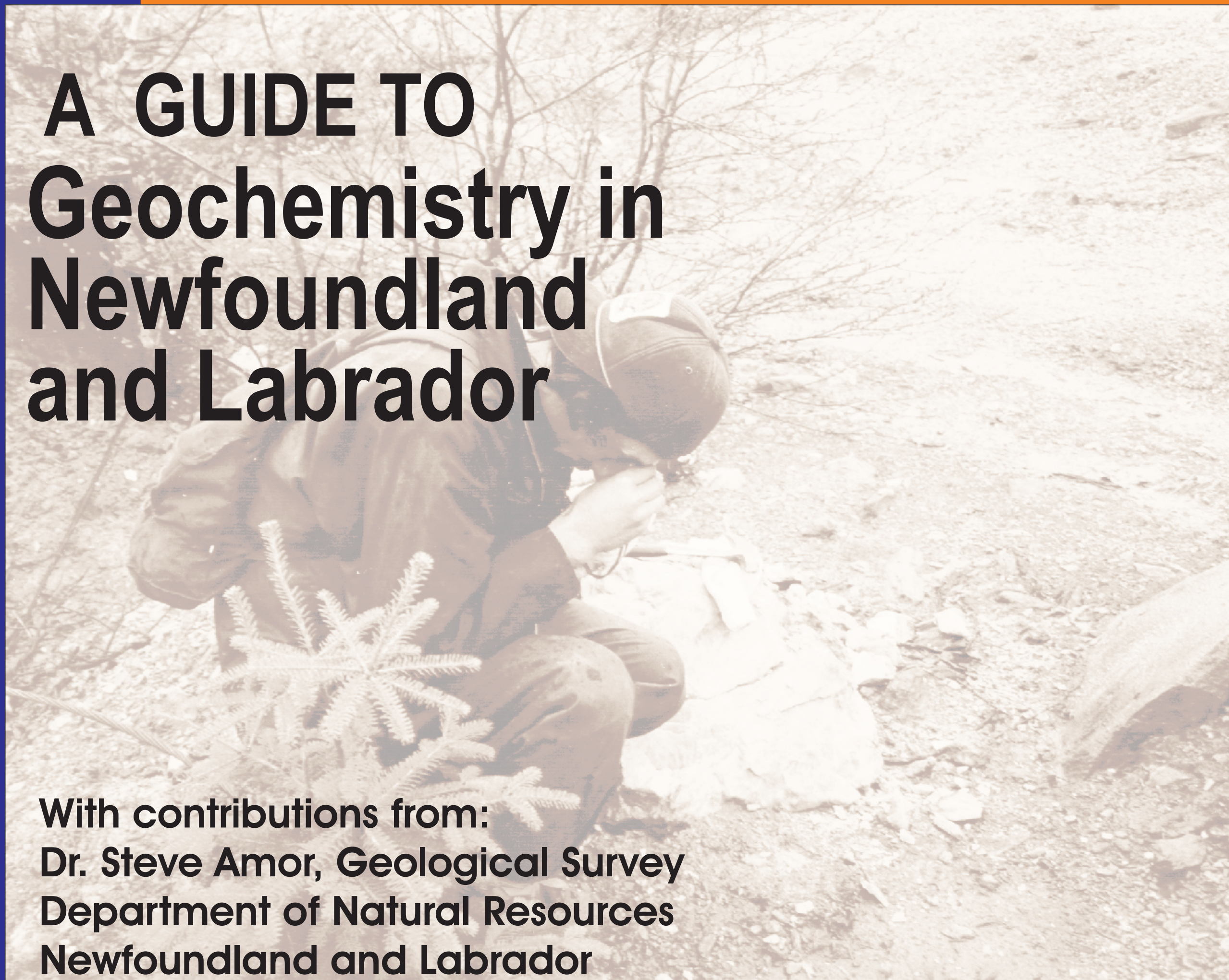

A GUIDE TO Geochemistry in Newfoundland and Labrador

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Information Circular Number 6

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What is Geochemistry?

Geochemistry is the study of the chemistry of rocks and any naturally-occurring material that is derived from them, e.g. soils. In terms of its use for the prospector, geochemistry looks at the distribution and amounts of elements in these materials, and their relation to nearby mineral deposits. Prospectors using geochemistry may collect rock, soil, stream or lake sediment samples; even material left behind by glaciers of the last ice age can be sampled. These samples are then usually sent off to a commercial laboratory for analysis. Various techniques are used by these laboratories to measure the abundance, or concentration of elements contained in the sample of rock, soil or other natural material, and sometimes just a few parts per million of an element may be of interest to the prospector. Geochemical analyses are used extensively in mineral exploration to assist prospectors to find poorly exposed or buried ore deposits. To understand how geochemistry is used in prospecting, let's start with some basics.

What are Elements and Minerals?

A ***chemical element*** is a pure substance consisting of **one type of atom** (the building block of nature) that cannot be broken down into a different substance by chemical means. One needs a nuclear explosion to break up elements (or atoms)! Common examples of elements are oxygen, hydrogen, gold (Figure 1), carbon, nitrogen and silver. In total, 117 elements have been found as of 2010, of which 94 occur naturally in the Earth's crust. A **metal** is a chemical element that is a good conductor of both electricity and heat, and usually has a shiny appearance or lustre. Most metals are malleable and ductile and are, in general, denser (heavier) than the other elemental substances.

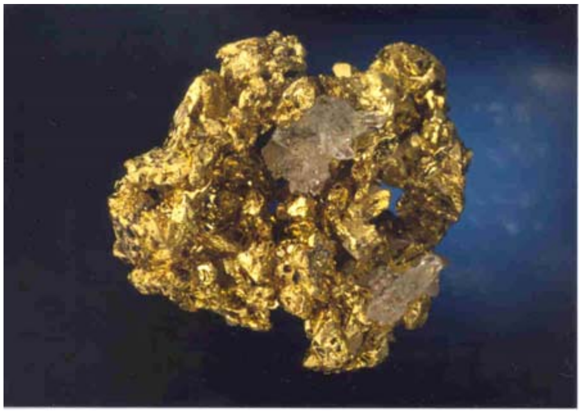


Figure 1:
Gold – a metallic element

Sulphur - a non-metallic element

Generally, prospectors explore for rocks which contain economic deposits of metals. The periodic table of the chemical elements is a tabular method of displaying these elements (Figure 2). A quick look at this table reveals that the majority of the elements are various types of metals. Most of these have some economic value, so prospectors have a great variety of metals to look for. When elements combine in nature, a ***mineral*** is formed. A mineral is any naturally occurring, solid substance having a definite chemical composition and characteristic crystalline structure, colour and hardness. Not all minerals are exploited economically. A typical well-known mineral is pyrite, a combination of iron and sulphur, also known as “fool’s gold”.

At present there are over 3,800 known minerals but prospectors need only be familiar with about 20 of these. Prospectors hunt for rocks containing economic minerals such as chalcopyrite, or other minerals containing base or precious metals, or for gemstones.

Most minerals are combinations of several metallic and non-metallic elements, for example chalcopyrite, chemical formula $CuFeS^2$ (copper (Cu), a metal, Iron (Fe), a metal and sulphur (S), a non-metal (Figure 1)). A metal that occurs naturally in an uncombined state is called a ***native*** metal. Most precious metals, like gold, silver, and platinum occur commonly in the native state, while most base metals do not, although there are exceptions , for example copper and bismuth.

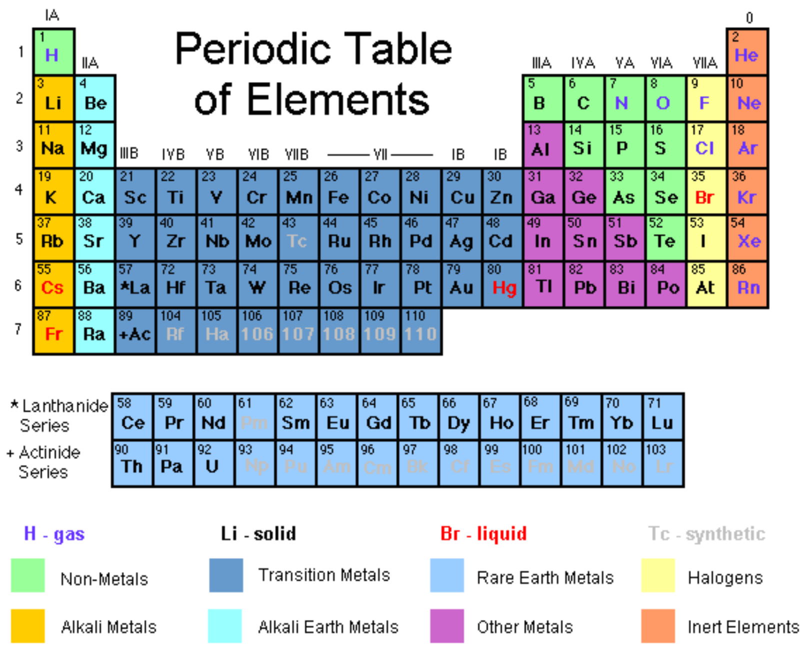


Figure 2

Source: http://www.corrosionsource.com/handbook/periodic/periodic_table

Why use Geochemistry?

To find Minerals! Geochemistry is a tool, just like geophysics or geology, to find interesting minerals and ore deposits. Hence it is important for prospectors to gain an appreciation of the meaning of geochemical terms such as "background", "anomaly" etc. Metals occur in tiny amounts in rock and soil. The amounts of the metals that are normally present in rock or soil are called ***"background levels"*** and have been calculated by geochemists using tens of thousands of analyses of various un-mineralized rocks from around the world (Table 1). In very simple terms, the background is an average value for un-mineralized rocks. We can see from Table 1 that, for example, gold has a background /average value of 4 parts per billion (ppb). If your rock sample was analysed by a commercial lab and shown to contain, say, 160 ppb Au, (40 times the background) the sample would be considered anomalous (in other words, having higher than background levels of gold – see below for explanation). This would encourage you to "follow up", by returning to that location and taking some more samples. Speaking of terms, what does "ppb" mean?

Units of measurement

Refer to Appendix 4 for an overview on Units of Measurement such as parts per million (ppm), parts per billion (ppb), ounces per ton, grams per tonne (g/t) and so on.

Distribution of elements in the earth's crust

The most abundant element in the earth's crust is oxygen, making up 46.6%. Silicon is the second most abundant element (27.7%). Both of these elements are non-metals. They are followed by aluminum (8.1%), iron (5.0%), calcium (3.6%), sodium (2.8%), potassium (2.6%). and magnesium (2.1%), all of which are metals. These eight ***Major*** elements account for approximately 98.5% of the total mass of the earth's crust. This means that the other 86 naturally occurring elements make up just 1.5% of the crust – in terms of looking for metallic ores, we really are looking for needles in a haystack. ***Minor*** elements such as titanium and manganese make up a significant fraction of the remaining 1.5% and are generally between 0.1 and 1%.

Table1: Abundance levels or Background of minor and trace elements in common rocks

Element Name	Element Symbol	Unit	Crust	Mafic	Intermediate	Felsic	Shale	Black Shale	Sandstone	Limestone
Antimony	Sb	ppm	0.2	0.2	0.2	0.2	1		<0.1	0.2
Arsenic	As	ppm	1.8	2	2	1.5	15		1	2.5
Barium	Ba	ppm	425	250	500	600	700	300-700	10-100	100
Beryllium	Be	ppm	2.8	0.5	2	5	3		0.1-1.0	1
Bismuth	Bi	ppm	0.17	0.15		0.1				
Cadmium	Cd	ppm	0.2	0.2	0.2	0.2	0.2		<0.1	0.1
Cerium	Ce	ppm	60	35	40	46	50		90	10
Chromium	Cr	ppm	100	200	20	4	100		35	10
Cobalt	Co	ppm	25	50	10	1	100	10-20	35	10
Copper	Cu	ppm	55	100	30	10	50	70-150	10	15
Fluorine	F	ppm	625	400	500	735	740		270	330
Gold	Au	ppb	4	4	4	4	4			4
Lead	Pb	ppm	13	5	15	20	20	20-70	7	8
Lithium	Li	ppm	20	10	25	30	60		15	20
Manganese	Mn	%	0.1	0.13	0.11	0.02	-	-	-	0.05
Mercury	Hg	ppm	0.08	0.08	0.08	0.08	0.5		0.07	0.05
Molybdenum	Mo	ppm	1.5	1	1	2	3	10	0.2	1
Nickel	Ni	ppm	75	150	20	0.5	70	50-200	2	12
Niobium	Nb	ppm	20	20	20	20	20		<1	0.3
Phosphorus	P	%	0.1	0.19	0.24	0.06	0.09	0.17	-	0.02

Element Name	Element Symbol	Unit	Crust	Mafic	Intermediate	Felsic	Shale	Black Shale	Sandstone	Limestone
Platinum	Pt	ppb	20	200		80				
Selenium	Se	ppm	0.05	0.05		0.05	0.6			0.08
Silver	Ag	ppm	0.07	0.1	0.07	0.04	0.05	<1-5	<0.01	1
Tellurium	Te	ppb	10	10	10	10	100			
Thorium	Th	ppm	10	2	10	17	12		2	2
Tin	Sn	ppm	2	1	2	3	4		<1	4
Titanium	Ti	%	0.4	1.3	0.85	0.15	0.54	0.05	0.01	0.06
Tungsten	W	ppm	1.5	1	2	2	2		1.6	0.5
Uranium	U	ppm	2.7	0.6	3	4.8	4	3-1,250	0.45-3.2	2
Vanadium	V	ppm	135	250	100	20	130	150-700	20	15
Zinc	Zn	ppm	70	100	60	40	100	<300-1000	16	25

Terms: Crust refers to the rock beneath our feet – the crust or skin of the earth. Mafic refers to mafic (rich in magnesium and iron) igneous rocks; examples are basalt and gabbro. Felsic refers to felsic (rich in feldspar and silica) igneous rocks; granites and rhyolites are examples. Intermediate refers to rocks intermediate in chemistry between mafic and felsic, for example diorite. Shale is essentially a mudstone that has been cooked a bit in the earth's crust. Black Shale is formed in low oxygen conditions and is unusually rich in carbon and sulphur. Sandstone is a common sedimentary rock and limestone is another common sedimentary rock rich in calcium carbonate and/or remains of shells.

Table 1 (Cont.) Abundance levels or Background of common elements in common rocks

Element Name	Element Symbol	Unit	Crust	Mafic	Intermediate	Felsic	Shale	Black Shale	Sandstone	Limestone
Oxygen	O	%	46.6	40.6	42.8	47.1	52.1	49.2	53.2	46.8
Silicon	Si	%	27.7	19.4	20.7	30.0	28.1	25.4	45.3	2.9
Aluminum	Al	%	8.1	10.3	12.6	10.5	7.1	6.4	0.56	0.43
Iron	Fe	%	5.0	18.1	13.6	3.2	6.3	8.0	0.47	0.60
Calcium	Ca	%	3.6	5.7	4.3	0.66	2.1	0.49	0.30	33.7
Magnesium	Mg	%	2.1	2.1	1.4	0.11	1.0	0.55	0.03	3.8
Potassium	K	%	2.6	0.87	1.2	6.1	2.2	2.2	0.06	0.25
Sodium	Na	%	2.8	1.4	2.3	2.0	0.51	0.17	0.07	0.02
Carbon	C	%	-	-	-	-	-	3.3	-	11.5
Sulphur	S	%	-	-	-	-	-	4.1	-	-

The rest of the elements, including most of the metals sought by prospectors, are referred to as ***Trace*** elements. These are generally even rarer at less than 0.1 %. However, on the bright side, Newfoundland and Labrador, because of their particular geological makeup, has been well endowed with mineral deposits where these metals are strongly enriched, and there is much fertile ground out there yet waiting to be prospected.

How to assess your assay results

Once you receive your first set of lab results with all those numbers and strange abbreviations, the next task is to interpret them.

A typical package of results might include analyses for more than 30 different elements including ***"base" metals***, that is, those metals that are basic to everyday living and ***precious metals*** such as gold and silver. Elements commonly analyzed include:

Au	Gold	Ce	Cerium	Sr	Strontium
Ba	Barium	Fe	Iron	P	Phosphorus
Hg	Mercury	Mg	Magnesium	As	Arsenic
V	Vanadium	Na	Sodium	Mo	Molybdenum
Al	Aluminum	Be	Beryllium	Ca	Calcium
Zn	Zinc	Cu	Copper	Sb	Antimony
Ag	Silver	Pb	Lead	Bi	Bismuth
Ti	Titanium	Cd	Cadmium	Co	Cobalt
Ni	Nickel	W	Tungsten	La	Lanthanum
K	Potassium	Mn	Manganese	Sn	Tin
Cr	Chromium				

Most of these elements are metals and are of economic importance. Other metals which are of economic interest include the Platinum Group of metals and Rare Earth Elements (See Appendix 3). Those which are commonly found in Newfoundland and Labrador and are of most interest to exploration companies are highlighted in red. Some of the 31 elements, shown in blue, (e.g. K) are relevant because enrichment or depletion of these metals (above or below the element's crustal abundance) may indicate the presence of ***alteration*** of the rocks, which in turn is suggestive of certain types of mineralization. Certain other elements shown in green are called ***pathfinder*** elements, because they are commonly associated with economic minerals, without being economically interesting themselves. One notable exception is Sb which is produced at the Beaver Brook Antimony Mine near Gander. Beaver Brook is the only operating Sb mine in North America, and is one of the world's largest antimony deposits outside of China. Another useful element is As, which is commonly used as a pathfinder for Au.

The amount of the element present in the rock is indicated in ***ppb, ppm or %,*** as defined in Appendix 4. This is the unit of measurement given in the third column of Table 1. Some metals, e.g. gold, are present in very small amounts in the earth's crust and their concentrations are listed as parts per billion. The fourth column, "Crust" refers to the average crustal abundance of the element. Other elements, e.g iron, are present in major amounts in the earth's crust and are measured in per cent. The analytical package will usually show iron as being present in amounts from 0.5% to 10% in most naturally-occurring material. In rocks referred to as Iron Ore, the percentage of iron would be between 30 to 60 % generally.

Now we have to determine if the analytical results for the elements are promising or not. To do that, we need to know what is anomalous and what is background.

The calculation of background values for the elements, as described above, is slightly complicated by the fact that the abundance may vary from rock type to rock type. A good example of this would be the element nickel (Ni); the normal abundance or background of Ni in granitic rocks is approximately 1 ppm, but in ultramafic rocks (which are quite common in Newfoundland and also characterized by high levels of magnesium and iron), a typical background level would be 2000 to 2500 ppm – quite a difference! The ***average crustal abundance*** of Ni is 75 ppm.

Table 2 is a short list of the background levels for some common metals and what would be considered anomalous in rocks and soils.

Table 3 shows the partial lab results from a laboratory based in Newfoundland and Labrador. Note that a couple of analyses have the "less than" (<) sign in front of them. This shows that these samples contained so little of the element in question that the equipment used for analysis was unable to detect it.

Element	Crustal Abundance	Typical Anomalous Concentration in Rocks (ppm)	Typical Anomalous Concentration in Soils (ppm)
Au	4 ppb	50 – 100 ppb	40 – 100 ppb
Ag	70 ppb	0.5 – 1	0.2 – 0.5
Cu	55 ppm	100 – 200	50 – 200
Pb	13 ppm	40 – 100	40 – 100
Zn	70 ppm	100 – 500	200 – 300
Mo	1.5 ppm	5 – 20	2 – 5
W	1.5 ppm	10 – 50	2 – 10
Ni	75 ppm	100 – 200	100 – 200
As	1.8 ppm	5 – 10	5 – 20

Table 2: Common metals and their abundances

These results allow the prospector to decide whether further work is required. To make that decision, the prospector needs to have an appreciation of what are "background" and "anomalous" levels for various elements in various types of environment e.g. rock, soil, stream and lake sediment, and till. To give an example, 10 ppb gold may not be anomalous from a rock sample, but may be significant if it is from a till sample.

The cut-off between background and anomalous values, for a particular element in a particular sample medium, is referred to as the ***Threshold***. Estimation of the threshold for a particular element can be kept very simple, by assigning a single value for any sample type (soil, lake sediment, etc.), wherever it is collected, following up all values that exceed it and rejecting all values that do not. Some prospectors prefer to keep it that way. For more detail on threshold values, see Appendix 1.

				Au Fire Assay/ICP Geochemistry Certificate				
Client:	Mr./Mrs Prospector							
Geologist:						Eastern Analytical Limited		
Project:	The Big Kahuna					P.O. Box 187		
Sample:	Rock					Little Bay Road		
						Springdale, NL		
DskFile:						A0J 1T0		
DateIn:						Phone: 709-673-3909		
DateOut:						Fax: 709-673-3408		
				Email:easternanalytical@nf.aibn.com				
Sample Number	Au ppb	Ba ppm	Fe %	As ppm	Na %	Mo ppm	Al %	Zn ppm
MIP-2009-1	5	10	0.26	>2200	0.11	10	0.03	3
MIP-2009-2	<5	34	2.17	5	0.15	<1	1.10	14
MIP-2009-16	38	32	1.38	5	0.16	1	0.39	39
MIP-2009-21	102	30	2.01	220	0.16	5	0.23	22
MIP-2009-22	44	10	5.91	5	0.18	>220	1.22	17

Table 3: Typical (partial) rock assay

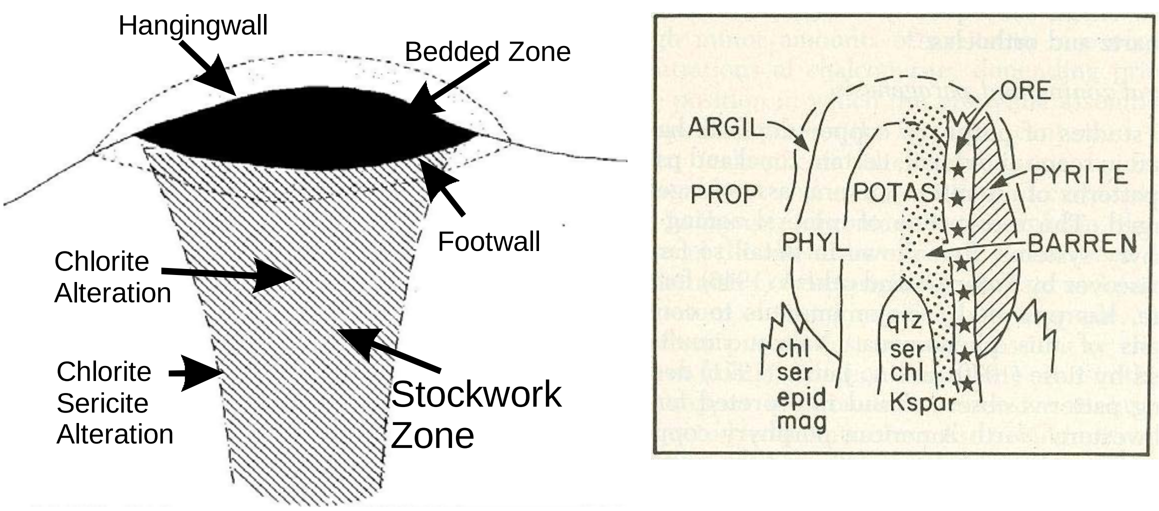
Let's look at anomalous values in Table 3 again.

Gold and Arsenic (Au and As): Two gold values of 5 or less than 5 (< 5) can be ignored as they are normal or background levels. Three values are of interest: two at 38 and 44 ppb are what could be termed slightly anomalous levels and worth following up. The value of 102 ppb is definitely anomalous (see Table 2) and would have a high priority in terms of follow-up. Note also that As levels at 220 ppm are also elevated for that sample which makes it even more interesting. Now let's look at sample MIP-2009-1: Although Au is only 5 ppb, As is extremely anomalous at > 2200 ppm (greater than 2200) (you may see arsenopyrite crystals, needles and cubes, in the specimen). Now, we know that As is a pathfinder for gold, so there are two ways of looking at this result. One is that there is simply no Au in the area (because As need not indicate the presence of Au 100% of the time). Secondly, we may be seeing the result of the ***"Nugget Effect".*** The erratic and localized nature of gold is a common feature of many vein-style gold deposits. This style of mineralization is often referred to as being nuggety or possessing a high-nugget effect. In other words, gold grains may be very scattered throughout the rock. A prospector may pick a sample that has no gold grains in one part of the outcrop (result 5 ppb Au in the assay) and take a second sample from a foot away and get several thousand parts per billion Au in the assay. The high level of As in the case of sample MIP-2009-1, may be telling the prospector that this is an example of the nugget effect.

Molybdenum (Mo): Mo (background crustal abundance = 1.5 ppm) is elevated in one sample at > 220 ppm. Note that gold is also elevated in this sample. As a prospector, you would definitely follow up this result by further sampling. Gold and molybdenum can occur together in porphyry deposits, for example.

Dispersion and Alteration

Most, but not all, mineral deposits or ore bodies are surrounded or flanked by a zone in which the concentration level of certain metals is above normal. In geo-chemical jargon, this zone is referred to as a ***dispersion halo*** because the metallic elements have become dispersed from the central mineralization (the ore body) by various chemical means. A dispersion halo that forms at the same time as the mineral deposit itself, in the rocks that surround the deposit, is called a ***primary halo***. The dispersion of the elements into a primary dispersion halo may cause the minerals in the wallrocks to change into different minerals. This is known as ***alteration***. Alteration minerals are often quite distinctive; for example, zinc-lead-copper ore bodies like those which were mined at Buchans usually have alteration zones dominated by chlorite (called ***chloritization)***, which turns the rock dark green, or sericite (called ***sericitization)***, which turns it pale grey or white. Even if these minerals cannot be observed directly, the alteration can often be detected by observing chemical changes in the wall rocks, with chloritization being accompanied by an increase in magnesium and iron, and sericitization accompanied by an increase in potassium and a decrease in sodium.



Examples of alteration zones around a massive sulphide deposit. One zone envelopes the ore body, while the other is concentrated in the footwall (below the ore body) only.

Alteration zones around a porphyry copper deposit. PROP=propylitic alteration (epidote-chlorite-pyrite-carbonate); ARGIL=argillic alteration (clay minerals); PHYL=phyllic alteration (quartz-sericite-pyrite); POTAS=potassic alteration (potassium feldspar and biotite)

Figure 3: Alteration patterns

If the ore body were completely exposed at the surface of the earth, we might stumble onto its dispersion halo first, particularly because dispersion haloes are always larger than the ore bodies themselves (so essentially, the exploration target has become much larger and easier to find). However, a dispersion halo may be exposed at surface even when the ore body is not (this is called a ***"blind" ore body***). Therefore, it is helpful to recognize the various types of dispersion haloes or alteration patterns (Figure 3 shows some examples).

Examples of deposits that have extensive alteration zones that can be used to locate them are volcanogenic massive sulphide (VMS) deposits of copper, zinc and lead like Buchans; epithermal gold deposits like Hope Brook, and the huge porphyry copper-gold-molybdenum deposits in western North and South America.

Though rare in the east, several porphyry copper-molybdenum-gold type deposits are currently being explored in Newfoundland, for example the Moly Brook, molybdenum-copper-gold Prospect (Creston Moly Corp.) on the south coast of the island and the Mosquito Hill gold Prospect (Golden Dory Resources and Paragon Minerals) in Central Newfoundland. Deposits that have no associated alteration include magmatic deposits of nickel and copper, like Voisey's Bay, and deposits hosted in clastic sedimentary rocks, like the very rich gold-uranium deposits of the Witwatersrand in South Africa.

If a mineral deposit or ore body is at or near the surface of the earth, the metallic elements that are part of that deposit and its primary dispersion halo can be mobilized after the formation of the rocks by simple weathering, leaching and groundwater action. Elements are moved from the mineralization into the rocks or the soil and even into plants and water bodies such as lakes in the vicinity of the deposit. These haloes are called ***secondary dispersion haloes*** and occur over a much bigger area than the original ore body, or the primary dispersion halo.

RELATIVE MOBILITY	Oxidizing conditions (Near surface)	Reducing conditions (At depth)
Mobile	Na, Mg, F, Sr, Zn, U, Mo, V	Ca, Na, Mg, F, Sr, Mn, Zn, Cu, Ni, Pb, Cd
Slightly mobile	K, Mn, Pb, Ni, Cu, Co, As, Cd, Ag	Fe, Co, Ag, K, As, Ag
Immobile	Fe	U, Mo, V

Table 4: Mobility of Elements

They are, therefore, that much easier to find (Figure 3). The mobility of some common elements is shown in Table 4.

Geochemical Surveys

Modern exploration geochemical surveys sample a variety of materials from rocks, soil gases, vegetation, waters and stream and lake sediments. The aim of the survey is to detect dispersion haloes (or actual ore bodies) as described above, where metals occur in above average or anomalous amounts and assist in "zeroing in" on the target.

Types of Geochemical Surveys

Soil Surveys

Soil surveys (Figure 4) are one of the most frequently used surveys by prospectors in the search for minerals and are useful in defining patterns of anomalous levels of metallic elements, at the scale of most prospectors' properties. The term "soil" is used here in the broad sense and includes soil formed by the breakdown of the underlying bedrock, or of till, a transported material left behind after the retreat of the glaciers in the last ice age, approximately 10,000 years ago (see below). Soils typically display 3 principal layers or horizons (Figure 5). The A horizon at the top is composed of an upper layer of humus or topsoil, normally black, consisting of decaying vegetation, and a lower, grey, leached layer (the Ae horizon). The underlying B horizon is normally reddish brown and is typically rich in iron and other metals. It represents material from the C horizon below, with material leached from the A horizon above added to it. The B horizon may also contain clay minerals, iron and organic material. This is the best horizon from which to take soil samples as it represents a zone of enrichment where metals from both the A and C horizons have been preferentially concentrated.

Figure 4: Soil sampling using an auger

Lake sediment sampling using a "Hornbrook bomb" shown in detail at the bottom.

The C horizon consists of relatively unweathered source material of the Ae and B horizons. This may be bedrock but in Newfoundland and Labrador, it most commonly consists of glacial sediment from the last Ice Age. It is usually grey or greenish grey, though its colour depends on the rock that it is derived from.

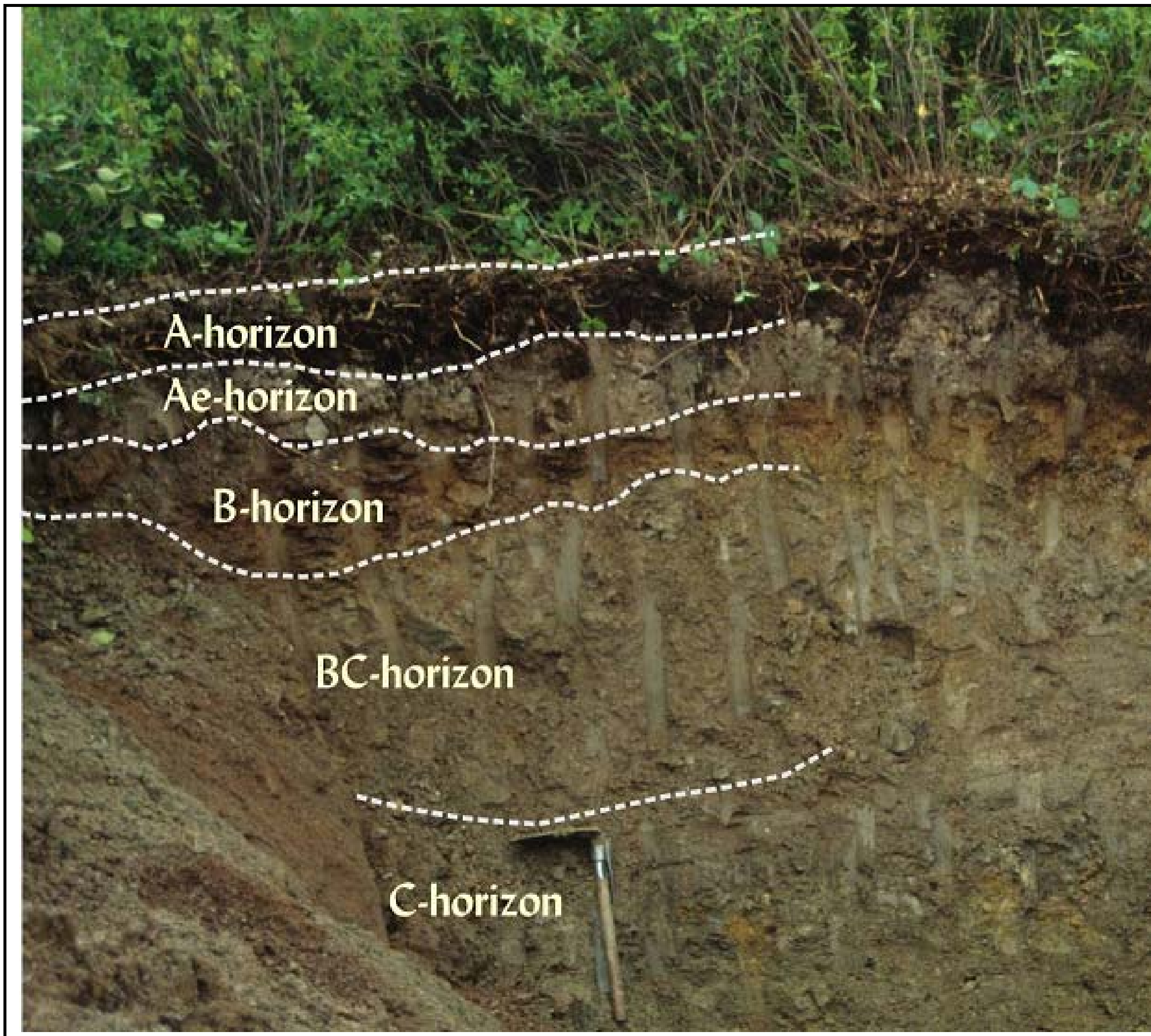


Figure 5: Typical Newfoundland soil profile, showing the organic A-horizon, the pale grey, metal-depleted Ae-horizon, the metal-enriched B horizon, the intermediate BC-horizon and the C-horizon that represents the relatively-unweathered rock from which the soil is derived.

When conducting a soil survey, it is important to try to collect all of your samples from the same horizon so that the differences in composition between the different soil horizons do not swamp the differences that are due to dispersion from a mineral deposit. Also, remember that in Newfoundland and Labrador most soils are derived from glacial tills that will not directly overly the bedrock that they are derived from (see below).

Rock, Till, Stream and Lake Sediment Surveys

Rock Geochemical Surveys

If bedrock exposure is good on your prospect, sampling the rocks themselves is a good prospecting tool. This may seem obvious, but bear in mind that the primary dispersion halo from a mineral deposit may be much larger than the deposit itself, and may be exposed at surface even when the mineralized zone itself is not. The variations in the content of certain elements, especially major elements, between different rock types may be as great as or greater than those resulting from alteration around a mineral deposit, so it is important to record the rock type for each sample if you can.

Figure 6: Geologist on the rocks! Channel sampling

Some of the questions that prospectors ask frequently include:

- How big a sample should I take?
- Haw many samples do I take from one outcrop?
- Do I sample all the rocks in an outcrop or just some?
- Is it OK to include the weathered surface in my sample?

In terms of sample size, always take a minimum fist-size grab sample. Usually, one sample from the outcrop is sufficient, particularly if the mineralization is visible and you know you are getting a representative sample. On your first visit to an outcrop, just sample the rocks that you suspect contain mineralization. Weathered surfaces are usually quite thin and if they represent only a tiny fraction of the entire sample, then you can safely ignore them. When taking rock samples, avoid leaving clay or dirt on the sample – wash it off, it may contaminate your results! Also, avoid wearing gold or other jewellery, especially rings since an accidental contact will contaminate your sample. Grab samples, chip samples and channel samples (Figure 6) are some of the sample types that a prospector will take. Refer to the "Prospecting In Newfoundland and Labrador Guide" for more information.

Of course, you may be lucky enough to work a prospect where mineralization is exposed at surface. If it consists of metallic sulphides (like most deposits of copper, lead, zinc and nickel, and many precious-metal deposits too) they will almost certainly have oxidized to a greater or lesser extent (Figure 7). Sometimes the oxidized minerals will form a stain with a distinct colour, like the turquoise colour of a copper bloom, the pink cobalt bloom, the green nickel bloom or the yellow uranium bloom. Sometimes the staining will just be a variety of browns, yellows and greens – prospectors and geologists call this a "sulphide burn".

A rock that consists of nothing but sulphide ("massive" sulphide) will, when weathered, be converted to oxides of the metals that were originally present as sulphides. As sulphides of iron are predominant in most massive sulphide deposits, the resulting weathered material, which is called a "gossan" (Figure 8), is characteristically yellow and brown from the iron oxides the rock originally contained, although it may also display the characteristic "bloom" colours of copper, nickel or other metals. Chemical analysis of the gossan will give some clue as to what other metals it contains, although such analyses may

Copper bloom (malachite), Labrador

Cobalt Bloom (erythrite), unknown location

Nickel bloom (annabergite), Finland

Uranium bloom (torbernite and saleeite), Uranium City, Saskatchewan

Sulphide burn, near Stewart, BC

Figure 7: Mineral Stains

Gossan, India

Gossan, Nunavut

Figure 8: Gossans

not be entirely reliable since some of the valuable metals may have been leached away by the weathering process (usually, most of the gold, if present, is left behind!). Also, a number of iron-rich rocks that look like gossans, are not derived from sulphides. In warm climates, gossans can go down tens or even hundreds of metres before passing out of the weathered zone and into fresh sulphide rock. However, they are a useful indicator of sulphide or precious-metal mineralization, either in place or as loose boulders, even in northern Canada.

Till Geochemical Surveys

Much of Newfoundland and Labrador is covered by deposits of sediment left behind by melting ice sheets at the end of the last ice age. These deposits can completely cover the bedrock surface, in some cases to depths of hundreds of metres. However, depending on how they were deposited, they can be a useful prospecting tool. Of the many different glacial sediment types, the most useful (and one of the most common) is “till” (or, more specifically, “basal till”). This is material that is scraped from the bedrock by a moving ice sheet, and redeposited some distance “down ice”. The transportation distance of material eroded in this way can be as little as a few tens of metres, or many kilometres.

The tracing of mineralized boulders (float), picked up in till, back “up ice” to their bedrock source, is a prospecting technique that has been used successfully in Newfoundland and Labrador for many years and is called drift prospecting. The tracing of the source of geochemical anomalies in till makes use of the same principles and requires the same information: you need to know in what direction the ice was moving when the bedrock was eroded and redeposited as till, and you need to have some idea of the transportation distance. Geologists can get some idea of ice movement directions from striations on bedrock surfaces, from “crag and tail” features in the landscape, and other methods. A striation database for the island of Newfoundland is available from the Geoscience Atlas of the provincial geological survey. Data for Labrador are sparser. As for the transportation distance, you can get some idea of this by looking at the boulders and pebbles in the till and comparing them to local bedrock types. Angular boulders generally have travelled only short distances from their source whereas rounded boulders may have travelled hundreds of kilometres from source. The largest boulders are often the ones that have travelled the furthest, however, so you should be prepared to wash some of the smaller fragments and examine them too, because they may be more local.

When sending samples of till to the lab it is customary to request either that they be sieved to minus (less than) 80 mesh (0.177 millimetre) or minus 230 mesh (0.063 millimetre) as these fine fractions provide the best contrast between background responses and those derived from mineralization. They can also be panned, but manual panning of tills is difficult and time-consuming and it is preferable to do it mechanically. The panned concentrates can be analyzed chemically, or examined under the microscope for gold, sulphides and other indicator minerals.

Stream Sediment Geochemical Surveys

Presently, little stream sampling is carried out in Newfoundland and Labrador. A number of companies, including Noranda, did carry out a lot of stream sediment sampling in the 1970's and 1980's. The composition of a stream sediment sample reflects the composition of all of the rocks that have been eroded in the stream's catchment basin. In areas where there is a well-defined drainage system stream-sediment sampling offers a useful regional exploration technique; anomalies thus identified are normally followed up by prospecting and soil sampling in the stream's catchment area to pin down their bedrock source.

As with till sampling, the fraction of the stream sediment that is most useful to the prospector is either the fine fraction (less than 80 or 230 mesh) or the panned concentrate (although the best place in the stream bed to collect a sample is different for the two sample types: conventional stream-sediment samples should be collected where the sediment is finest, while panning is best done on material from gravel bars). Panning of stream sediments is easier than panning tills because plentiful water is available and because if you pick your site carefully, the stream will have done a lot of the work (of concentrating the heavy minerals) for you. Successful panning is an art that requires a good deal of practice, but there are a number of Internet sites that provide useful instructions for getting started.

Stream-sediment sampling works best in unglaciated terrain that is at least moderately hilly. Although stream-sediment sampling has been much used in the past to support mineral exploration in Newfoundland, the complex glacial history of both Newfoundland and Labrador mean that lake and pond sampling are more effective as a regional exploration tool and very little stream sampling is done now.

Lake Geochemical Surveys

Sampling of lake sediments has proven to be an effective reconnaissance exploration technique in glaciated areas like Newfoundland and Labrador, The basic principle is the same as for stream sampling: if the rocks in a lake's catchment basin are mineralized in a particular metal, then the lake's sediments and waters will be enriched in that metal also, compared to lakes that do not have mineralization in their catchment basins. However, the real-world situation is a good deal more complicated than this as the composition of lake sediments can be strongly influenced by factors that are unrelated to local geology. Nevertheless, carefully-interpreted lake sediment data have led to the discovery of a number of mineral deposits, including the Strange Lake Rare Earth/Rare Metal deposit in northern Labrador.

There is general agreement that the best material to sample in a lake-sediment program is the organic-rich ooze from the deeper parts of the lake. It is important to take basic notes at each site regarding the depth, colour and texture of your sample, as these may be of critical importance in interpreting your results when you get them back.

Collection of lake-sediment samples can be done with a "Hornbrook Bomb" Figure 4) which is a heavy, hollow missile-shaped device that penetrates the lake-bottom sediment after being dropped from surface with a rope attached. The nose of the sampler is fitted with a butterfly valve which closes as it is pulled out of the sediment so that a core of sediment remains inside. The sampler is then hauled to the surface and its contents emptied into a sample bag. There are no commercially-available samplers of this type but they can be made relatively inexpensively. However, some prospectors have collected lake-sediment samples successfully by ramming a plastic pipe into the bottom of the lake; obviously, this will be difficult if the lake is more than a couple of metres deep.

This type of survey is carried out by prospectors often in the winter on ski-doo when ponds are frozen. An ice auger is used to cut a hole in the ice and then the "Hornbrook Bomb" type of device is dropped to the lake bottom to recover a sample. Results of regional government lake sediment surveys are available on the Resource Atlas (Geological Survey website http://gis.geosurv.gov.nl.ca/) and are much used by prospectors as a guide to base claim staking on.

Appendix 1

Threshold Values: Our understanding of the way metals are dispersed from ore bodies into the natural environment is not normally sufficient to establish threshold values on chemical principles alone. Therefore, threshold values are normally established statistically from the values themselves, preferably from a very large set of samples and not just from the samples the prospector has just collected. The online geochemical database of the Geological Survey includes large lake-sediment and till data sets that can be used for this purpose. A variety of methods can be used to establish threshold values. Some are very complex and some much less so, although all are more easily accomplished with the aid of a computer. One of the simplest is to base threshold values on percentile values. The 90-percentile value of any geochemical population is the value that exceeds nine-tenths (or 90 per cent) of all the values (and is exceeded by the other one-tenth, or ten per cent). The 97.5-percentile is the value that exceeds 97.5 per cent of all the values (and is exceeded by the other one-fortieth, or 2.5 per cent). Table 4 shows the 97.5-percentiles, for Government lake sediment data from the Island of Newfoundland, of a number of metals of interest.

Metal	97.5 Percentile for Nfld ("Threshold")
Gold	5 ppb
Silver	0.4 ppm
Arsenic	164 ppm
Copper	57 ppm
Lead	55 ppm
Antimony	1.1 ppm
Uranium	73.9 ppm
Zinc	290 ppm

Table 4: Threshold values for common metals in Newfoundland

As a very general rule, these values can be used to determine what values should be followed up, and what can be discarded, but they should be used very carefully, because background levels of certain elements can vary greatly from region to region. For example, the 97.5-percentile value of arsenic, an important pathfinder for gold, is 164 ppm for the whole island but as high as 388 ppm in Central Newfoundland, and only 83 ppm in eastern Newfoundland. In other words, if you collected a lake sediment sample from the Buchans area that returned an analysis of 200 ppm arsenic, it would probably not be worth following up, whereas the same value from a lake near Carbonear, on the Avalon Peninsula, would be reason to get quite excited.

Appendix 2

Notes on the Formation of Ore Deposits.

Water is a superb solvent and is the principal factor in the creation of dispersion haloes. Water can carry many elements in solution under different conditions of temperature and pressure, and deposit them when these conditions change. Processes involving water account for the formation of many ore deposits, in which extreme concentrations of some elements occur relative to their average abundance in the earth's crust. One example is given by circulating hydrothermal solutions in volcanically active parts of the crust. These hot, water-rich solutions can percolate through large volumes of volcanic rocks and leach out metals and incorporate them into the hot solution. These metals are at normal or background levels in the rocks. As the solutions cool, they can no longer carry their load of dissolved metals and the metals are deposited in various zones of concentration, such as different rock types and structures e.g. faults,. Many of these zones of concentration are extensive enough, and of high enough metal concentrations, to create the mines of today.

Appendix 3

Minerals and Their Uses

Every segment of society uses minerals and mineral resources everyday. The roads we ride or drive on and the buildings we live, learn and work in all contain minerals. Below is a selected list of commonly used metallic and non-metallic minerals, ore minerals, mineral by-products, aggregates, and rock types that are used to make products we use in our daily life (Frank, Dave, Weathers, Judy, and Galloway, John, 2001, Mineral Resources Out of the Ground Into Our Daily Lives: U.S. Geological Survey Open-File Report 01-360.).

Aggregates Natural aggregates include sand, gravel, and crushed stone. Aggregates are composed of rock fragments that may be used in their natural state or after mechanical processing, such as crushing, washing, or sizing. Recycled aggregates consist mainly of crushed concrete and crushed asphalt pavement.

Aluminum Aluminum is the most abundant metallic element in the Earth's crust. Bauxite ore is the main source of aluminum. Aluminum is used in automobiles and airplanes (36%), bottling and canning industries (25%), building and electrical (14%) and in other applications (25%).

Antimony Antimony is a blue-white metalloid. Yellow and black antimony are unstable non-metals. Antimony is used in electronics and flame-proofing, in paints, rubber, ceramics, enamels, drugs to treat Leishmania infection and a wide variety of alloys. The major use of antimony is in lead alloys - mainly for use in batteries - adding hardness and smoothness of finish. The higher the proportion of antimony in the alloy, the harder and more brittle it will be.

Asbestos Asbestos is a class of minerals that can be readily separated into thin, strong fibers that are flexible, heat resistant, and chemically inert. Asbestos minerals are used in fireproof fabrics, yarn, cloth, and paper and paint filler. Asbestos is used to make friction products, asbestos cement pipes and sheets, coatings and compounds, packing and gaskets, roofing and flooring products, paints and caulking, and chemical filters. Fibers are dangerous when breathed, so uses must protect against fibers becoming airborne.

Basalt Basalt is an extrusive igneous rock. Crushed basalt is used for railroad ballast, aggregate in highway construction, and is a major component of asphalt.

Barium Barium is an element, derived primarily from the mineral barite, and used as a heavy additive in oil-well-drilling mud, paints, rubber, plastic and paper; production of barium chemicals; and glass manufacturing.

Beryllium Beryllium, an element commonly associated with igneous rocks, has industrial and nuclear defense applications and is used in light, very strong alloys for the aircraft industry. Beryllium salts are used in x-ray tubes and as a deoxidizer in bronze metallurgy. The gemstones of beryl, a beryllium mineral, are emerald and aquamarine.

Cadmium Cadmium is used in plating and alloying, pigments, plastics, and batteries. Cadmium is obtained from the ore minerals Sphalerite $(Zn,Cd)S$ and Greenockite (CdS).

Cement Cement is used for building materials, stucco, and mortar. Cement is "a mixture of powdered lime, clay, and other minerals that crystallize to form a hard solid when water is added (hydraulic cement) or as a binding material in concrete".

Chromium Chromium is used in the production of stainless and heat-resistant steel, full-alloy steel, super alloys and other alloys. Chromium is obtained from the ore mineral Chromite (Mg,Fe)(Cr,Al,Fe)2O4.

Clays There are many different clay minerals that are used for industrial applications. Clays are used in the manufacturing of paper, refractories, rubber, ball clay, dinnerware and pottery, floor and wall tile, sanitary wear, fire clay, firebricks, foundry sands, drilling mud, iron-ore pelletizing, absorbent and filtering materials, construction materials, and cosmetics.

Cobalt Half of the consumption of cobalt is used in corrosion- and abrasion-resistant alloys with steel, nickel, and other metals for the production of industrial engines. Other uses of cobalt metal include magnets and cutting tools. Cobalt salts are used to produce a blue color in paint pigments, porcelain, glass, and pottery. Cobalt is obtained from the ore minerals Linneaite (Co3S4), Cobaltite (Mg,Fe)(Cr,Al,Fe)2O4, and (Fe,Ni,Co)1-xSx.

Copper Copper is used in electric cables and wires, switches, plumbing; heating, electrical, and roofing materials; electronic components; industrial machinery and equipment; transportation; consumer and general products; coins; and jewellery.

Diatomite Diatomite is a rock composed of the skeletons of diatoms, single-celled organisms with skeletons made of silica, which are found in fresh and salt water. Diatomite is primarily used for filtration of drinks, such as juices and wines, but it is also being used as filler in paints and pharmaceuticals and environmental cleanup technologies.

Dolomite Dolomite is the near twin-sister rock to limestone. Like limestone, it typically forms in a marine environment but also as has a primary magnesium component. Dolomite is used in agriculture, chemical and industrial applications, cement construction, refractories, and environmental industries.

Feldspar Feldspar is a rock-forming mineral. It is used in glass and ceramic industries; pottery, porcelain and enamelware; soaps; bond for abrasive wheels; cement; glues; fertilizer; and tarred roofing materials and as a sizing, or filler, in textiles and paper applications.

Fluorite Fluorite is used in production of hydrofluoric acid, which is used in the pottery, ceramics, optical, electroplating, and plastics industries. It is also used in the metallurgical treatment of bauxite, as a flux in open-hearth steel furnaces, and in metal smelting, as well as in carbon electrodes, emery wheels, electric arc welders, and toothpaste as a source of fluorine.

Garnet Garnet is used in water filtration, electronic components, ceramics, glass, jewelry, and abrasives used in wood furniture and transport manufacturing. Garnet is a common metamorphic mineral that becomes abundant enough to mine in a few rocks.

Germanium Most germanium is recovered as a byproduct of zinc smelting. It is also found in some copper ores. Applications include use in fiber-optic components, which are replacing copper in long-distance telecommunication lines, as well as in camera lenses and other glasses and infrared lenses.

Gold Gold is used in dentistry and medicine, jewellery and arts, medallions and coins, and in ingots. It is also used for scientific and electronic instruments, computer circuitry, as an electrolyte in the electroplating industry, and in many applications for the aerospace industry.

Granite Granite can be cut into large blocks and used as a building stone. When polished, it is used for monuments, headstones, countertops, statues, and facing on buildings. It is also suitable for railroad ballast and for road aggregate in highway construction.

Graphite Graphite is the crystal form of carbon. Graphite is used as a dry lubricant and steel hardener and for brake linings and the production of "lead" in pencils. Most graphite production comes from Korea, India, and Mexico.

Gypsum Processed gypsum is used in industrial or building plaster, prefabricated wallboard, cement manufacture, and for agriculture.

Halite Halite (salt) is used in the human and animal diet, primarily as food seasoning and as a food preservation. It is also used to prepare sodium hydroxide, soda ash, caustic soda, hydrochloric acid, chlorine, and metallic sodium, and it is used in ceramic glazes, metallurgy, curing of hides, mineral waters, soap manufacture, home water softeners, highway de-icing, photography, and scientific equipment for optical parts. An excellent review of the salt industry can be found at http://www.saltinstitute.org/15.html.

Industrial Diamond Industrial diamonds are those that can not be used as gems. Large diamonds are used in tools and drilling bits to cut rock and small stone. Small diamonds, also known as dust or grit, are used for cutting and polishing stone and ceramic products.

Iron Ore Iron ore is used to manufacture steels of various types and other metallurgical products, such as magnets, auto parts, and catalysts. Most U.S. production is from Minnesota and Michigan. The Earth's crust contains about 5% iron, the fourth most abundant element in the crust.

Lead Lead is used in batteries, construction, ammunition, television tubes, nuclear shielding, ceramics, weights, and tubes or containers. The United States is largest producer (mainly from Missouri), consumer, and recycler of lead metal.

Limestone A sedimentary rock consisting largely of the minerals calcite and aragonite, which have the same composition CaCO3. Limestone, along with dolomite, is one of the basic building blocks of the construction industry. Limestone is used as aggregate, building stone, cement, and lime and in fluxes, glass, refractories, fillers, abrasives, soil conditioners, and a host of chemical processes.

Magnesium Magnesium (see dolomite) is used in cement, rubber, paper, insulation, chemicals and fertilizers, animal feed, and pharmaceuticals. Magnesium is obtained from the ore minerals Olivine (Fe,Mg)2SiO4, Magnesite MgCO3, and Dolomite CaMg(CO3)2.

Manganese Manganese is essential to iron and steel production. Manganese is obtained from the ore minerals Braunite (Mn,Si)2O3, Pyrolusite MnO2, and Psilomelane BaMn9O18•2H2O.

Mercury Mercury is extracted from the mineral cinnabar and is used in electrical products, electrolytic production of chlorine and caustic soda, paint, and industrial and control instruments (thermometers and thermostats).

Mica Mica minerals commonly occur as flakes, scales, or shreds. Sheet muscovite (white) mica is used in electronic insulators, paints, as joint cement, as a dusting agent, in well-drilling mud and lubricants, and in plastics, roofing, rubber, and welding rods.

Molybdenum Molybdenum is used in stainless steels (21%), tool steels (9%), cast irons (7%), and chemical lubricants (8%), and in other applications (55%). It is commonly used to make automotive parts, construction equipment, gas transmission pipes, and as a pure metal molybdenum is used as filament supports in light bulbs, metalworking dies, and furnace parts because of its high melting temperature (2,623°C).

Nickel Nickel is vital as an alloy to stainless steel, and it plays a key roll in the chemical and aerospace industries. Leading producers are Canada, Norway, and Russia.

Phosphate rock Primarily a sedimentary rock used to produce phosphoric acid and ammoniated phosphate fertilizers, feed additives for livestock, elemental phosphorus, and a variety of phosphate chemicals for industrial and home consumers. The majority of U.S. production comes from Florida, North Carolina, Idaho, and Utah.

Platinum Group Metals (PGMs) PGM's include platinum, palladium, rhodium, iridium, osmium, and ruthenium. These elements commonly occur together in nature and are among the scarcest of the metallic elements. Platinum is used principally in catalytic converters for the control of automobile and industrial plant emissions; in jewellery; in catalysts to produce acids, organic chemicals, and pharmaceuticals; and in dental alloys used for making crowns and bridges.

Potash Potash is an industry term that refers to a group of water-soluble salts containing the element potassium, as well as to ores containing these salts. Potash is used in fertilizer, medicine, the chemical industry, and to produce decorative color effects on brass, bronze, and nickel.

Pyrite Pyrite (fools gold) is used in the manufacture of sulfur, sulfuric acid, and sulfur dioxide; pellets of pressed pyrite dust are used to recover iron, gold, copper, cobalt, and nickel.

Pyrophyllite Pyrophyllite belongs to the clay family and composed of aluminium silicate hydroxide and is very similar to talc. The compact variety of pyrophyllite is used for slate pencils and tailors chalk. It is added to clay to reduce thermal expansion when firing but it has many other industry uses when combined with other compounds, such as in insecticide and for making bricks. It is carved by the Chinese into small images and ornaments of various kinds.

Quartz Quartz crystals are popular as a semiprecious gemstone; crystalline varieties include amethyst, citrine, rose quartz, and smoky quartz. Because of its piezoelectric properties (the ability to generate electricity under mechanical stress), quartz is used for pressure gauges, oscillators, resonators, and wave stabilizers. Quartz is also used in the manufacture of glass, paints, abrasives, refractories, and precision instruments.

Sandstone Sandstone is used as a building stone, road bases and coverings, construction fill, concrete, railroad ballast, and snow and ice control.

Silica Silica is used in the manufacture of computer chips, glass and refractory materials, ceramics, abrasives, and water filtration; and is a component of hydraulic cements, a filler in cosmetics, pharmaceuticals, paper, and insecticides; as an anti-caking agent in foods; a flatting agent in paint, and as a thermal insulator.

Silicon Silicon is used in iron, steel, and aluminum, as well as in the chemical and electronic industries.

Silver Silver is used in photography, chemistry, electrical and electronic products (because of its very high conductivity), fine silverware, electroplated wire, jewellery, coins, and brazing alloys and solders.

Sulfur Sulfur is widely used in manufacturing processes, drugs, and fertilizers.

Talc The primary use for talc is in the production of paper. Ground talc is used as filler in ceramics, paint, paper, roofing, plastics, cosmetics, and in agriculture. Talc is found in many common household products, such as baby (talcum) powder, deodorant, and makeup. Very pure talc is used in fine arts and is called soapstone. It is often used to carve figurines.

Tin Tin is used in the manufacture of cans and containers, electrical equipment, and chemicals.

Titanium Titanium is a metal used mostly in jet engines, airframes, and space and missile applications. In powdered form, titanium is used as a white pigment for paints, paper, plastics, rubber, and other materials.

Trona Trona, a sodium carbonate, is formed when inland lakes in hot arid climates evaporate. Trona is used in glass container manufacture, fiberglass, specialty glass, flat glass, liquid detergents, medicine, food additives, baking soda, photography, cleaning and boiler compounds, and control of water pH. Trona is mined mainly in Wyoming.

Tungsten Tungsten is used in steel production, metalworking, cutting applications, construction electrical machinery and equipment, transportation equipment, light bulbs, carbide drilling equipment, heat and radiation shielding, textile dyes, enamels, paints, and for coloring glass.

Uranium Uranium is a radioactive material used in nuclear defense systems and for nuclear generation of electricity. It is also used in nuclear-medicine x-ray machines, atomic dating, and electronic instruments.

Zeolites Some of the uses of zeolite minerals include aquaculture (for removing ammonia from the water in fish hatcheries), water softener, catalysts, cat litter, odor control, and removing radioactive ions from nuclear-plant effluent.

Zinc Zinc is used as protective coating on steel, as die casting, as an alloying metal with copper to make brass, and as chemical compounds in rubber and paint. Additional uses include galvanizing iron, electroplating, metal spraying, automotive parts, electrical fuses, anodes, dry-cell batteries, nutrition, chemicals, roof gutters, cable wrapping, and pennies. Zinc oxide is used in medicine, paints, vulcanizing rubber, and sun-block lotions.

Zirconium Zirconium is a metal recovered from zircon. Zircon is used in mineral form in refractory products, where it is valued for its high melting temperature of 2,550°C. Some zircon is processed by chemical leaching to yield elemental zirconium. The best known use for zirconium metal is in nuclear reactors, where zirconium contains the fuel.

Rare Earths and Rare Metals

These two terms are used somewhat interchangeably as both have become increasingly important in the "new technology", and they tend to occur in the same types of mineral deposit (See tables below for abundances in the crust and typical rocks). Both Newfoundland and Labrador are considered attractive places to look for them.

Starting with the lightest rare earth, lanthanum (La) and ending with the heaviest, lutetium (Lu) the fourteen rare earth elements occupy a specific sequence in the Periodic Table (See tables below): Lanthanum (La), Cerium (Ce), Praesodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb) and Lutetium (Lu). They all have similar chemical properties and are difficult to separate from one another chemically, although they do not all occur in the same minerals. The element yttrium (Y), while not a part of this sequence, has very similar properties to the rare earths and is usually grouped with them.

Rare Earth Elements - Abundances

Element Name	Element Symbol	Unit	Crust	Mafic	Intermediate	Felsic	Shale	Limestone
Lanthanum	La	ppm	30	10.5	36	25	20	6
Cerium	Ce	ppm	60	35	40	46	50	10
Praesodymium	Pr	ppm	8	4	8.5	4.6	6	1
Neodymium	Nd	ppm	28	18	26	18	24	3
Samarium	Sm	ppm	6	4	7	3	6	1
Europium	Eu	ppm	1	1	1		1	
Gadolinium	Gd	ppm	5.4	4.7	7.4	2	6	0.6
Terbium	Tb	ppm	0.9	0.6	1.3	0.05	1	
Dysprosium	Dy	ppm	3	3	3.2	0.5	5	0.4
Holmium	Ho	ppm	1.2	0.6	1.6	0.07	1	0.1
Erbium	Er	ppm	2.8	1.7	4.8	0.2	2	0.5
Thulium	Tm	ppm	0.5	0.2	0.5		0.2	0.1
Ytterbium	Yb	ppm	3	1.1	3.6	0.06	3	0.1
Lutetium	Lu	ppm	0.5	0.2		0.01	0.5	
Yttrium	Y	ppm	30	25	30	40	25	15

Rare Metals - Abundances

Beryllium	Be	ppm	2.8	0.5	2	5	3	1
Cesium	Cs	ppm	3	1	2	5	5	
Gallium	Ga	ppm	15	12	18	18	20	0.06
Hafnium	Hf	ppm	3	2	2	4	3	0.5
Indium	In	ppm	0.1	0.1	0.1	0.1	0.1	0.02
Lithium	Li	ppm	20	10	25	30	60	20
Niobium	Nb	ppm	20	20	1	1	20	
Rubidium	Rb	ppm	90	30	120	150	140	5
Tantalum	Ta	ppm	2	0.5	2	3.5	2	
Scandium	Sc	ppm	16	38	10	5	15	5

The rare metals do not form a distinct group in the Periodic Table and their definition varies depending on whom you ask. Examples are beryllium (Be), cesium (Cs), gallium (Ga), hafnium

(Hf), indium (In), lithium (Li), niobium (Nb), rubidium (Rb), tantalum (Ta) and scandium (Sc). The term “rare metals” is also sometimes used for metals like gold and platinum that are better described as “precious” metals.
In fact, in terms of overall crustal abundance, most elements from both groups are not particularly rare: rubidium, cerium, lanthanum, neodymium, yttrium, gallium, lithium and niobium are more abundant than lead, and all of them except promethium are more abundant than mercury. They have traditionally been regarded as “rare” because of the difficulty of extracting them from their host minerals.

Rare earths can occur as trace constituents of many common minerals but their ores mainly consist of monazite ((Ce, La, Pr, Nd, Th, Y)PO^4), bastnasite ((Ce, La)CO^3F) and xenotime (YPO^4).

Uses of the rare earth metals include the automobile industry (a hybrid automobile battery for a Toyota Prius requires 10 to 15 kg of lanthanum), glass and ceramics, semiconductors, light-emitting diodes and phosphors for TV and computer screens (europium is used for this purpose and is the most valuable of the rare earths at about $800 a kilogram), supermagnets, and specialized alloys .

Appendix 4

Units of Measurement

An important part of geochemistry is the unit of measurement which we use to tell us the amount of the various elements in the material that we have sampled. The most commonly-used units are ppm, ppb, ounces and %.

Definitions

1% = 1 part from 100 parts

1 ppm = 1 part per million = 1 part from 1,000,000 parts

1 ppb = 1 part per billion = 1 part from 1,000,000,000 parts (See table below).

The traditional unit of weight for gold is the troy ounce of the Imperial system of weights and measures. Despite the gradual conversion to the metric system, the troy ounce remains a traditional fixture of the gold trade and the most important basis for expressing quotations of gold assays on a majority of the leading gold markets. So in most press releases that you will see from junior or major exploration companies, they will quote gold in terms of grams per tonne or ounces per ton. Note that the tonne or metric ton is a unit of mass equal to 1,000 kilograms or 2,204.6 lbs.

In many English speaking countries there are two systems for measuring weight. Many people don't realize that gold (and other precious metals) are weighed in their own system called the Troy System, and they are sold by the Troy ounce. A Troy ounce is heavier than the typical ounce found at the grocery store.

There are 31.1034 grams in a Troy ounce.

The other system is for commodities such as sugar, grains, and the typical grocery items. It is called the Avoirdupois System.

There are 28.35 grams in an Avoirdupois (avdp) ounce

An Avoirdupois pound and a Troy pound weigh the same. Each pound contains 16 of the smaller Avoirdupois ounces, and only 12 of the larger Troy ounces.

When measuring and reporting gold weights:

To convert from grams to Troy ounces Divide number of grams by 31.1034

For example 100 grams 3.215 Troy ounces

To convert from Troy ounces to grams Multiply number of ounces by 31.1034

For example 10 ounces 311.034 grams

When measuring and reporting gold grades:

1 ounce (Troy) per short ton = 31.1034 grams per short ton

1 ounce (Troy) per short ton = 34.2857 grams per metric tonne

Metric Measurements

A weight of 1 kilogram (kg) = 32.151 ounces (troy) or 35.274 ounces (avdp) or 2.205 pounds (avdp)

A grade of 1 gram per metric tonne = 0.0292 troy ounce per short ton

Value of gold-bearing rock

Assay returns 1,000 ppm Au - what is the value of that rock?

1000 ppm is the same as 1000 grams per tonne

Price of gold is always given in $ per troy ounce, so first convert grams to Troy ounces

1000/34.2857 gives 29.17 troy ounces per short ton

Then multiply number of Troy ounces by price of gold

29.17 ounces * $1,200 gives $35,004

Value of copper-bearing rock

Assay returns 0.4 % Cu (4000 ppm) - what is the value of this rock?

0.40% = 8 pounds per short ton

Price of copper $3.21 per pound

This gives $3.21 times 8.96 pounds $25.68 for a short ton of rock

(we use non-metric price unit measures because metal prices are typically quoted in $US/lb)

Using metric measurements:

One tonne contains 1000 kilograms (kg) and at 0.4% Cu, would contain 4 kg of Cu. This gives 4 kg*$3.21*2.204 pounds to the kilogram or $28.29 for a metric tonne of rock

Value of copper and nickel-bearing rock

Consider an intersection over some significant width reported to grade 2% Ni and 1% Cu.

One tonne equals 1,000 kilograms (kg) and at 2% Ni, would contain 1,000 x 0.02 (that is, 2%) =20 kg of Ni.

Similarly, it contains 1000 x 0.01 (that is, 1%) = 10 kg of Cu.

2010 Ni and Cu prices are about $10.34/lb and $3.21/lb, respectively ($US)

and there are 2.204 pounds in a kilogram, so the value of a tonne of rock at these grades is

(20*$10.34*2.204) for the nickel + (10*$3.21*2.204) for the copper = approximately $527 per metric tonne.

Note on difference between weights and grades:

To explain the difference between weights, and grades, let's think of the analogy of cars and driving. When describing how far we have driven we talk in terms of **distance**: that is, kilometres, miles, or possibly (when I think of some cars I have owned) feet.

When we talk about the **performance** of a car, we also talk in terms of distance, but not just distance. If describing the speed of a car, we talk in terms of time as well – miles or kilometers **per hour**, or possibly (again, when I think of some cars I have owned) hours per mile.

Grades - Conversion Table

PPB	PPM	Wt%	Gram/Metric Ton	Gram/Short Ton	Troy Oz/Short Ton	Lbs/Short Ton	Lbs/Long Ton
1	0.001	0.0000001	0.001	0.0009	0.00003	0.000002	0.000002
10	0.01	0.000001	0.01	0.009	0.00029	0.00002	0.00002
100	0.1	0.00001	0.1	0.091	0.0029	0.00020	0.00022
200	0.2	0.00002	0.2	0.2	0.0058	0.00040	0.00045
300	0.3	0.00003	0.3	0.3	0.0088	0.0006	0.0007
400	0.4	0.00004	0.4	0.4	0.012	0.0008	0.0009
500	0.5	0.00005	0.5	0.5	0.015	0.0010	0.0011
600	0.6	0.00006	0.6	0.5	0.018	0.0012	0.0013
700	0.7	0.00007	0.7	0.6	0.020	0.0014	0.0016
800	0.8	0.00008	0.8	0.7	0.023	0.0016	0.0018
900	0.9	0.00009	0.9	0.8	0.026	0.0018	0.0020
1,000	1	0.0001	1	0.9	0.029	0.0020	0.0022
2,000	2	0.0002	2	1.8	0.058	0.0040	0.0045
3,000	3	0.0003	3	2.7	0.088	0.0060	0.0067
4,000	4	0.0004	4	3.6	0.12	0.0080	0.0090
5,000	5	0.0005	5	4.5	0.15	0.010	0.011
6,000	6	0.0006	6	5.4	0.18	0.012	0.013
7,000	7	0.0007	7	6.3	0.20	0.014	0.016
8,000	8	0.0008	8	7.3	0.23	0.016	0.018
9,000	9	0.0009	9	8.2	0.26	0.018	0.020
10,000	10	0.001	10	9.1	0.29	0.020	0.022
20,000	20	0.002	20	18.1	0.58	0.040	0.045
30,000	30	0.003	30	27.2	0.88	0.060	0.067
34,286	34.286	0.0034286	34.286	31.1	1.00	0.069	0.077
40,000	40	0.004	40	36.3	1.17	0.080	0.090
50,000	50	0.005	50	45.4	1.46	0.10	0.11
60,000	60	0.006	60	54.4	1.75	0.12	0.13
70,000	70	0.007	70	63.5	2.04	0.14	0.16
80,000	80	0.008	80	72.6	2.33	0.16	0.18
90,000	90	0.009	90	81.6	2.63	0.18	0.20
100,000	100	0.01	100	90.7	2.92	0.20	0.22
200,000	200	0.02	200	181	5.83	0.40	0.45
300,000	300	0.03	300	272	8.75	0.60	0.67
400,000	400	0.04	400	363	11.67	0.80	0.90
500,000	500	0.05	500	454	14.58	1.0	1.1
600,000	600	0.06	600	544	17.50	1.2	1.3
700,000	700	0.07	700	635	20.42	1.4	1.6
800,000	800	0.08	800	726	23.33	1.6	1.8
900,000	900	0.09	900	816	26.25	1.8	2.0
1,000,000	1000	0.1	1,000	907	29.17	2.0	2.2
2,000,000	2000	0.2	2,000	1,814	58.33	4.0	4.5
3,000,000	3000	0.3	3,000	2,721	87.50	6.0	6.7
4,000,000	4000	0.4	4,000	3,628	116.7	8.0	9.0
5,000,000	5000	0.5	5,000	4,536	145.8	10	11
6,000,000	6000	0.6	6,000	5,443	175.0	12	13

7,000,000	7000	0.7	7,000	6,350	204.2	14	16
8,000,000	8000	0.8	8,000	7,257	233.3	16	18
9,000,000	9000	0.9	9,000	8,164	262.5	18	20
10,000,000	10,000	1	10,000	9,071	291.7	20	22
100,000,000	100,000	10	100,000	90,710	2917	200	224
1,000,000,000	1,000,000	100	1,000,000	907,100	29167	2000	2240

Precious Metals Base Metals Uranium

If we want to describe the fuel efficiency of a car, we also need to talk in terms of quantity of fuel but again, not only the quantity – miles **per gallon**, or kilometres **per litre.**

Even if your vehicle gives a consistent consumption of twelve kilometres per litre, you won't know how many litres of fuel you're going to use tomorrow, or how many hours you will be driving for, unless you also know how far you're going to drive.

The situation is similar in describing a mineral deposit. A mineral deposit will be described as having a certain **grade**, expressed in per cent (that is, parts per hundred) for metals like copper or zinc, or ounces per ton (commonly) for precious metals. Those grades do **not** tell you, in absolute terms, how many kilograms of copper, or ounces of gold your deposit contains (and, therefore, what its dollar value is). For that, you need to know, as well as the grade, how many tons of ore at that grade your deposit contains. Ounces per ton of gold, multiplied by tons of gold ore, will give you ounces. Per cent copper, multiplied by tons of ore, will give you tons of copper metal.

So, that's the difference between weights and grades. Grades are always the same, and can be used to describe the richness of a deposit. Weights vary depending on how much you mine.