Four-Acid Digest & Advanced ICP-MS Technology

## Extract the most value from your geochemical analysis

Four-acid digest methods, coupled with the latest mass spectrometry technology, provide robust data sets that have the potential to be used throughout the life cycle of an economic ore deposit, adding significant value at various stages of exploration and mining

Exploration budgets are often tight and there is a temptation, particularly in gold exploration, to analyse samples only for gold and a small number of associated elements. Defining the value of a resource project goes beyond determining the amount of metal contained. The four acid digestion based methods offered by ALS provide clients with data that can be used to estimate mineralogy and establish proxies for physical and chemical deposit characteristics such as ore hardness, deleterious gangue mineralogy, weathering and oxidation fronts, identification of construction materials such as road base and mapping of reactive sulphides for acid mine drainage management.

Through advances in technology and refinement of laboratory procedures, ALS continually strives to provide clients with the best possible solutions to their exploration problems. Extensive experience in the analysis of geochemical samples has provided a comprehensive understanding of how elements and minerals behave through digestion processes and instrumentation. The use of a "near total" four-acid digest provides high quality and robust exploration data packages with a range of sensitivities, allowing clients to choose the method and detection limits most appropriate for their targets, deposit types and stage of exploration. The four-acid digest is able to effectively dissolve almost all rock-forming minerals, with only the most refractory minerals remaining incompletely dissolved.
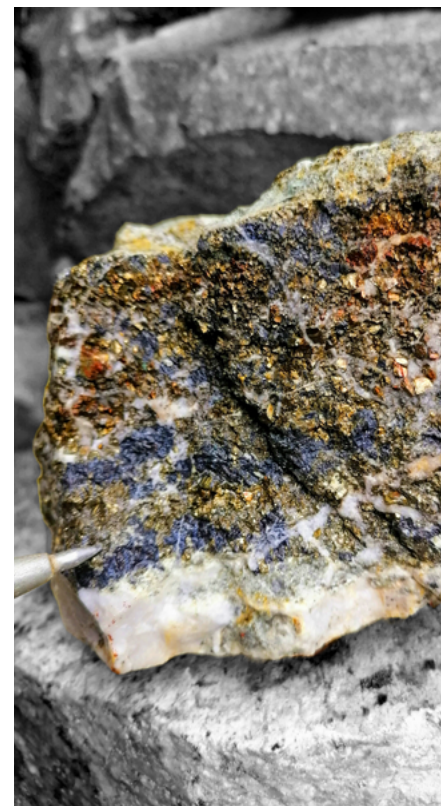
CODE	ANALYTES & RANGES (ppm)										
	Ag	0.002-100	Ce	0.01-10000	Hf	0.004-500	Na	0.001-10%	Sb	0.02-10000	Ti	0.001-10%
	Al	0.01-50%	Co	0.005-10000	In	0.005-500	Nb	0.005-500	Sc	0.01-10000	Tl	0.002-10000
	As	0.02-10000	Cr	0.3-10000	K	0.01-10%	Ni	0.08-10000	Se	0.006-1000	U	0.01-10000
	Ba	1-10000	Cs	0.01-10000	La	0.005-10000	P	0.001-1%	Sn	0.02-500	V	0.1-10000
ME-MS61L™	Be	0.02-1000	Cu	0.02-10000	Li	0.2-10000	Pb	0.01-10000	Sr	0.02-10000	W	0.008-10000
	Bi	0.002-10000	Fe	0.002-50%	Mg	0.01-50%	Rb	0.02-10000	Ta	0.01-500	Y	0.01-500
	Ca	0.01-50%	Ga	0.05-10000	Mn	0.2-100000	Re	0.0004-50	Te	0.005-500	Zn	0.2-10000
	Cd	0.005-1000	Ge	0.05-500	Mo	0.02-10000	S	0.01-10%	Th	0.004-10000	Zr	0.1-500

Why spend extra budget on low level analysis for your drill core?

Modelling lithology and alteration zones is an important part of developing a robust resource model for an ore deposit, but data collected throughout the life of an exploration project is collected by geologists with a wide range of experience and logging styles. Consistent logging of rock types and alteration minerals is often very difficult to achieve, particularly in drill chips from weathered horizons. By routinely obtaining a 48 element multi-element analysis on drill samples in addition to gold assays, companies are able to build very valuable and useful databases that can assist mining personnel throughout the life of the mine and throughout the mining and processing stages. By interrogating multi-element data collected by methods such as the ALS ME-MS61L™ and ME-MS61™ packages, geologists can correctly identify rock types, determine alteration zonation, define

the presence of clay minerals, quantify silicate and sulphide mineralogy, delineate alteration phases for input into robust 3D geological modelling and map fluid pathways using pathfinder element data.

ME-MS61L™ provides robust results at levels well below the lowest regional backgrounds for most elements, allowing an unprecedented level of detail in major and trace element geochemistry on any sample. Previously, the detection limits of multi-element methods were often close to crustal background abundances for many elements. With the significantly reduced detection limits of the ME-MS61L™ package, ALS is able to provide clients with high quality multi-element data at levels up to an order of magnitude below crustal abundance. It also improves the precision of trace element analysis by up to an order of magnitude.

As shown below, detection limits this low allow for the regional background

level of an element to be determined, while providing confidence in the resulting anomaly. An additional consideration with respect to the lower detection limits of the ME-MS61L™ method is that the precision of the data at crustal abundance levels is increased by lowering the detection limit below these background levels. Instead of database columns filled with "<" symbols, the geologist has access to additional data on which to build and expand their interpretation and deposit model.

Such data is becoming increasingly important as exploration moves into covered terrain and other areas where deposits may be harder to find due to structural setting or the stigma of previous negative exploration results. By providing a cost effective, robust and comprehensive multi-element package with crustal abundance sensitivity, ALS works with clients to move forward in the modern exploration environment.
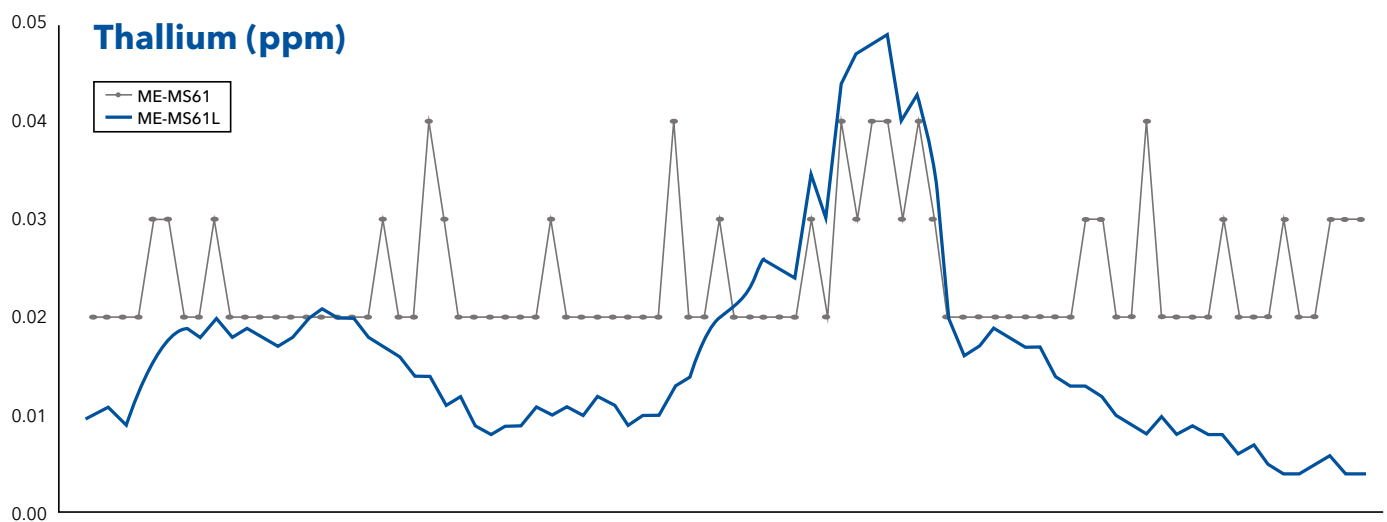
Adding value to an exploration project throughout the project lifecycle

A range of lithological and geochemical parameters can be determined through proper interrogation of the ME-MS61L™ data. Three primary objectives of lithogeochemical data analysis are to identify rock types within the deposit, quantify alteration

and establish useful pathfinder associations to aid future exploration and resource definition.

Defining rock types: Within a typical project, geological logging is carried out by a large number of geologists with a wide range of experience. This makes it difficult to build reliable geological models based on subjective observations. Assay data is quantitative, and removes

"observer bias". Lithological groups can be identified from point clusters within scatterplots of immobile trace elements, as per the example below. Once the assay data are available in the project database, comparing the chemistry with the logging will result in more accurate and consistent logging and will allow geologists to see through the overprinting effects of alteration and mineralisation.

Classifying Alteration: Whole rock analyses from ME-MS61L™ data can be plotted so that trends in the data can be directly related to mineralogy. This provides the basis for defining and modelling alteration zones within a project. Silica content is also very useful in this exercise, but this data is provided by an additional method due to the loss of Si in the four acid digestion process. Silica and several other elements can be provided by a cost effective portable XRF add-on method.

The definition of gangue mineral domains within an ore resource model has direct applications in terms of geometallurgy and mine planning, such as providing rock hardness information for drill and blast and mill processing, proxies for mill throughput rates, and identification of high clay zones and weathering profiles that may affect physical pit design. This exercise may also identify additional exploration targets.

The types of plots that could be utilised in a Lithogeochemistry Workflow to quantify alteration include:

1. K/Al (molar) vs Na/Al (molar) (sericite and advanced argillic alteration)
2. Ca-K-Na ternary plot (hydrothermal feldspars)
3. Al-K-Mg ternary plot (Mg metasomatism)
4. Fe vs S to (sulphidation)
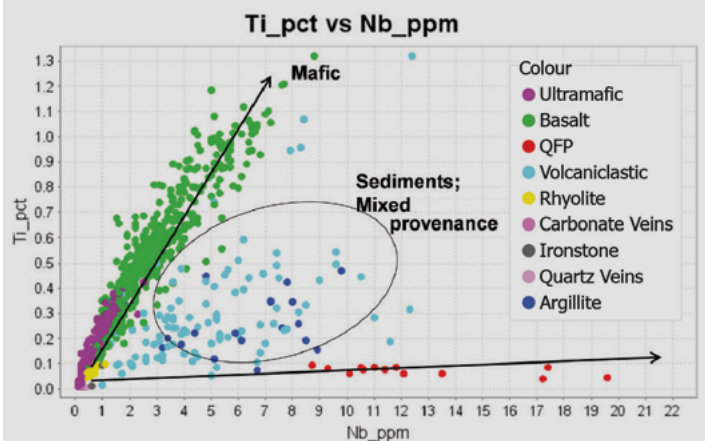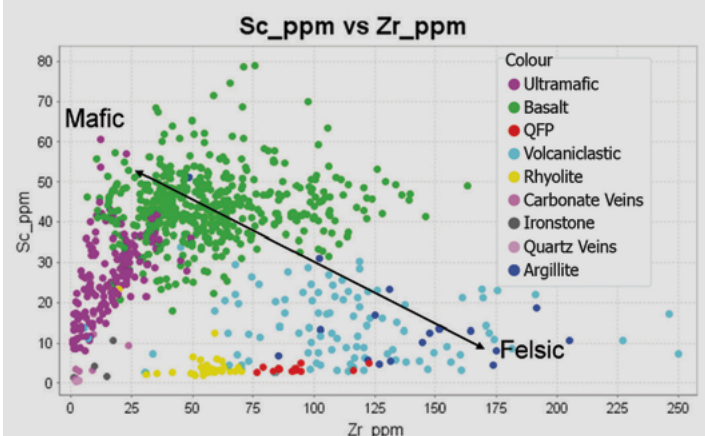5. Cu-Fe-S ternary (Cu-sulphide mineralogy)

K/Al (molar) vs Na/Al (molar)
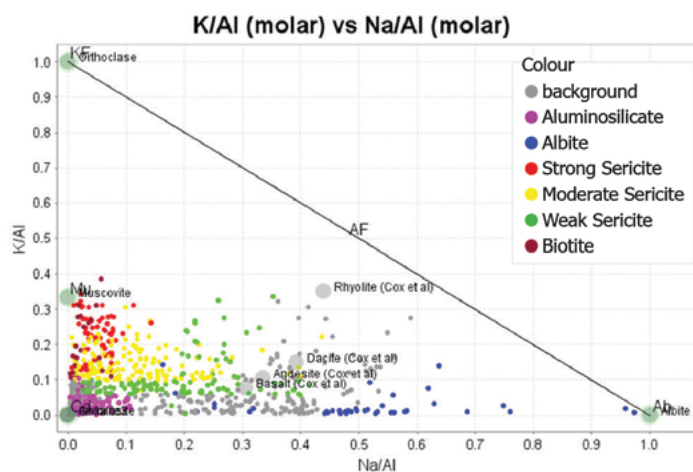
Pathfinder Elements: Of primary interest to many exploration managers and geologists is the ability to identify and map pathfinder elements which have broader primary dispersions than the ore metals, are more mobile than gold and provide larger halos around mineralisation.

The data can also assist in identifying prospective structures and lithologies, allowing geologists to use the data to define vectors to mineralisation and therefore identify future exploration targets. In addition, the data can be used to "ground truth" the results of previous work, such as determining whether historical drilling was deep enough or in the best orientation.

A lithogeochemistry workflow to establish pathfinders may include the generation of split cumulative frequency plots coloured by mineralogy to identify correlations between pathfinders and alteration; Au, Cu, Mo, Sn, W, Se, Bi, Te, As, Sb, Tl. Mineralogical controls can also be established, such as determining the host minerals for each element, their distribution, setting and associations. Information on assay "variance" can be collected, for example, narrow vein hosted mineralisation with few pathfinders will have greater variance than widely disseminated mineralisation. This information can also be used to determine sample spacing requirements.

A Lithogeochemistry Workflow may use a range of parameters to classify rock types, for example:

1. xY plots Sc vs Cr, Mg, Al, Zr (ultramafic rocks)
2. xY plots Sc vs Ti, Th, V, Zr, Nb, P, Cr, Al, La, Ce
3. xY plots Ti vs Sc, Th, V, Zr, Nb, P, Cr, Al, La, Ce
4. Plot Sc vs V (to check for magnetite and/or hornblende fractionation)
5. Plot Zr vs Hf (check for zircon fractionation)
6. REE spider plots or Sr vs Y (check for plagioclase fractionation)


Sc_ppm vs Zr_ppm

Ti_pct vs Nb_ppm

Sb in pyrite provides a significantly larger exploration target than the Cu in chalcopyrite restricted to veinlets

The inside workings of ME-MS61L™ analysis

As with any tool, it is important to understand the advantages and limitations of an analytical method. Although it provides a "near total" digestion, a number of elements are not fully dissolved by the four-acid digestion and several elements are lost as volatiles in the digestion stage, most notably Si and Hg. Partial loss of semi-volatile elements such as As, Se, Sb and Te is common with this type of digestion, but the ALS proprietary four acid digestion used with the ME-MS61™ and ME-MS61L™ methods mitigates the loss of volatiles. It is often said that analysis is a trade-off between the elements required in solution and the elements that can be are useful despite lack of dissolution or partial loss during the digestion process.

Nitric acid and perchloric acid are added to the pulverised sample and proceed to oxidise the samples, changing the oxidation states of some semi-volatile elements and reducing losses in later stages of the dissolution process. Hydrofluoric acid is then added to the samples to dissolve the silicate lattice and release the major rock-forming elements such as Ca, K, Mg and Na. Depending on the mineral type and concentration, these major rock-forming elements may be under-reported, but below a few per cent the results are robust. The solution is heated and then evaporated with the addition of hydrochloric acid as a final step before instrumental analysis. The use of the latest ICP-MS technology allows ALS to minimise interferences, thereby reducing detection limits to levels below typical crustal abundances for most elements.
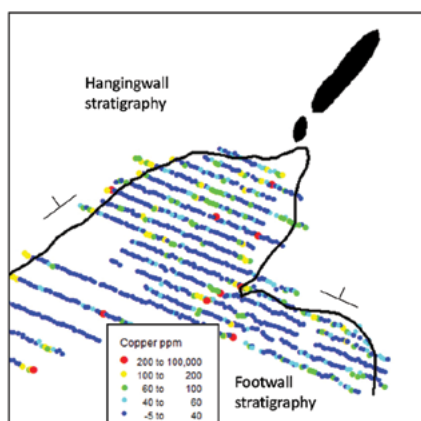
VMS stringer zone. Cu is in chalcopyrite; restricted to sparse veinlets
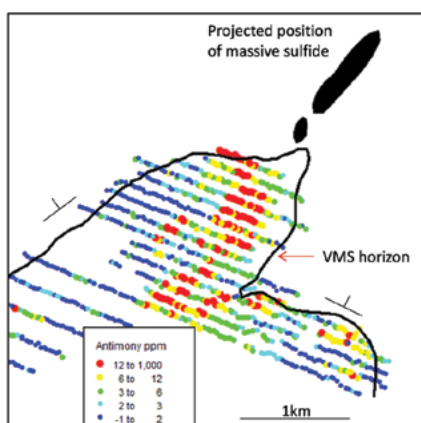
Sb is the lattice of the pyrite. Maps the footprint of the stringer zone.

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