Till and Lake Sediment Surveys layers can be loaded at the same time so that the results from different sample media can be compared in a particular area.

Accessing Rock Geochemical Data

Data for selected suites of rocks are available for visual examination (by clicking on individual points), and download (in the form of zipped GIS-compatible shape files), from the Geoscience Atlas, and are continually being added to. No geochemical symbol or image maps are available for rock data. These data sets comprise plutonic rocks (currently from Newfoundland only), volcanic rock major element analyses and volcanic rock trace element analyses (selected sites from both Newfoundland and Labrador).

Plutonic Rock Data: This database contains analyses for samples collected over many years (1972 to 1999) by different Geological Survey project geologists. The database consists of about 5000 rock samples, presently all from the island of Newfoundland. It contains all available major and trace element analyses for each sample. It also contains some field descriptions, ***such as presence of sulphide minerals***. The data can be downloaded. Data from samples collected on the Island from 2000 to the present, as well as from Labrador, will be added in the future. The field and major element variables are listed in Table 1 and the trace elements are listed in Table 2.

Volcanic Rock Data: The original database, organized by Saunders (1995), comprises volcanic and sub-volcanic rock samples collected from 1966 to 1994 by the Newfoundland and Labrador Geological Survey (published and unpublished data), from M.Sc. and Ph.D. theses completed at various universities and from select exploration companies (Bitech and Falconbridge). It contains all analyses for each sample. The simplified online database consists of 5081 rock samples: 1040 samples from Labrador and 4041 samples from Newfoundland. It contains a large number of variables, including field descriptions and major and trace element analyses, so the data are presented in two files: one for the field information and major element analyses (Volcanic Field Majors) and another for the trace element analyses (Volcanic Traces) (Table 1 and Table 2 respct). ***Table 2 includes analyses for base and precious metals*** and other elements of interest to prospectors. These two files can be downloaded from the Resource Atlas Online and combined using the unique variable "LabNum", which is common to both files. The full database, including all the analyses, standards and duplicates, will be made available through the Publications Section (Geofile NFLD/3078). Future updates will include more recent data.

Accessing Detailed Lake Sediment Sites / Detailed Lake Water Sites

Since 1978, a number of focussed, detailed lake-sediment sampling programs have been carried out at various localities in Labrador. In many cases the surveys were prompted by encouraging results from the regional surveys, or favourable geology for mineralization of various types. The data can be downloaded as zipped GIS-compatible shape files but no geochemical symbol or image maps are available.

Elements and Analytical Methods

Analyses in the databases (accessible through the Geoscience Atlas) of lake sediments and waters, tills and rocks, are described in terms of their elemental symbol and a numeric suffix denoting the digestion reagent (where applicable) and in some cases, the laboratory where the analyses were performed, as follows:

Lake Sediments and Tills

No Suffix: Gravimetric Analysis

This technique is only used for the determination of Loss on Ignition (LOI), whereby a sample is weighed before and after heating to 1,000ºC. Depending on the nature of the sample, the LOI may represent the contained water and carbon dioxide in a sample (in the case of rocks and tills) or its organic content (in the case of lake sediments). Certain elements concentrate preferentially into either the organic or inorganic fractions of lake sediments, to such an extent that false anomalies may be created; and the LOI content is a useful monitor of the relative amounts of organic and inorganic material in the sediment.

Suffix 1: Neutron Activation (INAA)

This is a “total” analytical method; that is, the entire element contained in a sample is measured without it being necessary to digest it using strong acid or another leaching reagent. Of the methods used to analyze the samples of lake sediment, lake water and till in the Geoscience Atlas, the Neutron Activation method is unique in this respect.

Because the sample is bombarded with neutrons, the analysis can only be carried out in a nuclear reactor. Neither the Geological Survey of Canada nor the Geological Survey of Newfoundland and Labrador have access to such a device and the neutron-activation analyses denoted by this suffix have been carried out by the commercial enterprises XRAL, ActLabs and Becquerel.

Elements analyzed by INAA in some or all samples of lake sediment and till in the Geoscience Atlas include Silver (Ag)*, Arsenic (As)*, Gold (Au), Barium (Ba), Bromine (Br), Cadmium (Cd)*, Calcium (Ca)*, Cerium (Ce), Cobalt (Co)*, Chromium (Cr), Cesium (Cs), Europium (Eu), Iron (Fe)*, Hafnium (Hf), Iridium (Ir), Lanthanum (La), Lutetium (Lu), Molybdenum (Mo)*, Sodium (Na), Neodymium (Nd), Nickel (Ni)*, Rubidium (Rb), Antimony (Sb), Scandium (Sc), Samarium (Sm), Selenium (Se), Strontium (Sr)*, Tantalum (Ta), Terbium (Tb), Thorium (Th), Uranium (U)*, Tungsten (W), Ytterbium (Yb), Zirconium (Zr)* and Zinc (Zn)*. Elements endorsed with an asterisk are also analyzed by other methods in some samples.

Suffix 2: ICP-OES / Multiacid Digestion

Like most of the analytical methods in the Geoscience Atlas, ICP-OES (Induction-Coupled Plasma-Optical Emission Spectrometry) is a “wet-chemical” method; that is, the metallic constituents must be leached from the sample into an aqueous solution, with the aid of a strong acid or combination of acids, although for certain purposes, a much weaker reagent may be used.

This method involves the use of a combination of perchloric ($HC1O_4$), hydrofluoric (HF) and hydrochloric (HCl) acids; the intended effect being that all mineral phases are broken down and their metallic constituents go into solution. In practice this is not always achievable, with minerals such as zircon, chromite and barite resisting even this powerful acid combination.

Elements analyzed by ICP-OES / Multiacid Digestion of some or all samples of lake sediment and till in the Geoscience Atlas include Aluminum (Al), Arsenic (As), Barium (Ba), Beryllium (Be), Calcium (Ca), Cadmium (Cd), Cerium (Ce), Cobalt (Co), Chromium (Cr), Copper (Cu), Dysprosium (Dy), Iron (Fe), Gallium (Ga), Potassium (K), Lanthanum (La), Lithium (Li), Magnesium (Mg), Manganese (Mn), Molybdenum (Mo), Sodium (Na), Niobium (Nb), Nickel (Ni), Phosphorus (P), Lead (Pb), Rubidium (Rb), Scandium (Sc), Strontium (Sr), Thorium (Th), Titanium (Ti), Vanadium (V), Yttrium

(Y), Zinc (Zn) and Zirconium (Zr). The analyses have been carried out in the laboratory of the Department of Natural Resources in St. John's.

Suffix 3 Atomic Absorption / Aqua Regia Digestion

Flame Atomic Absorption Spectrophotometry (FAAS) is also a "wet-chemical" method and as such, requires some means of getting the metals contained in the sample into solution. Aqua Regia (3 parts concentrated hydrochloric acid / one part concentrated nitric acid) is commonly used to digest geochemical samples, although it is not capable of dissolving minerals like quartz and feldspar to a significant extent. The term "flame" refers to the acetylene flame that converts the resulting solution to a vapour within which the contained metals are detected and measured.

This method was applied to lake sediment samples from Labrador and Newfoundland prior to the introduction of ICP-OES (see above), at the labs of the Geological Survey of Canada and the Department of Natural Resources respectively. The samples were analyzed for Silver (Ag – Labrador only), Cadmium (Cd; selected map sheets only), Cobalt (Co)*, Copper (Cu), Iron (Fe)*, Manganese (Mn), Nickel (Ni)*, Lead (Pb) and Zinc (Zn).

Suffix 4 Atomic Absorption / Aqua Regia Digestion

This method of digestion and analysis is the same as Method 3 but applies to stream sediments, soils and tills, analyzed at the labs of the Department of Natural Resources, as opposed to lake sediments.

Suffix 5 Atomic Absorption / Aqua Regia + Al^{3+} Digestion

This method of digestion and analysis is similar to Methods 3 and 4; however, a small amount of aluminum is added to stabilize the molybdenum (Mo) and vanadium (V) compounds in the solution, so that they remain detectable by the analysis. This method was applied at the Geological Survey of Canada's lab to lake-sediment samples from Labrador, for both Mo and V, and at the Department of Natural Resources' lab to lake-sediment samples from Newfoundland, for Mo only.

Suffix 6 Atomic Absorption / Nitric Acid Digestion

Pure nitric acid is used in preference to Aqua Regia, which contains hydrochloric acid, to digest all geochemical samples for silver (Ag) analysis, because the insolubility of silver chloride will cause some of that element to precipitate out and be unavailable for detection. This method was applied by the Department of Natural Resources' laboratory to lake-sediment samples collected on the island of Newfoundland, although conventional Aqua Regia digestion was used by the Geological Survey of Canada and the results were considered to be satisfactory.

Suffix 8 Delayed Neutron Counting (DNC)

This method is used primarily for uranium (U) analysis. Like neutron-activation analysis, and unlike most of the "wet-chemical" techniques, the total content of uranium is measured and results are generally very similar to those of neutron activation, although DNC has an upper limit of about 1,000 ppm. As with neutron-activation analyses, the work requires access to a nuclear reactor and the work was contracted out to Activation Laboratories (ActLabs) of Ancaster, Ontario.

Suffix 9 Ion selective electrode

This very sensitive method is used for determination of elemental fluorine in sediments, and fluoride ion in lake waters. It was, and continues to be, carried out on all sediment samples from regional and more detailed sample surveys from both Newfoundland and Labrador.

Suffix 18 Aqua Regia; cold vapour

This method is specific to Mercury (Hg) and takes advantage of that element's tendency to vaporize at relatively low temperatures, removing the need for a high-temperature flame. The method was used on lake sediment samples from Labrador, by the Geological Survey of Canada, but has not been applied to lake sediment samples collected in Newfoundland, or any other media.

Suffix 19 Hydride Atomic Absorption

Certain elements, notably arsenic and antimony, have non-metallic character and readily form gaseous hydrides that are amenable to atomic-absorption. This method was used by the Geological Survey of Canada to analyze about 76% of the lake-sediment samples from Labrador and was the method of choice for both elements until neutron-activation analyses became readily available.

Suffix 21 Colorimetry

This method, one of the earliest developed for analyzing trace amounts of arsenic (and many other metals) was applied to the remaining 24% of the lake-sediment samples from Labrador that were not analyzed by Hydride Atomic Absorption.

Suffix 25 ICP-OES / Lithium Tetraborate ($LiBO_2$) fusion

This method was applied to the analysis of chromium (Cr) and zirconium (Zr) on a limited number of lake sediment samples from the detailed lake sediment sampling program. Many minerals that host these elements are resistant to digestion by even the strongest acids; hence the application of a fusion technique to get the Cr and Zr into solution.

Suffix 26 Neutron Activation

This method denotes Neutron Activation analysis carried out in 1978 by Atomic Energy Canada (AEC) on a batch of 746 detailed lake-sediment samples.

Suffix 27 Fire Assay / ICP-MS

The fire-assay technique can be used to concentrate trace amounts of gold and other precious metals to the point where they can be measured by conventional methods more suited to more abundant elements. Combination of fire-assay preconcentration with induction-coupled mass spectrometry (ICP-MS) produces a highly sensitive analysis, of which 595 were performed for palladium (Pd) and platinum (Pt) on samples from the detailed lake sediment data set.

Lake Waters - No suffix

Conductivity. This is measured with a Corning conductivity sensor and readings are available for about 50% of the samples in the Detailed Water Database.

pH. This metric of the acidity (low values)/alkalinity (high values) of the water is measured with the Corning combination pH electrode. All of the water samples in regional lake sediment/water database, and approximately 80% of the samples in the detailed water database, have pH measurements.

hvymtl_w Total Heavy Metal

About 8% of the detailed water samples from a 1979 program were analyzed for this parameter by a colorimetric method, which seems rather primitive from the perspective of 2015 but which has the advantage that analyses can be performed in a field laboratory. "Total Heavy Metal" refers to the combined content of Cu, Zn and Pb.

Suffix w1 ICP-OES

For the relatively abundant elements Ca, Fe, K, Mg, Mn, Na, Si and SO_4 (sulphate ion), conventional induction-coupled plasma-optical emission spectrometry, analogous to lake sediment/till Method 2, is applied. About 50% of the water samples from the detailed lake sediment surveys have been subjected to this analysis.

Suffix w2 ICP-OES - Ultrasonic nebulizer

The less abundant elements Al, As, Ba, Be, Co, Cr, Cu, Li, Mo, Ni, P, Pb, Sr, Ti, V, Y, Zn can be analyzed by conventional ICP-OES if an ultrasonic nebulizer, which creates a fine mist of the water sample, is available to provide the necessary signal enhancement. About 50% of the water samples from the detailed lake sediment surveys have been subjected to this analysis.

Suffix w3 Inductively Coupled Plasma-Emission Mass Spectrometry

This sensitive method is suitable for determination of As, Ba, Be, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Gd, Ho, In, La, Li, Lu, Mn, Mo, Nd, Ni, Pb, Pr, Rb, Re, Se, Sm, Sr, Tb, Th, Ti, Tl, Tm, U, V, Y, Yb and Zn, although its relatively recent introduction means that less than 5% of the water samples in the detailed lake water database have been analyzed in this way, and in many cases for a rather small subset of these elements.

Suffix w9 Ion-selective electrode

This method is used to determine fluoride ion content. All of the water samples in the regional Labrador database, and about 35% of the detailed water samples, were subjected to this method (at the labs of the Geological Surveys of Canada and Newfoundland and Labrador, respectively), although it was not applied to the regional samples from Newfoundland.

Suffix w10 Fluorimetry

Analyses by this sensitive method of uranium detection were performed by Bondar Clegg Ltd. and applied to 50% of regional lake water samples from Labrador (the other 50% being subjected to Fission Track analysis; see below) and 20% of the detailed lake water samples from the detailed programs.

Suffix w11 Fission Track Analysis

This method involves the irradiation of the water sample with thermal neutrons and the electronic counting of the uranium fissions that take place. All of the regional lake water samples from Labrador, that were not analyzed by fluorimetry (see above) were analyzed by this method at Atomic Energy Canada Ltd. The method was not applied to water samples from Newfoundland.

Suffix w12 Dithizone/colorimetric

About 12% of the lake waters, from an early detailed survey in Labrador, were analyzed by this long-supplanted method which can be carried out in a very basic field lab.

Frequently-Asked Questions

Q: How do I know whether a sample analysis is worth following up?

A: This question is asked frequently by prospectors and the following are general guidelines only!

In interpreting surficial geochemical data (that is, analyses of almost any natural medium except rock that is from outcrop, or believed to be locally derived) the term “threshold” is used. This is the upper limit of background variation (the natural variation of an element in the absence of mineralization). Any values of that element that exceed it are, in theory, anomalous and deserving of follow-up, and the higher the values are, the higher the priority that should be assigned to the follow up work.

It is, however, difficult or impossible to determine thresholds that can be used in ***any*** situation because the results of the analysis depend on the way in which the sample is prepared (for example, the size fraction of the soil) and method of analysis (for example, the acid or other reagent that is used to digest the sample). The results are also influenced by the rock type (or types) from which the samples are derived.

A more reliable way to judge whether an analysis justifies follow-up, is to plot the values of all the samples on the map and highlight the high ones (say, the top 10 percent). If these high value samples are concentrated in one area, they are probably related to enrichment of that element in bedrock. If they are scattered randomly, with no spatial concentrations, they are probably not.

The above method is not very helpful if only a few samples (less than 50-100) have been collected. In that case, it may be useful to consult the crustal abundances of the elements in Appendix B. In surficial geochemical data (for solid material only; values would be much lower for water), an analysis of between 5 and 10 times the average crustal abundance is probably worth following up; in rock, the corresponding figures are 50 to 100. It is emphasized once again that these are general guidelines only.

Q: Why have these elements (and not others) been selected for the database?

A: The reasons for the inclusion and exclusion of certain elements in this and other data sets are varied. Elements may have been analyzed because of their economic value (e.g., gold, nickel, uranium and zinc), their usefulness as pathfinders, as described in Appendix A (e.g., arsenic, cadmium), or both (silver, copper, antimony, lead). They may have been included because of their usefulness as monitors of environmental conditions that in turn influence the content of the above elements, and others (iron, manganese, loss on ignition). They may also have been analyzed simply because the technology exists to do so inexpensively, and because in general, the more complete the analysis of a sample or suite of samples, the more potential, possibly unforeseen uses for the data in the future. The analyses of rare-earth elements (REE) and rare metals (RM), to which lake-sediment samples were subjected, are an example of analyses whose value has increased with the current economic interest in these commodities, which could not have been foreseen when a decision was taken to perform the analyses.

The elements in the lake sediment, lake water and till databases are dependent on analytical methods that were available at reasonable cost at the time, and which have in some cases been largely replaced. Flame Atomic Absorption Analysis (FAAA; suffix “3”) is an example. This method produces high-sensitivity analyses of a number of elements and was an industry standard until the early 1980s; however, it suffers from the disadvantage that only one element can be analyzed at a time and the method has been replaced by multi-element techniques such as Induction-Coupled Plasma-Optical Emission Spectrometry (ICP-OES; suffix “2”), and more recently Induction-Coupled Plasma-Mass Spectrometry (ICP-MS; no analyses in Geoscience Atlas yet).

Even at current levels of technology, it is not possible to analyze certain elements cost-effectively, at levels of sensitivity that are useful in geochemical exploration. The most notable examples are the platinum-group elements, excepting iridium, which is particularly amenable to neutron-activation analysis (although some form of preconcentration, like fire assay, is usually necessary even for iridium).

Appendix B lists the geochemical applications of a wide variety of the elements whose results are presented in the Geoscience Atlas, as well as certain others that are often reported in the multi-element packages currently offered by commercial geochemical labs.

Q: Why do the maps for the same element, analyzed by two different methods and displayed in different ways, sometimes give a different impression?

A: The maps that result from the plotting of the same element by two (or more methods) often exhibit differences, that vary from slight to considerable. An example is shown in Figure 16, which shows the distribution of arsenic in the Makkovik area of Labrador, as measured by three different methods and displayed in two different ways. The values of As, as measured by hydride atomic absorption analysis (HAAS), show an area of enrichment that has greater contrast and homogeneity than the corresponding neutron activation analyses (INAA).

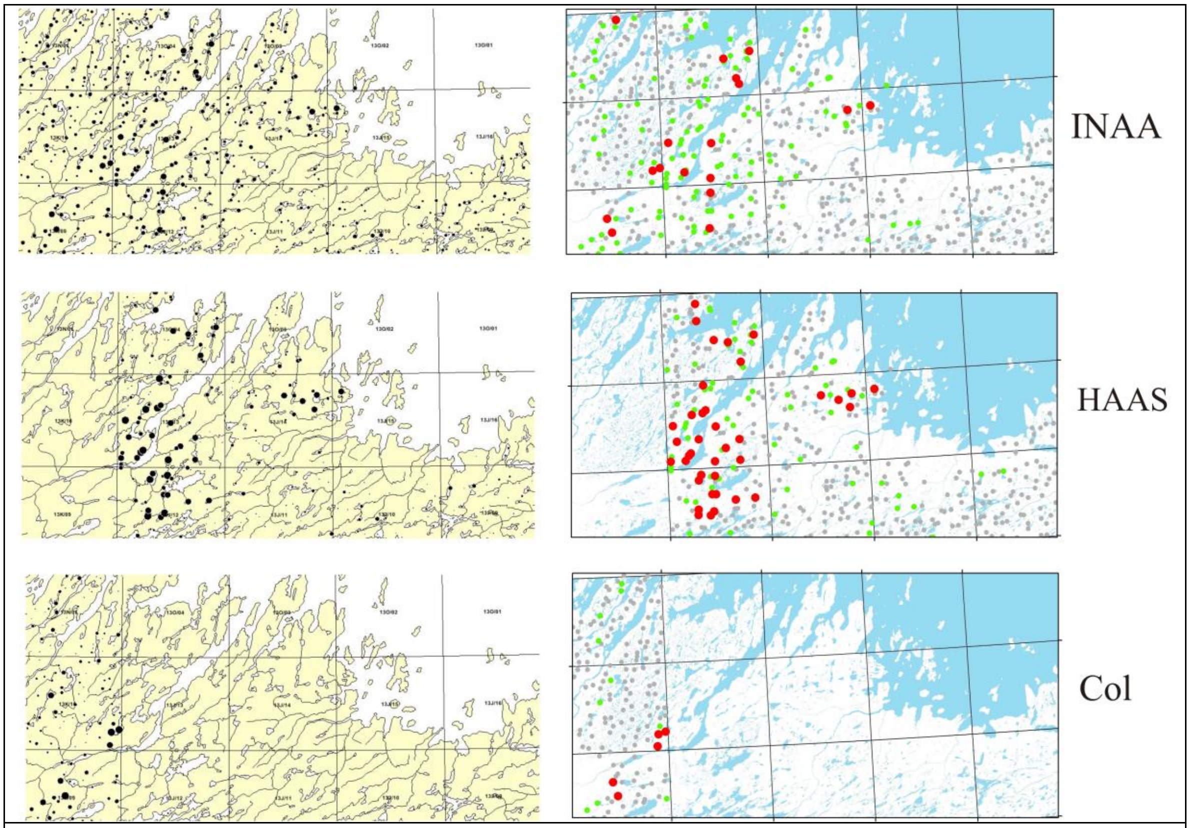


Figure 16: Arsenic in lake sediments, Makkovik Area, Labrador. The coloured symbols on the right representing "elevated" (green) and "anomalous" (red) values are generally better at indicating areas of enrichment than the dot plot symbols on the left, but hydride atomic absorption spectrometric (HAAS) analyses delineate the enriched area more strongly in both dot plot and coloured symbols than the neutron-activation (INAA) analyses. Colorimetric analyses, in the west of the map area, also appear to delineate the enriched area more strongly than the INAA analyses.

To explain the difference in responses, which are just one example of a very widely-observed phenomenon, it is necessary to bear in mind that the neutron activation analyses measure the total arsenic content of the samples, whereas the atomic-absorption method, including the hydride variant used for arsenic and antimony (see above), is only a partial (albeit fairly efficient) measure of the sample's composition, if it is preceded by an aqua regia or other non-total digestion. If a local source of arsenic enrichment occurs within a highly soluble mineral phase, whereas a less significant proportion of the arsenic occurs within an insoluble one, the local anomaly will be expressed more strongly by the non-total analysis. This is the justification for the many partial-extraction methods, like Enzyme Leach and MMI, whose use continues to be advocated by many workers.

Also, the appearance of a geochemical map is a function of both the composition of the samples whose results are being plotted, and various settings chosen by the person responsible for the plotting. These choices include the number of contour or symbol intervals, and the values that separate those intervals.

Q: I sampled the same lake that the Government did. Why are my results different to the results they reported?

A: There are a number of possible reasons for this. One is that your method of sample preparation and analysis may not be the same as the Government's. As described above, a sample that is digested in aqua regia, which is not capable of attacking certain silicate and oxide minerals, will return a different analysis to that returned after a multiacid digestion, or performed by a "total" method like neutron activation.

In the case of certain sample media, including stream sediments, soils and tills (but not lake sediments), the sample is normally dried and sieved, with only the fine fraction submitted for analysis. What constitutes the fine fraction is also variously defined; the most common sieve sizes are 80 mesh (0.177 millimetres) or 200 mesh (0.063 millimetres). A properly-prepared lab or geochemical report should always specify the sieve mesh size but this information is frequently omitted from assessment documents.

However, even if you go to considerable lengths to recreate the preparation and analytical conditions of the original sample, the chances that the analytical value or values will be exactly the same as those originally reported, are vanishingly small. This is because of the inhomogeneity of the sample medium; the composition of a lake's sediment would not be expected to remain constant throughout the lake's extent, whatever its size.

It would be expected, however, that the pattern displayed by many new samples in a particular area will be similar to that generated by the original. An example is shown in Figures 17a and 17b, where the results of two lake-sediment sampling programs in an area of western Labrador are displayed. The same lakes were sampled, and samples were analyzed for arsenic by neutron-activation (INAA), in both cases. Plotting of the earlier analyses (GSC 1989) against their more recent (GSNL 2010) counterparts (Figure 17a) shows that very few pairs consist of identical analyses in both years; nevertheless, it is clear that there is a strong relationship between the two sets of analyses. Furthermore, the colour-contoured values of the arsenic results (Figure 17b) show that the large-scale patterns indicated by the two surveys are essentially the same.

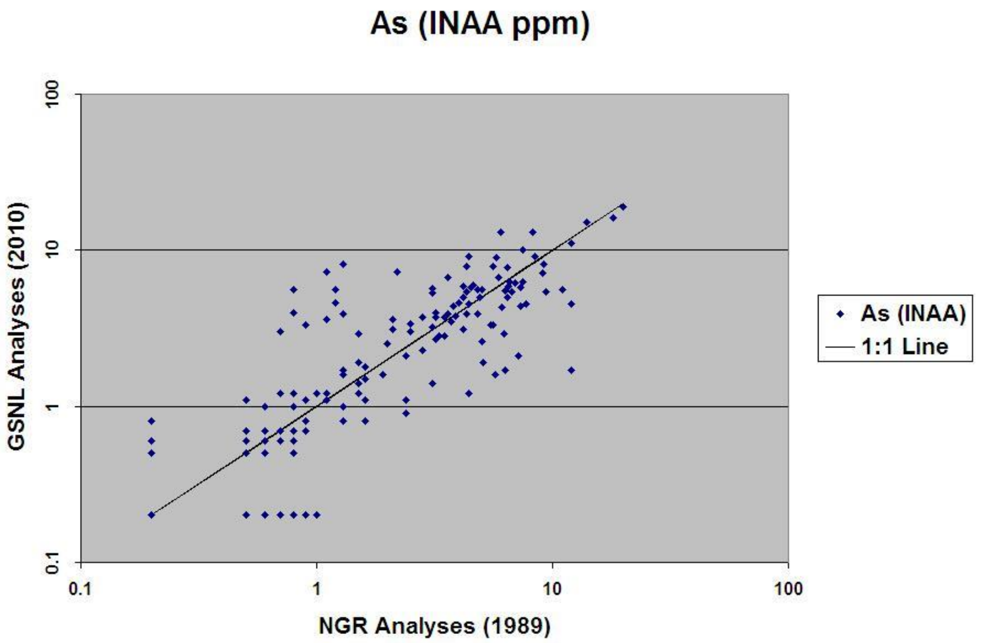


Figure 17a: Comparison of INAA As analyses on lake-sediment samples, analyzed in 1989, with results for new samples from the same lakes, analyzed in 2010. Although there is a linear relationship between the two sets of analyses, the number of points falling on the 1:1 line (indicating the same analytical result in both years) is relatively small.

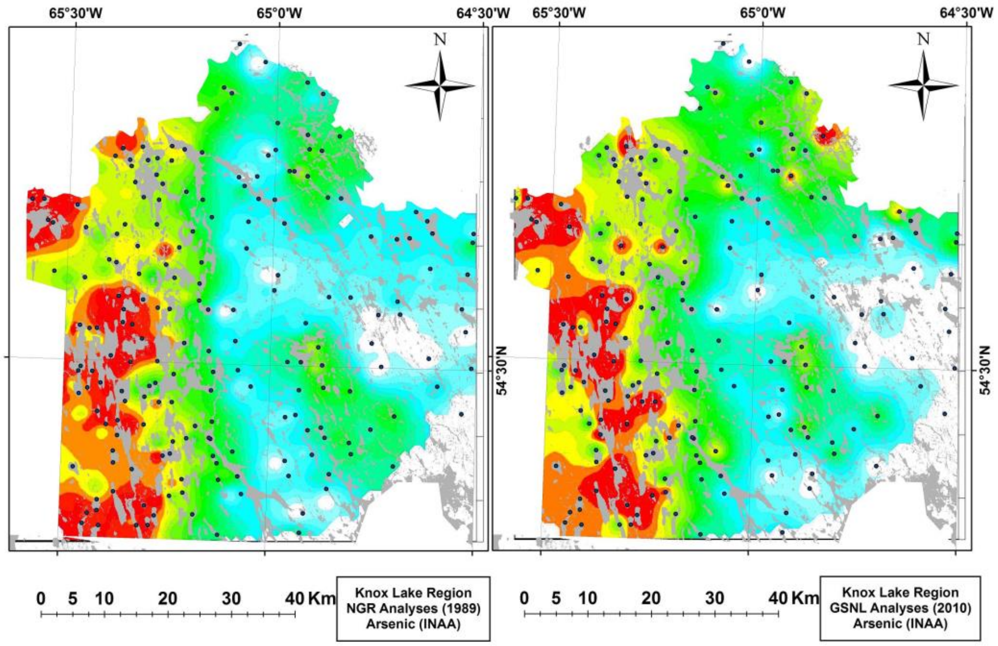


Figure 17b: Comparison of As in lake sediments from two sampling programs, Knox Lake region, western Labrador

Q: Prospecting and geophysical work suggest that my claims may host significant mineralization. Should I drop the claims if the geochemical data are not encouraging?

A: No! Geochemistry is a means to end, like other exploration techniques, but it doesn't always work. There are many instances of economic mineral deposits giving rise to no anomalous response at all, and Voisey's Bay is a case in point. No anomalous response, in copper, nickel, cobalt or any other analyzed element, was detected in sediments or waters from lakes draining this very large mineral deposit.

Q: I have 10,000 ppm Mn and / or 10 % Fe in my <u>lake sediment / stream sediment assay</u> results – does this suggest the presence of mineralization?

A: Probably not. Hydroxides of iron and manganese may precipitate rapidly out of flowing water, as sediment, if it meets another body of water in which the physicochemical conditions are different. This is a commonly observed phenomenon throughout Canada, and elsewhere. Furthermore, the Mn and Fe hydroxides may drag other elements (notably Co and Zn) out of solution with them and these will also appear enriched in the analysis of the sediment.

Q: I have 10,000 ppm Mn and / or 10 % Fe in <u>my rock assay results</u> – does this suggest the presence of mineralization?

A: Probably not. One percent (10,000 ppm) manganese is a good deal higher than what is typically found in most rocks, but only about one fortieth of typical ore grades in operating manganese mines. Ten per cent iron is not unusual in many gabbros and basalts (though much lower in most other rocks) while economic ore grades are in the region of 50-60%.

Q: I have 10,000 ppm Mn and / or 10 % Fe in my <u>soil assay results</u> - is this a good sign?

A: Possibly. Precipitation of Mn and Fe hydroxides from groundwater in soils is also quite common and could give rise to a false anomaly with these kinds of values, particularly in the rusty-brown B horizon. However, if such precipitation has not taken place, and the sample was collected from the C horizon, these values are consistent with the soil being derived from bedrock that may be enriched to near-economic grades.

Q: I have highly anomalous arsenic on my property and visible arsenopyrite, but all my gold values are just background. Isn't arsenic supposed to be a pathfinder for gold?

A: Yes, but if you check Appendix B you'll see that arsenic is more than 500 times as abundant in the earth's crust than gold. In other words, there's a lot more of it about, and not all of it is associated with gold. By the same token, not all quartz veins are auriferous but that doesn't mean that a quartz vein, any quartz vein, isn't worth a close look.

The very rich conglomerate-hosted gold deposits of the Witwatersrand in South Africa are not enriched in arsenic so you would not expect arsenic to act as a pathfinder for this type of mineralization.

Appendix A: Glossary of Terms

Anomaly

Although it does not conform to the dictionary definition of the word, in geochemical exploration an anomaly is a sample or group of samples whose composition is anomalous in an element of economic interest, or a pathfinder element (see below), and which justifies some form of follow-up exploration or prospecting work. The word **anomalous**, in this context, means any geochemical value that exceeds the threshold (see below).

Background

Background is defined as the normal range (not a single value) of concentrations for an element in a given area. Even within that area, it varies depending on the rock type from which the sample medium is derived, as well as the horizon that is sampled (in the case of soil sampling), the size fraction that is analyzed and the reagent that is used to digest the samples. The upper limit of background variation is called the ***threshold*** (see below).

Digestion

This is the process whereby the metals contained in a geochemical sample are dissolved into an aqueous solution so that they can be analyzed by such "wet-chemical" methods as AAS, ICP-OES or ICP-MS. It does not necessarily mean that the entire sample is dissolved, although this is the objective of "Total" or "Multiacid" digestion. More commonly, the sample will be digested with aqua regia (which is a combination of nitric and hydrochloric acids that will dissolve sulphides, oxides, hydroxides and some silicate minerals, but has little effect on quartz and feldspars) or a nitric-perchloric acid combination.

For some purposes, the digestion reagent may be relatively weak, but specific to a particular mineral phase in which the element of interest, derived from mineralization, is believed to concentrate. This is the principle behind the popular Enzyme Leach and MMI methods.

"Total" or "Multiacid" digestion may not dissolve certain highly resistant minerals, such as barite, chromite and zircon. If the samples are believed to contain significant amounts of such minerals, a fusion digestion (using a flux such as sodium peroxide, or lithium tetraborate) may be necessary.

Pathfinder Elements

Pathfinder elements are those which are enriched in certain types of mineral deposit, and show an anomalous response in sampling media derived from the deposit, even though they may have little or no economic value themselves. The most commonly cited example is arsenic (As) which is still extensively used as a pathfinder for most types of gold deposits because it is more mobile, and dispersed more homogeneously, than gold. It also used to be significantly cheaper to analyze, though that is less true now than it was 40 years ago. Other pathfinders are listed under the heading "Applications" in Appendix B.

It should be noted that certain elements constitute pathfinders when they are significantly low. Sodium is depleted in the wallrocks of most types of hydrothermal deposit and the zones of depletion can be very extensive; as such, they can be a useful exploration target.

Sample Media

Sample media refers to the particular type of sample that is used in a survey; examples are rock, soil, till, lake sediment, lake waters, stream sediment and vegetation.

Scale

Maps are often described as large-scale or small-scale. A large-scale map is one whose representative fraction or RF (e.g. 1/25,000) is a larger fraction than a small-scale map with an RF of, say, 1/250,000 to 1/7,500,000. To a prospector, large-scale maps typically will have an RF of 1/50,000 or greater (e.g., 1/10,000) and can be expected to show the greatest detail. Maps between 1:50,000 to 1:250,000 are described as having an intermediate scale. Maps of the world that fit on two 8½ by 11 inch pages are very small scale, about 1 to 100 million. You can find out more about map scales at the following website: http://geography.about.com/cs/maps/a/mapscale.htm

Threshold

The threshold is the upper limit of background variation, above which analytical values are regarded as anomalous (see above). Because background can vary with geology, sampling and analytical conditions and region, the threshold can vary too.

UTM (Universal Transverse Mercator)

This is a metric coordinate system covering most of the earth’s surface, with the exception of the polar regions. The earth’s surface is divided into 60 zones, each shaped like the segments of an orange, over each of which a metric grid is drawn. Most of Newfoundland is in Zone 21, although the Avalon Peninsula is in Zone 22, while most of Labrador is in Zone 20, with the southeastern coastal region in Zone 21.

Most GPS units can be set to record positions in UTM coordinates, or latitudes and longitudes. The UTM coordinates, and zone, can be calculated directly from the latitude and longitude, and vice versa, although in the latter case it is important to specify the zone correctly. A useful MS-Excel workbook application for doing this can be found at www.uwgb.edu/dutchs/usefuldata/UTMConversions1.xls.

Zip File

A ZIP (or zipped) file contains one or more files that have been compressed to reduce file size. This makes them easier to archive, and also to email. The degree to which files can be compressed varies with file type; word-processing and spreadsheet files can often be compressed to less than one-tenth their original size; others, such as JPEGs and PDFs, are hardly compressed at all and are stored “as is”.

The ZIP format is now supported by many software utilities other than PKZIP, the original one; WinZip is a very commonly-used one. Microsoft has included built-in ZIP support (under the name "compressed folders") in versions of its Windows operating system since 1998. Apple has included built-in ZIP support in its Mac computers 10.3 and later, along with other compression formats. ZIP files generally use the file extension ".zip" or ".ZIP".

Appendix B: Geochemical Table of the Elements

Crustal abundance data taken from http://www.webelements.com/periodicity/abundance_crust/

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
Li	Lithium	3	*17 ppm*	1 ppm[1]	0.5 ppm[1]	N/A	None[2]	Elevated values are indicative of felsic rocks, possibly of distinctive chemistry and origin
Be	Beryllium	4	*1.9 ppm*	0.5 ppm[1]	0.1 ppm[1]	N/A	For certain pegmatites.	Elevated values are indicative of felsic rocks, possibly of distinctive chemistry and origin
B	Boron	5	*8.7 ppm*	5 ppm[1]	0.3 ppm[1]	N/A	Tourmaline (typical formula $NaFe^{++}{}_{3}Al_6[BO_3]\ 3Si_6O_{18}[OH]_4$) is an important accessory mineral in many types of gold deposit.	Elevated values may serve to "fingerprint" felsic intrusive rocks of distinctive composition and origin
F	Fluorine	9	*540 ppm*	N/A	N/A	N/A	Fluoride ion content of waters shows association with REE mineralization. Association of fluorine in sediments is not as strong	Elevated values may serve to "fingerprint" felsic intrusive rocks of distinctive composition and origin
Na	Sodium	11	*2.3%*	0.01%[1]	N/A	0.05%	Often depleted in hydrothermally-altered and mineralized rocks	Often depleted in hydrothermally-altered rocks
Mg	Magnesium	12	*2.9%*	0.01%[1]	10 ppm[1]	N/A	May be enriched in hydrothermally-altered and mineralized rocks, particularly in the wallrocks of VMS deposits, for which it constitutes a pathfinder. Possible kimberlite indicator.	High values indicate may mafic or ultramafic rocks (in association with Cr, Ni, V etc.) or calcareous rocks (with Ba, Ca, Sr).
Al	Aluminum	13	*8.2%*	0.01%[1]	100 ppm[1]	N/A		Although most naturally-occurring Al resides in feldspars and their

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
								weathering and alteration products, it tends to correlate with elements such as Fe, Cr and V in weathered material subjected to partial digestion, and is thus an indicator of the presence of mafic rocks
P	Phosphorus	15	*0.1%*	0.001 to 0.01%[1]	N/A	N/A	As component of monazite [(Ce,La,Y,Th,Pr,Nd)PO_4] may serve as pathfinder for REE deposits	
K	Potassium	19	*1.5%*	0.01%[1]	N/A	N/A	May be enriched in hydrothermally-altered and mineralized rocks	Elevated values indicate presence of felsic rocks, esp. kaolinized intrusives
Ca	Calcium	20	*5%*	0.01%[1]	100 ppm[1]	1%	May be depleted in hydrothermally-altered and mineralized rocks	Indicative of calcareous rocks, especially in association with Sr, Mg and Ba
Sc	Scandium	21	*26 ppm*	0.5-5 ppm[1]	0.1 ppm[1]	0.1 ppm	None	None
Ti	Titanium	22	*0.7%*	0.01%[1]	10 ppm[1]	N/A	Possible kimberlite indicator.	Elevated values indicative of mafic rocks
V	Vanadium	23	*19 ppm*	1-2 ppm	10 ppm	N/A	Possible kimberlite indicator.	Elevated values indicative of mafic rocks
Cr	Chromium	24	*14 ppm*	1 ppm[1]	1 ppm[1]	10 ppm	Possible kimberlite indicator.	Elevated values indicative of mafic or ultramafic rocks; very low values may indicate presence of felsic rocks
Mn	Manganese	25	*1,100 ppm*	1-5 ppm	5 ppm	N/A	In association with Fe, Mn may indicate the effects of co-precipitation in soils and stream or lake sediments, and allow the screening of false anomalies of other elements	High values indicate mafic rocks but not as effective as Cr, Ni, V
Fe	Iron	26	*6.3%*	0.01%	0.01%	0.02%	Although Fe is enriched in a variety of mineral deposit types, it is rarely used as a pathfinder because of the	Indicative of iron-rich source rocks. Very low values may indicate presence of felsic rocks, esp.

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
							many masking effects of geological and surficial processes, and the superiority of other readily-analyzed elements. In association with Mn, Fe may indicate the effects of co-precipitation in soils and stream or lake sediments, and allow the screening of false anomalies of other elements.	kaolinized intrusives.
Co	Cobalt	27	*30 ppm*	1 ppm	0.05 ppm	1-5 ppm	Co deposits, and possibly "Red-Bed" Cu	Indicative of mafic rocks, though Cr and Ni are less ambiguous indicators
Ni	Nickel	28	*9 0ppm*	1 ppm	0.5 ppm	5-10 ppm	Usefulness as a pathfinder for magmatic nickel deposits limited by high background (Ni in silicate) values associated with host rocks (see Cu). Possible kimberlite indicator.	Elevated values indicative of mafic or ultramafic rocks. Very low values may indicate presence of felsic rocks
Cu	Copper	29	*68 ppm*	0.5-1 ppm	0.5 ppm	N/A	Indicator of Cu mineralization of any type; also important pathfinder for many types of gold deposit. Although further investigation is always justified, elevated Cu values are, however, more likely to indicate the presence of mafic rocks. Elevated Cu values may enable the discrimination of Ni anomalies associated with sulphide from those derived from unmineralized ultramafic rocks.	Indicative of mafic rocks, though Cr and Ni are less ambiguous indicators.
Zn	Zinc	30	*79 ppm*	0.5-2 ppm	1 ppm	50 ppm	For Zn mineralization, esp. if accompanied by Cd. False anomalies common	Elevated values more likely to be indicative of mafic rocks

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
As	Arsenic	33	*2.1*	2-5 ppm	N/A	2 ppm	Important pathfinder for gold.	None known
Se	Selenium	34	*50 ppb (0.005 ppm)*	N/A	0.4 ppm	5 ppm	Potential pathfinder for gold and base-metal sulphides if sensitive analytical method is used.	None known
Br	Bromine	35	*3 ppm*	N/A	N/A	1 ppm	None	As an indicator of presence of evaporites
Rb	Rubidium	37	*60 ppm*	N/A	0.05 ppm	5 pm	Specialized applications e.g. for Rb-rich pegmatites	Strongly associated with potassium. May serve as "potassium surrogate" if that element is not analysed.
Sr	Strontium	38	*360 ppm*	0.5-1 ppm	0.1 ppm	0.05%	None	Strongly associated with calcium. May serve as "calcium surrogate" to indicate presence of calcareous rocks, or evaporites
Y	Yttrium	39	*29 ppm*	0.5-1 ppm[1]	0.05 ppm[1]	N/A	As a pathfinder to various types of rare-earth element (REE) and rare-metal (RM) mineralization	Elevated values may be indicative of felsic rocks, esp. intrusives, of distinctive composition
Zr	Zirconium	40	*130 ppm*	0.5-5 ppm[1]	0.2 ppm[1]	50 ppm	As a pathfinder to various types of rare-earth element (REE) and rare-metal (RM) mineralization	Elevated values of total Zr indicative of felsic rocks, esp. intrusives. When analyzed by ICP methods, Zr may correlate with elements like Fe, Ni and Cr in some sample media.
Nb	Niobium	41	*17 ppm*	5 ppm[1]	0.05 ppm[1]	N/A	Elevated Nb values are associated with alkaline rocks, including potentially productive kimberlites and carbonatites,	See Applications in Mineral Exploration
Mo	Molybdenum	42	*1.1 ppm*	1 ppm	0.1 ppm	5 ppm	Pathfinder for gold under certain conditions, and for porphyry copper/gold mineralization.	None known
Ag	Silver	47	*80 ppb (0.008 ppm)*	0.2 ppm	0.02 ppm	5 ppm	Important pathfinder for most gold, silver, and Sedex or VHMS base-metal deposits	None known

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
Cd	Cadmium	48	*150 ppb (0.015 ppm)*	0.2-1 ppm	0.05 ppm	5 ppm	Elevated values generally indicative of sulphide mineralization. In association with Zn (especially), Pb, etc., strongly suggestive of the presence of Sedex or VHMS mineralization. Because of its strong chalcophile character (affinity for sulphur), Cd may be used to validate a questionable Zn anomaly.	None known
Sn	Tin	50	*2.2 ppm*	10-20 ppm	0.5 ppm	0.01%	None at typical concentration levels and detection limits	None at typical concentration levels and detection limits
Sb	Antimony	51	*200 ppb (0.02 ppm)*	2-5 ppm	0.05 ppm	0.2 ppm	One of the principal pathfinders for almost all varieties of gold deposits	None known
Te	Tellurium	52	*1 ppb*	10 ppm	N/A	5 ppm	None at typical concentration levels and detection limits. Important pathfinder for gold if more sensitive analytical method is used.	
Cs	Cesium	55	*1.9 ppm*	N/A	0.01 ppm[1]	1 ppm	As a pathfinder for Cs-rich (and possibly other) pegmatites	Elevated values may serve to "fingerprint" felsic intrusive (and possibly other) rocks of distinctive composition and origin
Ba	Barium	56	*340 ppm*	1-10 ppm[1]	1 ppm[1]	50 ppm	In association with Zn, Cd, Pb, anomalous Ba may indicate Sedex or VHMS mineralization	Elevated values may indicate presence of felsic rocks, especially kaolinized intrusives (in association with K), or calcareous rocks (in association with Ca, Mg, Sr)
La	Lanthanum	57	*34 ppm*	0.5 ppm[1]	0.05 ppm[1]	0.5 ppm	A relatively abundant and readily-analyzed pathfinder for most types of REE deposit Possible kimberlite indicator.	Elevated rare-earth values may be indicative of felsic rocks, esp. intrusives, of distinctive composition

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
Ce	Cerium	58	*60 ppm*	N/A	0.03 ppm[1]	0.5 ppm	A relatively abundant and readily-analyzed pathfinder for most types of REE deposit Possible kimberlite indicator.	See La
Pr	Praesodymium	59	*8.7 ppm*	N/A	0.05 ppm[1]			See La
Nd	Neodymium	60	*33 ppm*	N/A	0.1 ppm[1]			See La
Sm	Samarium	62	*6 ppm*	N/A	0.05 ppm[1]	0.1 ppm	A relatively abundant and readily-analyzed pathfinder for most types of REE deposit Possible kimberlite indicator.	See La
Eu	Europium	63	*1.8 ppm*	N/A	0.05 ppm[1]	0.2 ppm		See La
Gd	Gadolinium	64	*5.2 ppm*	N/A	0.05 ppm[1]			See La
Tb	Terbium	65	*0.9 ppm*	N/A	0.02 ppm[1]	0.2 ppm	A readily-analyzed pathfinder for most types of REE deposit, especially heavy REE Possible kimberlite indicator.	See La
Dy	Dysprosium	66	*6.2 ppm*	N/A	0.05 ppm[1]			See La
Ho	Holmium	67	*1.2 ppm*	N/A	0.01 ppm[1]			See La
Er	Erbium	68	*3 ppm*	N/A	0.01 ppm[1]			See La
Tm	Thulium	69	*450 ppb (0.045 ppm)*	N/A	0.005 ppm[1]			See La
Yb	Ytterbium	70	*2.8 ppm*	N/A	0.02 ppm[1]	0.2 ppm	A readily-analyzed pathfinder for most types of REE deposit, especially heavy REE Possible kimberlite indicator.	See La
Lu	Lutetium	71	*560 ppb (0.056 ppm)*	N/A	0.005 ppm[1]	0.05 ppm	A readily-analyzed pathfinder for most types of REE deposit, especially heavy REE Possible kimberlite indicator.	See La
Hf	Hafnium	72	*3.3 ppm*	N/A	0.05 ppm[1]	1 ppm	As a pathfinder for Hf-rich (and	Elevated values indicate the presence

Element Symbol	Element Name	Atomic No.	*Crustal Abundance*	Typical Detection Limits			Applications	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
							possibly other) pegmatites	of felsic rocks, esp. intrusives
Ta	Tantalum	73	*1.7 ppm*	N/A	0.02 ppm[1]	1 ppm	For Ta-rich pegmatites or carbonatites	For Ta-rich pegmatites or carbonatites
W	Tungsten	74	*1.1 ppm*	10 ppm[1]	0.05 ppm[1]	1 ppm	Important pathfinder for many types of gold deposit, and for deposits of tungsten itself	None known
Ir	Iridium	77	*0.4 ppb*	N/A	N/A	5 ppb	Potential pathfinder for PGE (platinum-group elements) deposits	None known
Au	Gold	79	*3.1 ppb*	2-5 ppb[3]	0.005 ppm	2-5 ppb	Important pathfinder for gold; usefulness limited by "nugget effect" in most natural media. Supporting anomalies of pathfinders such as As, Sb etc., are highly desirable.	None known
Hg	Mercury	80	*67 ppb (0.007 ppm)*	1 ppm	0.05 ppm	1 ppm	None at typical concentration levels and detection limits. Important pathfinder for gold, especially in younger rocks, and base-metal sulphides, if more sensitive analytical method is used.	None known
Tl	Thallium	81	*530 ppb (0.053 ppm)*	10 ppm 0.05	0.005 ppm	N/A	None at typical concentration levels and detection limits. Important pathfinder for gold, especially in younger rocks, if more sensitive analytical method is used	None known
Pb	Lead	82	*10 ppm*	1-2 ppm	0.05 ppm	N/A	Pathfinder for Sedex and VHMS deposits, and also for gold under some conditions	None known
Bi	Bismuth	83	*25 ppb (0.003 ppm)*	2-5 ppm	0.01 ppm	N/A	Common accessory element in many sulphide-rich deposits but has few advantages as a pathfinder over more abundant and more easily-analyzed	None known

Element Symbol	**Element Name**	**Atomic No.**	***Crustal Abundance***	**Typical Detection Limits**			**Applications**	
				ICP-OES	**ICP-MS**	**INAA**	**Mineral exploration**	**As an aid to geological mapping**
							elements	
Rn	Radon	86		N/A	N/A	N/A	As a gaseous and highly mobile decay product of uranium, radon is an important pathfinder for this element in areas of overburden cover.	Leakage anomalies may aid in the location or extrapolation of faults
Th	Thorium	90	*6 ppm*	2 ppm[1]	0.05 ppm[1]	0.5 ppm	Possible pathfinder for rare earths	Elevated values indicate presence of felsic rocks, especially intrusives
U	Uranium	92	*1.8 ppm*	5-10 ppm[1]	0.05 ppm[1]	0.5 ppm	For uranium mineralization	Elevated values indicate presence of felsic rocks, esp. intrusives

1: Some or most minerals containing this element resist strong-acid digestion. Therefore, analysis may not be total

2: May not be a useful pathfinder even in deposits of the element itself

3: Requires preconcentration by fire-assay or MIBK.