UPDATE ON MECHANISM OF FORMATION OF MMI™ ANOMALIES AND LITHOLOGICAL EXPRESSION OF BACKGROUND IN SURFACE SOILS

INTRODUCTION

A vast number of exploration areas particularly for Gold and Nickel, occur in landscape environments that are characterised by deeply weathered lateritic profiles. These lateritic environments can often be difficult to explore particularly when applying surface geochemistry. Low grade supergene mineralization formed from relocation and precipitation of weathered ore zones can create broad and displaced anomalies when using conventional geochemistry, which makes pin-pointing the primary ore zones very difficult.

Information from orientation surveys already completed has shown MMI™ geochemistry to be successful in landscapes dominated by deep lateritic weathering profiles. The case study sites have varied from areas characterised by hot, humid conditions with wet, organic surface soils through to areas with remnant duricrusts in arid environments. Some of the sites include areas in Australia, Venezuela, Surinam, Ecuador, Bolivia, Guyana, Cotê d'Ivor, Bukina Faso and Mali.

The difficulty for all models, and in fact a contributor to the general (mis)understanding and acceptance of any model is the requirement to explain element anomalies in the near surface in some cases from sources up to 100m below surface and encompassing transport through both vadose (unsaturated zone above water table) and phreatic (below water table saturated) zones.

SOIL SAMPLES AS SEEN BY PARTIAL DIGESTIONS AND PARTIAL EXTRACTIONS

Strong acid digestion of soils which includes aqua regia (AR) takes a 1-5gm charge of soil, and attempts to liberate the highest possible concentration of over 50 elements. When followed by Inductively Coupled Plasma Mass Spectrometry (ICPMS) it has low levels of detection. Compared to the total metal content of the soil it commonly achieves an extraction percentage of 20%-80%. On the other hand, a partial extraction, such as MMI™ deliberately aims to minimise the attack on soil grains, and from a 50g sample charge commonly achieves extraction percentages of 0.1%-15% for over 50 elements. When followed by ICPMS analysis it achieves very low levels of detection and high reproducibility. The methods are similar in principle but complementary in nature.
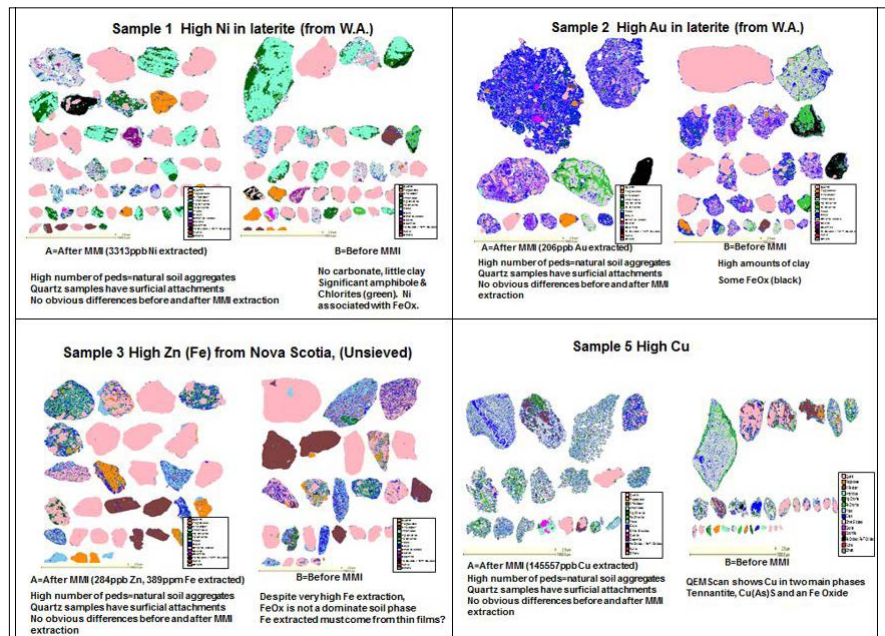
Figure 1: QEMSCAN Images of Anomalous Samples from Western Australia and Canada Before and After MMI™ Analysis (Modal Mineralogy – False Colours)

Several examples of QEMSCAN pictures of modal mineralogy of soil particles before and after MMI™ analysis are shown in Figure 1.

The samples, two from Western Australia (W.A.) and two from Canada are all significantly anomalous in at least one element; the concentrations liberated by MMI™ are shown on each diagram. All are from very different lithologies but have a number of features in common (a) each sample contains a number of peds (small particles stuck together) (b) there are a large number of grain boundaries and very high surface area because of this and (c) there is little noticeable difference between peds before and after MMI™ analysis. This suggests that the soil particles themselves have not been significantly attacked by the MMI™ solution and the anomalous concentrations of elements are derived from the exterior surfaces of

SGS

the soil particles and grain boundaries between them. Chao (1984) pointed out that neither partial digestions nor partial extractions fully achieve their respective aims. For residual soils, some dissolution of the soil particles may be reflected in the final analysis. In summary there is a supply of relatively easily solubilized ions which are not associated with the interior of soil particles but which are diagnostic of the soil and weathering bedrock regime.
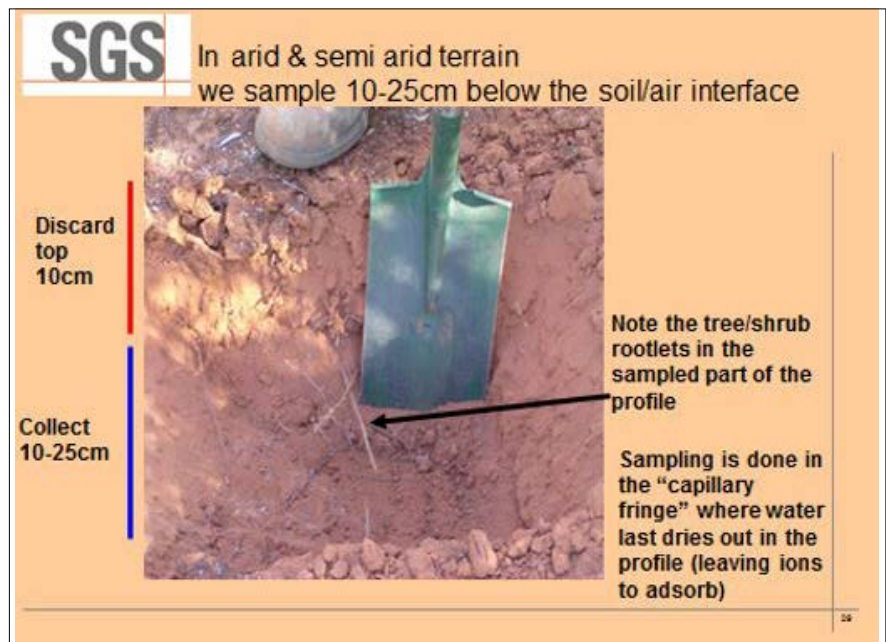
SAMPLING DEPTH

The issue of what depth to best sample a soil is given treatment in other Technical Bulletins TB-04, TB19 and TB22. In summary in tropical and temperate environments it is at a constant depth of 10-25cm, effectively the A horizon. In boreal regions the optimum sampling depth is approximately the same distance below the organic/mineral soil interface. For the latter, orientation surveys are often employed.

This (10-25cm) is believed to be the soil depth at which capillary action ceases and evaporation and evapotranspiration is at a maximum in the soil, and where any solutes (ions) contained in the soil pore water are deposited. Due to solubility differences not all elements deposit at exactly the same depth, hence we suggest sampling over a small range. It is a depth (range) at which tree and shrub roots are found in relative abundance as evidenced in Figure 2. In some regimes particularly those with abundant organic matter where capillary rise is inconsistent, the sampling depth is sometimes found by orientation to be further below the surface.

The zone of highest concentration can be demonstrated experimentally; a solution of blue food dye in water undergoing capillary rise will create a strong blue horizon near the top of the tube filled with fine sand.

Note that the colour (concentration) of blue dye below the surface horizon in Figure 3 is much weaker. The most import point to remember about sampling is to retain the same

Figure 2: Typical Soil Sample in Tropical/Temperate Environment
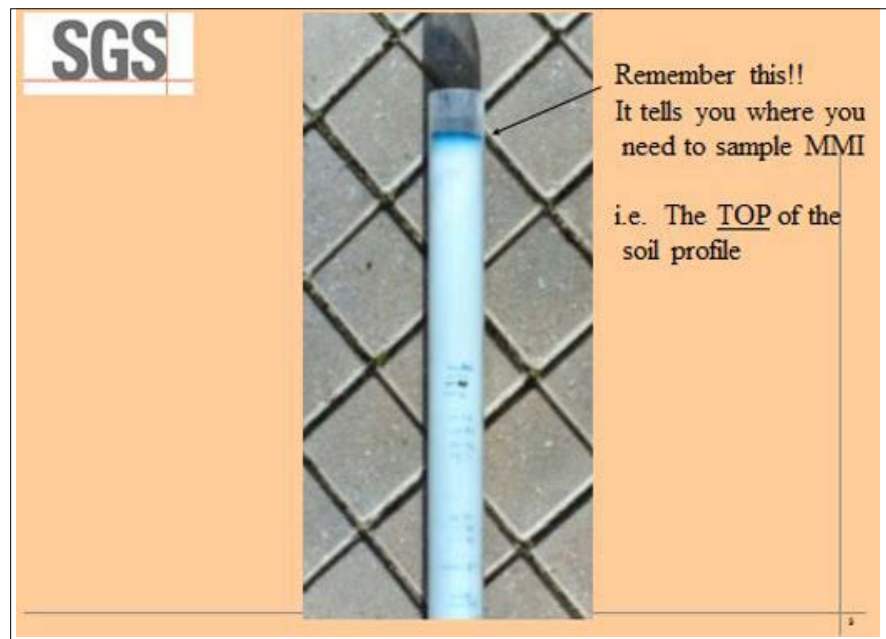
Figure 3: Capillary Rise in Fine Sand Illustrated with Blue Food Dye

sampling depth and protocol across the sampling area – MMI™ is a comparative technique, comparing the magnitude of element concentrations at the "anomaly" with values for the elements at background sites collected under the same conditions.

NEW INFORMATION ON CAPILLARY RISE

For many years soil physicists have maintained that the maximum depth over which capillary rise could occur was limited to 20-30m. Their calculations were theoretical, limited to "glass beads" and did not take into account chemical interactions such as hydrogen bonding in real materials such as clays.

Botanists have also been interested in capillary rise, as it is the mechanism by which large trees are thought to provide water to their uppermost cells. In some cases this is over 100m above ground level. An important paper entitled The limits to tree height by Koch et al., (2004) concluded that the maximum height of trees (and capillary rise therein) was limited to 122-130m. Is it a coincidence that this is also approximately the maximum depth of weathered profiles?

The greater the height of capillary rise the smaller must be the capillaries (and the longer the time taken) for ascension. Koch et al. (2004) provided the following calculations:

$h = 0.3/d$ where h=height and d= tube diam in cms

xylem of a redwood tree = 25 micrometres

So $h = 0.3/25 \times 10^{-6}$

$= 0.3/25 \times 10^{-4}$

$= 3000/25$

$= 120$ metres

VADOSE VERSUS PHREATIC ZONE

Given this principle and given enough time, the ions from an active water-saturated weathering front at 100m could reach the surface. There are some weathering zones in semi-desert areas with this profile, but most profiles contain ground water in the phreatic zone, so a mechanism has also to be considered for the migration vertically of ions within this saturated zone as well. One possibility, convection, was demonstrated by Mann et al.(2005), as shown in Figure 4.

In this experiment a small light bulb and thermocouple was inserted into a saturated profile with blue food dye initially at the base of the saturated layer. Within a day a plume could be

Figure 4: Convective Rise in Solution of Water and Blue Food Dye Induced by a Light Bulb Heating Surrounds by 1⁰C
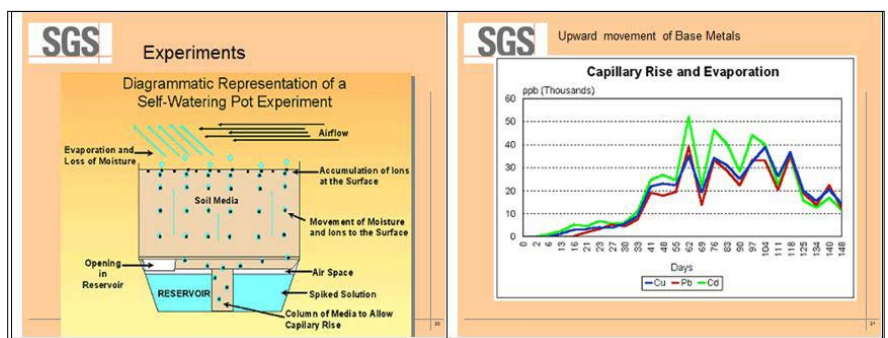
Figure 5: Diagram Showing (Left) Design of the Self-Watering Flower Pot and (Right) the Results Obtained after Analysis of Surface Soil using MMI™ Extraction
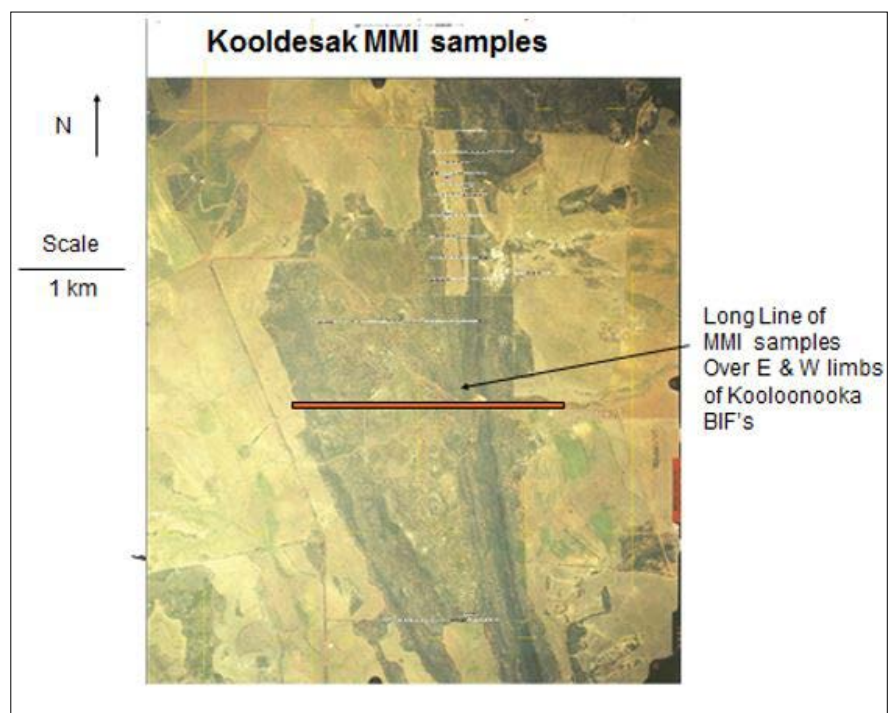
Figure 6: Location of a Line of MMI™ Samples over Two Limbs of Banded Iron Formation

observed ascending over the location of the light bulb. It was postulated that the heat generated from weathering of e.g. sulphides could provide the small temperature rise to cause this to occur in nature. This would provide ions to the water table in a relatively concentrated plume directly above the zone of heating (oxidation).

There may be some initial confusion as to how it is possible for there to be water in a phreatic zone beneath the vadose zone if capillary rise is consistent across the landscape. Recharge of groundwater has always been considered to take place via "preferred pathways" e.g. fault zones and tree roots. In addition, as pointed out by Greacen and Williams (1983) after any rainfall event there is initially an infiltration period followed then by vertical ascension which operates as the profile dries out and evaporation and evapo-transpiration become dominant again. This return to surface of water by "pumping" is not seismically induced, but is driven by evaporation and occurs by capillary rise.

TIME TAKEN FOR ESTABLISHMENT OF "ANOMALIES"

So what is enough time for a geochemical anomaly to form? In Ontario, Canada where glacial till is some 8,500 years old MMI™ anomalies have been recorded in a number of places over mineralisation to depths of 30-40m. The ability of capillary rise and evaporation to transport and deposit solutes near the surface of "exotic overburden" can be experimentally demonstrated with self-watering flower pots.

Figure 5 shows the build-up of the anomalies for Cu, Pb and Cd to measurable proportions in about 30 days (albeit from shallow depths).

Recently at the Roman townsite of Calleva Atrebatum in the U.K., significant MMI™ geochemical anomalies (up to 20ppb for Au, and up to 1700ppb for Ag) have been recorded in surface soils; they are believed to be derived from
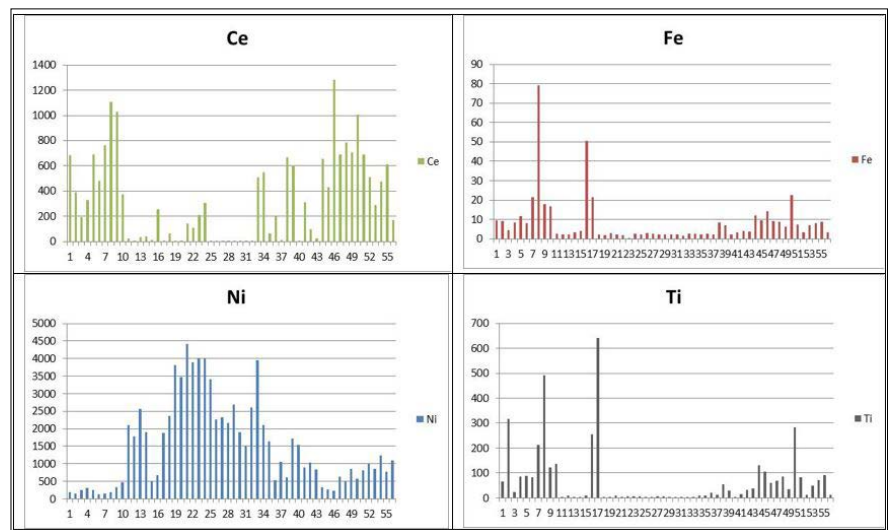
Figure 7: Element Concentrations after MMI™ Analysis of Soils Across BIF-Ultramafic-BIF Lithology (50m Spacings)

metallurgical activities carried out nearly 2000 years ago evidenced at depths of 1-3m below the current-day surface by archaeological excavation. Most interestingly where the soil profile at Calleva has been disturbed at House 1 during archaeological excavation 40 years ago, a "geochemical hole" (i.e. sharp decline in values) occurs in the surface expression of these elements (Sylvester et al., in press).

It appears that something shorter than "geological time" i.e. 100-1000 years is required to develop recognisable MMI™ anomalies over what we would consider "normal depth" profiles. It is also evident that the depth of the vadose zone is important in determining the time required for ions to reach the surface. With shallow profiles and/or coarse material capillary rise is rapid, compared to that required for a deep, and/or closely packed e.g. clay profile.

SURFACE EXPRESSION OF LITHOLOGY

Another factor which has become increasingly apparent over the past ten years is that MMI™ is capable of reflecting lithology in soils at surface. In Figure 6 the Google earth image of a traverse of MMI™ samples at 50m intervals across two limbs of Banded Iron Formation (BIF) separated by ultramafic lithology is shown.

In figure 7, the geochemical patterns of various elements in samples at 50m intervals across the BIFs are shown.

The two limbs of the BIF are marked by higher values of Ce, Fe and Ti at the ends of the traverse (Figure 7), the latter two elements deriving from weathering magnetite in the BIF. Between the two limbs of the BIF, the presence of Ni>2000ppb in soil samples reflects sheet flow ultramafic; these are residual soils where the geology can be easily verified. The antipathetic nature of Ni and Ce can be clearly seen; Ce being a large ion is excluded from ultramafic melts. It is also evident that MMI™ soil signatures are reflecting accurately the lithological changes.

In the Geochemistry of European Agricultural Soils (GEMAS) study, soil samples were taken at low density in agricultural fields, every 50km, and a continental map of soil geochemistry obtained. The study included MMI™ (see Case Study CS53) as well as AR and XRF analysis. One of the outcomes was an inferred geology map, derived from the MMI™ results as shown in Figure 8..

To the extent possible in such a low density sampling exercise, the MMI™ data provides an expression of regional geology via surface soils and subsurface lithology viz. the granitoids of Scandinavia and west coasts of

England, Scotland, Spain and Portugal (Ce>1ppm), the ophiolites of southern Europe (Ni>8ppm) and the widespread carbonates of central Europe and S.E. England (Ca>800ppm) are outlined. Again it is clear the phenomenon giving rise to these elemental variations is related to parent bedrock material and the ability of the surface soil to reflect this diagnostically.
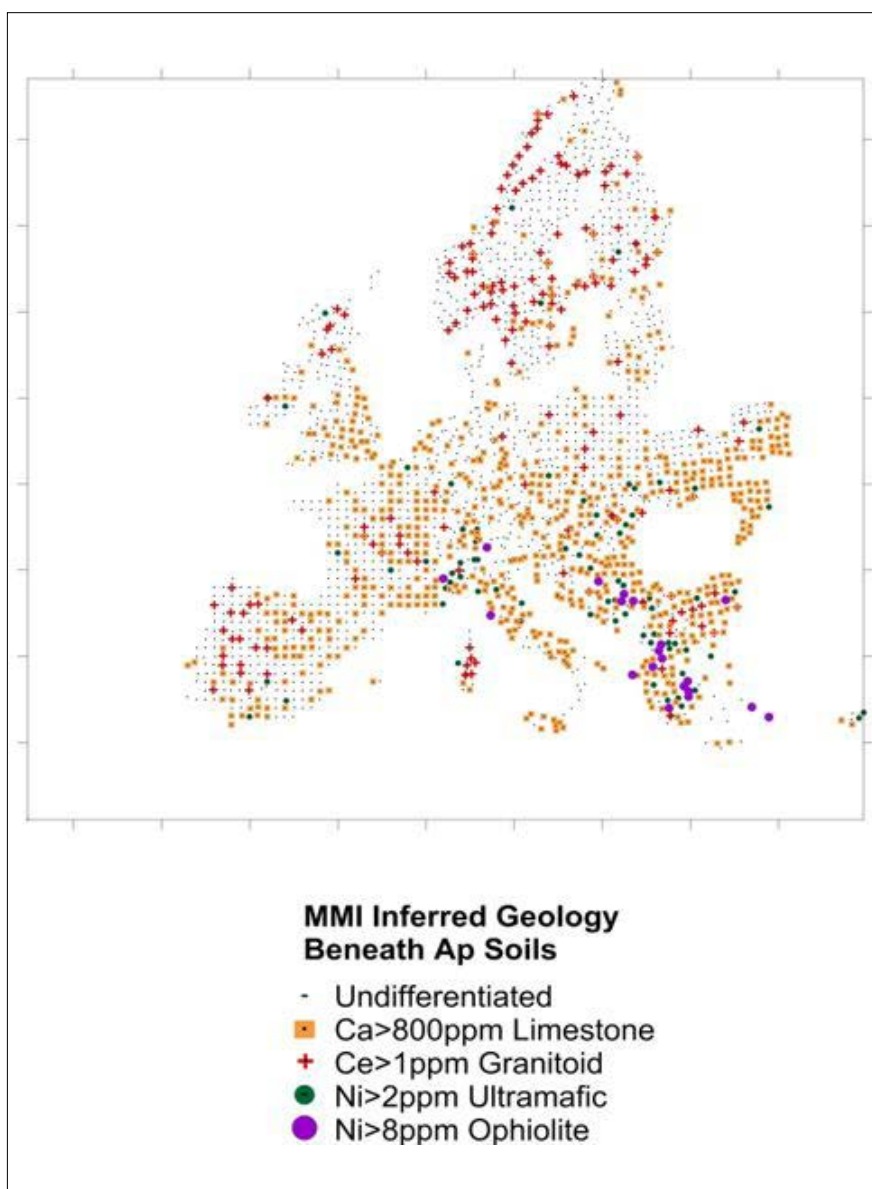
DISCUSSION AND CONCLUSIONS

Any mechanism to explain the formation of geochemical anomalies, and in particular that related to MMI™ needs to be able to accommodate the fact that surface expression in soils occurs across the landscape, not just at a position where base or precious metal anomalism occurs. Neither the electrochemical theory nor the seismic pumping theory provides this; both focus on explanation of geochemical "anomalies".

Capillary rise is a phenomenon which occurs across the landscape and is ubiquitous; ask anyone who has experienced "rising damp" in a building. It is persistent and consistent and well placed to describe many of the features of geochemical anomalies now observed. It does include explanation of "geochemical anomalies" where the substrate embodies mineralisation elements in high concentrations. It also explains the nature of background geochemistry usually reflective of bedrock lithology. Figure 9 shows schematically how both geochemical anomalies and lithological background are reflected in the soil horizon via capillary rise and evaporation.

The critical ingredients for appearance and detection of diagnostic geochemical elements in a soil are:

1. Weathering of bedrock and/or mineralisation.

2. Presence of oxygen and water at the weathering front.

3. Tight compacted overburden to

MMI Inferred Geology Beneath Ap Soils

-   -   Undifferentiated
-   ■   Ca>800ppm Limestone
-   +   Ce>1ppm Granitoid
-   ●   Ni>2ppm Ultramafic
-   ●   Ni>8ppm Ophiolite

Figure 8: Some Lithologically Diagnostic Elements at GEMAS Sampling Locations

provide for capillary rise above the water table.

4. Sufficient time (less than geological) to allow capillary rise to occur.

5. Lack of active horizontal surface movement of soil.

6. An appropriate analytical regime (extraction e.g. MMI/ICPMS) to detect elements at low concentrations relative to background.

REFERENCES

Cameron, E.M. and Leybourne, M.I., 2005. Relationship between groundwater chemistry and soil geochemical anomalies at the Spence copper porphyry deposit, Chile. Geochemistry: Exploration, Environment Analysis 5, 135-145.

Chao, T.T., 1984. Use of partial dissolution techniques in geochemical exploration. Journal of Geochem. Exploration. 20, 101-135.

Greacen, E.L., and Williams, J., 1983. Physical properties and water relations. In: Soils, An Australian Viewpoint,

Division of Soils, CSIRO. CSIRO: Melbourne /Academic Press. p499-530.

Gao, Y., Wang, M & Zhang, D. 2011. Application of "metals in soil gas" techniques to mineral exploration in exotic overburden. Geochemistry: Exploration, Environment, Analysis , 11, 63-70.

Hamilton, S.M., 1999. Transport mechanisms responsible for selective leach anomalies. In: Geoanalysis with emphasis on selective extractions. A short course, 19th IGES Vancouver, Canada, 16p.

Koch, G.W., Sillett, S.C., Jennings, G.M. & Davis, S.D. 2004. The limits to tree growth. Nature 428, 851-854.

Mann, A.W., Birrell, R.D., Fedikow, M.A.F. & de Souza, H.A.F. 2005. Vertical ionic   migration: soil anomalies, and sampling depth for mineral exploration. Geochemistry: Exploration, Environment, Analysis, 5, 201-210.

Sylvester, G., Mann, A., Cook, S. & Wilson C. 2017. MMI partial extraction geochemistry for the resolution of anthropogenic activities across the archaeological Roman town of Calleva Atrebatum. GEEA Accepted for publication

CONTACT INFORMATION

Email us at minerals@sgs.com
www.sgs.com/mining
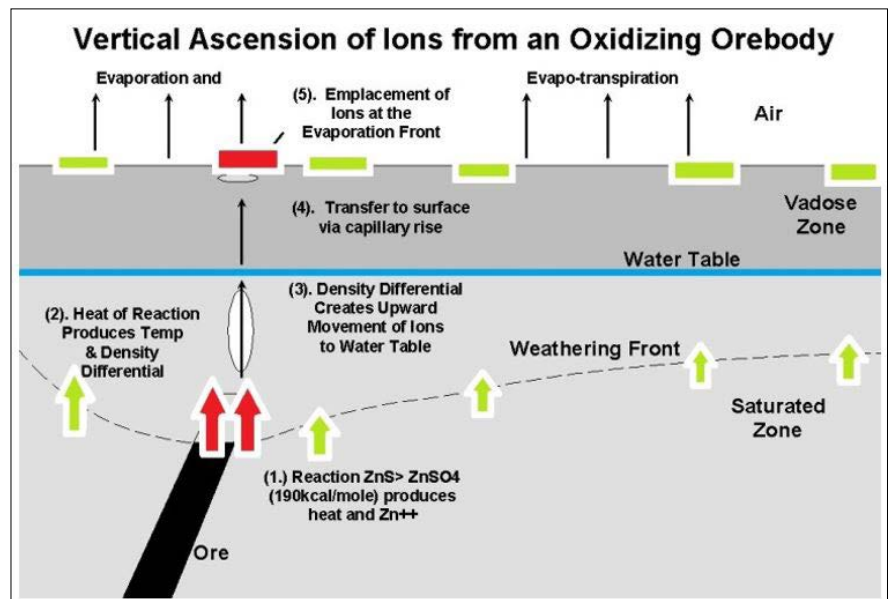
Figure 9: Schematic Diagram of Soil Anomaly and Backgrounds Produced by Convection and Capillary Rise and Evaporation

WHEN YOU NEED TO BE SURE