

SUMMARY OF MMI™ TECHNICAL BULLETINS

Index of SGS Mobile Metal Ion Soil Geochemistry Technical Bulletins



MMI™ TECHNICAL BULLETIN SUMMARIES

TB02 – Size Fraction Analysis on MMI™ Samples

The specific size fraction analysis was investigated to determine if one particular size fraction in soils adsorbs the majority of metal ions. In order to determine this a bulk sample of un-sieved near surface soil material was collected from four sites (three gold targets and a base metal area) and were then quartered using a riffle splitter (with the exception of the base metal sample which was done manually). 1kg samples were then extracted from each of the splits and were sieved into various size fractions. The results of these tests showed that for the nine commodity elements tested that there were varying degrees of metal concentrations in each of the size fractions.

TB06 – The Application of MMI™ Geochemistry in Deeply Weathered Lateritic Environments

MMI™ selectively targets mobile forms of metals in surface soils that defines sources of the metals at depth. It can discriminate between displaced geochemical anomalies in lateritic environments (both arid and tropical) and anomalies associated with the primary mineralization. The development of false or displaced geochemical anomalies can be caused by local chemical conditions in a weathering profile that can influence hydromorphic mobilisation, dispersion and re-deposition of elements and by selective physical dismantling of a lateritic landscape exposing different components of a profile. Conventional geochemistry can suffer due to attacking the complete soil particle as well as the absorbed ions. MMI™ is designed to target the only the mobile metal ions adsorbed onto the outer surface of the soil particle or within the pores.

TB08 – The Application of MMI™ Geochemistry in Carbonate Environments

Pedogenic carbonate, calcrete or caliche, are used to describe surficial soils over a variety of bedrock types, which have accumulations of carbonate in the upper part of the profile. These occur frequently in arid to semi-arid climates. Transgressive carbonate units often cover ore deposits of interest and limestones are often important host rock units for various ore style and types. Carbonate environments are known accumulators of metals including gold which makes MMI™ particularly useful in these environments as it doesn't fall prey to the "nugget" effect that other techniques are prone to. If partial dissolution near a deposit occurs due to weathering and transporting the ions to surface through a variety of mechanisms (gaseous, diffusion and capillary rise) the pH within this "neutralization envelope" will be lower. As many metals have pH dependant solubilities, metal ion migration in this area will be enhanced relatively quickly. MMI™ having a higher resolution can detect lower levels of mobile ions, including areas where pedogenic carbonate can cause barriers for some base metals.

TB17 – Geochemistry for Nickel Exploration in Western Australia

In MMI™ nickel is a reliable litho-geochemical indicator of ultramafic rocks. In the Coolgardie area of Western Australia, more than 30 komatiite channel flow areas were identified with MMI™. The MMI™ Ni values in the komatiites are all greater than 8000ppb. For nickel laterites (again using an 8000ppb threshold for Ni) in Kalgoorlie, Western Australia there is a good correlation between the MMI™ and aeromagnetic surveys. Ratios such as Ni/Cr and Cu/Zn proved to be a very useful tool to

vector to ore and they can be used across different regolith regimes, although they must be approached cautiously as if the denominator in the ratio approaches the detection limit large but spurious ratios can be generated. Partial digestions such as MMI™ also discriminate against mechanically transported forms of elements, particularly resistates like Cr making the use of ratios a more reliable tool. Ni/S targets in basal contacts are generally not wide (often less than 10m) and therefore samples should be taken 10m-20m spacing across on lines approximately 100m apart. The basal contact position is identified with Ni/Ti and Ti/Cr ratios which are very sensitive to the change from ultramafic to mafic lithology. Identifying fertile komatiites can also be aided by the presence of Rare Earth Elements. This increased presence of REEs can be seen in MMI™ concentration in overlying soils. MMI™ can aid in prioritizing geophysical targets which are highly utilized in nickel exploration. In summary, MMI™ can be very useful in nickel exploration however many factors need to be considered in order to prioritize targets and the nickel concentrations alone are not enough of an indicator.

TB18 – Rare Earths and MMI™ Geochemistry

The rare earths have good mobility in weathering profiles and can be complexed. Light rare earths are among the "incompatible" elements, meaning that they do not enter early rock building materials while Ce occurs primarily in bastnasite (carbonate), allanite and monazite (silicates). All are accessory minerals in granitoids as well as allanite

occurring in some limestone skarns and pegmatites. Kimberlites consistently have a reactive rim of rare earths which can be easily detected in MMI™ soil geochemistry. Similarly, MMI™ digestions often show high values of Ce, Nd, La and Yb coincident with high Au and Ag signals in soils above the mineralized part of a vein system. It can also be important to note the differences between light and heavy rare earth elements (LREE and HREE). The ratio of LREE to HREEs in rocks can provide a good method for identifying and categorizing magmatic history.

TB20 – Inferred Geology using MMI™ Ni and Ce in the Yilgarn Craton, Western Australia

The Yilgarn Craton in Western Australia is characterized by several greenstone belts comprising metamorphosed mafic and ultramafic sequences separated by granitic terrains of slightly younger age. Ni and Ce can aid in delineating geology, particularly as outcrop is limited or highly weathered. Ni and Ce were selected based on them being relatively abundant mobile and extractable elements from the compatible and incompatible element groups in the Earth's crust. In this area, Ni is present in soils wherever mafic and ultramafic rocks are present. When MMI™ values are greater than 2000ppb this typically characterizes sheet flow ultramafics and MMI™ values >8000ppb typically characterize channel flow ultramafics. REEs, like Ce, are notably absent in mafic and ultramafic rocks.

TB21 – The Application of MMI-M Leach to Mineralized Porphyry Exploration

The MMI-M multi-element leach incorporates specific ligands (organic and inorganic) to hold elements in the solution which resolves soil and solution pH issues recognised as problematic in other partial extraction geochemistry. Both residual and transported surface soils over porphyry systems that have been analyzed by MMI-M can reflect both the commodity metals and the alteration zones. Samples have been taken from across porphyry deposits in South America, Australia, USA and Scotland and have shown distinctive multi-element

responses reflecting mineralization styles, alteration halos and key lithologies. Prioritizing individual element responses that will reflect economic drill targets can be more difficult, instead a multiplicative index of elements of interest will aid to provide more reliable indicators of potential economic mineralization.

TB22 – MMI™ Sampling in Tropical and Temperate Climate Zones

Taking the appropriate sample is extremely important to ensure the best quality of MMI™ data. Sample sites should be undisturbed and preferably away from any major contamination. Ideal sample depth is related to capillary rise and evapotranspiration process and not the soil type (ex. B horizon soils). Variations between sample depth can cause issues with interpretation of the data as element concentrations can vary markedly at different sample depths. The sample should be collected 10-25cm below the organic-inorganic interface with the 10cm just below the soil interface being scraped away to eliminate loose organic matter, debris and any possible contamination. Contamination can occur if equipment is not properly cleaned between samples or if the sampler is wearing jewellery. Samples do not need to be entirely free of organics, however the sample should be primarily inorganic material. The sample collection protocol is the same for moist and dry samples. Where there is potential for contamination at a site the samples should be collected at a depth to avoid any contaminated material and the sampler's judgement must be relied upon. Skeletal soils can be sampled provided there is a thin layer of soil as this is the area that the evaporation process will have been confined. Sampling in grids is the ideal program layout but spacing of samples is dependant on the type of deposit.

TB23 – Processing and Presenting MMI™ Geochemical Data

Depending on your sampling program, MMI™ data can be presented in different ways, but care should always be given to the quality control when processing your results. Always ensure that your data is appropriately lined up with the correct

sample numbers and spatial coordinates as poor alignment can have disastrous results. Quality control should always be assessed, both between the laboratory duplicates (should be less than a mean 30% difference between samples) and the Standard Reference Materials (should have a coefficient of variation of 15% or less) inserted by the lab. When presenting univariate data, if the samples have been collected in a grid (>100 samples) isotopic kriging is ideal as it can also be well aligned with the geology and geophysical data. When samples have been collected in discrete sections or lines, simple bar charts can suffice, or classed post maps may be applied. When presenting multi-element data is presented it is recommended that the data is normalized by means of calculating background (average of the lowest quartile of data) and then doing a peak to background ratio (response ratio).

TB24 – Litho geochemistry and MMI-M

The behaviour of many rock-forming elements is dictated by their ionic radius. Substitution in silicates and other mineral lattices is often based on ionic radius and if common cations are re-arranged according to ionic radius, some mutual occurrences in rocks and soils are easily observed (ex. Pb (II) and Ag (I)). Elements common in magmas such as iron and lead have divalent cations with ionic radii in the range of 0.6-0.8Å and therefore elements within the periodic table with ionic radii which between 0.5 and 1Å are considered "compatible" as they can easily substitute into crystallizing silicates in early rock formation. Elements with an ionic radius greater than 1Å are considered "incompatible" meaning that they are less commonly substituted and are left behind in residual fluids (ex. Light REEs). These observations can be seen in soils although care must be taken as soils occurring near a lithological boundary will contain elements of both members so for reference purposes soils need to be collected from large well-developed units to eliminate the chances of lateral movements and contamination. When choosing elements that will provide useful lithological information a number of factors must be observed: 1) the element must be above detection for a number

of rock types 2) the element must be below the upper analytical limits for most rock types 3) the element must report at different levels in soils for various rocks and 4) reasons for reporting the different levels should ideally have some basis in hard rock geochemistry to allow for meaningful interpretation.

TB25 – Sampling Grids for MMI™

Designing an appropriate sampling program is critical in all geochemical surveys. MMI™ sampling does not need to be undertaken in a regular grid and in some cases the need to obtain a good sample overrides other considerations. Grid density and its layout are determined primarily by the type of deposit being sought as the “footprint” of a deposit should be totally covered in an appropriate survey. Low density grids (400m x 400m) may be appropriate to detect large tonnage deposits such as porphyry systems while high density grids are also capable of detecting shallow tabular deposits with lower tonnage such as carnotite in calcrete uranium deposits. Delineating an anomaly will require a higher sampling density than detecting it. While many exploration programs can be undertaken in a single pass, several large MMI™ programs are now undertaken initially at low density with subsequent infill sampling.

TB26 – Weak vs. Strong Leachants

Wet chemical digestions are one of the most common ways to obtain element concentrations from soils and rocks. As technology has advanced as such should our analytical methods. When detection limits were inferior it was more desirable that a leachant dissolved as much material as possible in order to maximize the concentration of available analytes. As detection limits have improved, strong digestions have become less desirable in soils due to a large amount of the matrix elements (silica, iron and calcium) are taken into solution and these can cause interference with other analytes being sought. Weaker leachants also provide a better signal to noise ratio. It is important to note the difference between a partial digestion (preferentially dissolves in its entirety one or more soil phases) and

a partial extraction (removes exterior analytes attached to soil particles). MMI™ has been tested against other digestion/ extraction techniques including Aqua Regia, fire assay, water leaches and Enzyme Leach and showed the strongest signal to background contrast.

TB27 – Particle Size and MMI™

The MMI™ solution aims to detach weakly bound elements from substrates in the soil. Sieving and analysis of the fine fraction of a sample is one way to understand more about the process involving desorption of surface adsorbed species or a partial dissolution of one or more phases. The fine fraction might be expected to contain higher concentrations of weakly adsorbed elements if surface adsorption were the dominant process. In this study sample pairs were identically run except one of the samples in the pair had been sieved to minus 150 mesh while the other was untreated. For all elements there is a positive degree of correlation between the sample pairs. The absolute values were also compared as it could reveal whether extraction is systematically more potent from the fine fraction. Data was very similar for commodity elements with only some small systematic differences for lithology-associated elements. This suggests that sieving is not required for the MMI™ leach.

TB28 – Application of Weak Leaches in Kimberlite Exploration

Kimberlite exploration is particularly difficult in areas of thick cover as the geophysical methods used might lack the resolution to identify them or other factors mask the kimberlite signal and as such complimentary exploration methods are needed. As instrument detection limits have improved it increases the ability of weak leach methods such as MMI™ to aid in the exploration for kimberlites. The geochemistry of kimberlites combines a high level of incompatible trace elements with major and minor elements. Diamond bearing rocks are characterized by highly enriched LREE patterns and a depletion of HREE. Two case studies of using MMI™ over kimberlite pipes in the Lake Temiskaming structural zone in NE Ontario, Canada. Both pipes show strong

REE responses over the kimberlite. Both are intruded into felsic magmatic rocks that are the potential sources of the REE anomalies. The MMI™ responses allow for discrimination between the kimberlite pipes and other ultramafic rocks and most other lithologies that lack the distinctive alkaline rock LREE enrichment even through thick exotic cover.

TB29 – Update on Mechanism of Formation of MMI™ Anomalies and Lithological Expression of Background in Surface Soils

Many lateritic environments can cause difficulties with conventional geochemistry as the low-grade supergene mineralization formed from relocation and precipitation of weathered ore zones can create broad and displaced anomalies. MMI™ is highly successful in these areas as it deliberately aims to minimize the attack on soil grains and only extracts the weakly adsorbed ions attached to the exterior of the soil grains. The use of QEMSCAN technology show very little difference in the attack on the soil grains before and after an MMI™ analysis. The ideal sampling depth in all environments is 10-25cms below the interface. The interface is dependent on the thickness of the organic cover. If no organics are present in the sampling location, the sample is collected between 10-25cms below surface, if organics are present, samples are taken 10-25cms below the organic / inorganic interface. This 10-25cm zone is believed to be where capillary action ceases and evaporation and evapotranspiration is at a maximum in the soil.

TB30 – Degree of Geochemical Similarity (LithoID) between MMI™ samples using Spearman Ranking and Correlation

Due to the amount of information that the MMI-M analysis provides, it is possible to determine lithological information from which the overlying soils was derived. The method first used is a statistical comparison of two samples which allowed for objective assessment and display of the information which allows for areas of similar lithology to be recognized and mapped. The method is based on converting MMI™ data to log(ppm) values and then obtaining a Pearson r between pairs of samples. The method did discriminate between granitoid versus marine derived soils as well as marine soils versus pedogenic carbonates; however, it does rely on having a sample of known provenance (known reference sample) for comparison with the other samples. An improvement to the methodology is that which the soil elemental values are ranked prior to applying the correlation function, thus providing a Spearman r coefficient which avoids systematic domination by elements in high or low concentration. The method was validated using known lithological samples from the Yilgarn Craton in Western Australia. Each different lithology was able to be well and clearly identified using the LithoID method. The method was also applied to the NGSA survey to determine chemically similar areas across Australia to known mineral deposit types.

TB31 – MMI™ Reference Samples from the GEMAS European Database for LithoID Comparison and Analysis

The Geochemical Mapping of European Agricultural Soils (GEMAS) project included 2108 samples of agricultural soil that were analyzed by MMI-M extraction (53 elements). The sampling density was on average 1 sample per 2500km² over most of Europe. After the samples had been analyzed by the MMI™ extraction, elements with >50% of results less than the Lower Limit of Detection were removed and any remaining values below the lower detection limit were replaced with half the respective detection limit. The steps to calculate the LithoID Spearman coefficient (outlined

in TB30) were followed in order to get the rankings for each sample. Based on comparison with geological maps, the LithoID technique using MMI™ data was successfully able to identify the underlying lithology in Eastern Europe.

TB32 – MMI™ Analysis of some selected North American Soils over known Geology

Soils are a product of weathering rock, and as such have the potential to be used to identify parent lithology. The classification system is based on the percentage of silica in felsic rocks (granites, monzonites, rhyolites), intermediate rocks (igneous – granodiorites, tonalites, andesites; sedimentary – carbonates, greywacke and sandstones) and mafic rocks (basalt, gabbro, peridotite, diabase). These form three rock classes. This bulletin outlines the chemistry differences between each classification type from samples collected throughout North America (Nova Scotia, New Brunswick, British Columbia, Ontario and Nevada) based on the MMI™ analyses.

TB33 – Degree of Geochemical Similarity (LithoID) Analysis of some selected North American Soils over known Geology

Data from TB32 underwent the LithoID interpretation technique to examine and interpret the data and identify geochemical similarities/differences between soil samples over different lithologies. Field duplicates generally have a Spearman ranking of +0.8 or greater. In comparing soils over rocks of different classes (felsic, intermediate and mafic) one would expect greater differences in Spearman correlation values. The similarities and differences between lithologies have been clearly and diagnostically presented through use of the Spearman r coefficient (LithoID).

TB35 – Rare Earths and MMI – Chondrite Plots, LREE/HREE Ratios

REEs provide interesting and often diagnostic geochemical behaviour between different rock types. Rare earth compositions of chondrites, a class of primitive meteorites are used to normalize and simplify rare earth patterns from different rock types. Alkaline Ocean Island Basalts (OIB) retain higher REE content due to a lower percentage of partial melting whereas Mid-Ocean Ridge Basalts (MORB) have a higher percentage partial melting and therefore are more depleted in REEs. In general, felsic-intermediate rocks have slopes like OIBs whereas mafic and ultramafic rocks are like MORBs. The results of the MMI™ extraction in soils for chondrite plots are similar to those for rocks after total digestion. A simple way to express the slopes of the chondrite patterns from MMI™ soil data is to calculate LREE to HREE ratios using the unnormalized calculation $(Ce+La)/(Er+Yb)$.

TB36 – Bioavailable Cation Index (BCI) for MMI™ Soil Data and its Application to Vineyard Soils

The cations Ca, K and Mg are all essential for plant growth and therefore have been closely monitored in soils particularly in relation to their exchange to and from clays, historically via the Cation Exchange Capacity (CEC). The CEC is a measure of how many cations can be retained on the surface of soil particles. It can be estimated by exchanging and measuring the concentrations of Ca, K and Mg which are displaced from a soil by alternative cations. It can also be calculated from a partial digest. The calculation from MMI™ data is $CEC = Ca/200 + K/390 + Mg/120$ which are the denominators reflecting that the calculation works in equivalents and incorporates a charge factor on the cation. In situations where all the nutrients are important the CEC is not ideal. The Bioavailable Cation Exchange (BCI) is a multiplicative index $(Ca * K * Mg / 1000)$ with the denominator simply to return a value with a reasonable number of significant figures. One of the main uses for the CEC and the BCI is to identify good from poor agricultural soils although the BCI is arguably more accurate. MMI™ samples from southwestern Australia

were collected and both the CEC and BCI were calculated. Results showed that the higher BCI values coincided with better vineyard soils (BCI>1000) and they also coincided with areas of vines identified by vineyard managers as producing better quality grape juice. It was also noted that the BCI values in soils increased after the application of potassium nitrate and dolomite.

CONTACT US



Leah Treloar
Global MMI™ Product Manager



LEAH.TRELOAR@SGS.COM



WWW.SGS.COM/MINING