Geophysical support for geochemistry in detecting deeply buried mineralisation: a case study from Mandamah, Australia

Introduction

The effects on the composition of transported and residual overburden by the oxidation of underlying sulfide mineralisation have been the subject of a large number of empirical and theoretical studies over the last two decades (Cohen et al. 2007). These studies have benefitted from advances in analytical techniques and the development of various geochemical dispersion models. Development of reliable techniques to detect mineralisation through thick transported overburden opens up previously underexplored areas, many of which are located in arid terrains. Whilst most studies have focused on the mineral associations and distribution of trace elements, others have looked more broadly at physico-chemical changes in, or characteristics of the overburden profile or groundwater. A recurring theme in most geochemical dispersion models and empirical studies is that of variations in the measured pH in regolith or groundwater due to the presence of oxidised or oxidising sulfides, or the effects that pH changes have had on regolith or overburden mineralogy and geochemistry (e.g. Govett 1976; Smee 1998; Hamilton et al. 2004; Mokhtari et al. 2009).

Electromagnetic surveys are commonly employed in exploration for primary sulfide ore bodies, and have been extended to soil and regolith studies to map salinity (mainly for agricultural purposes) and even to recognise regolith structure. Such methods have not been used extensively in exploration for deeply buried mineralisation in overlying transported regolith, despite various models indicating the potential for development of weak alteration haloes which may affect the composition of the blanketing regolith cover.

A comparison between the geochemical characteristics of the upper part of the transported regolith and the shallow EM response (reflecting soil conductivity) has been undertaken over the sub-economic Mandamah porphyry Cu-Au deposit (~0.3% Cu) in central NSW, Australia (Fig. 1). Here, structurally-controlled quartz-pyrite-chalcopyrite mineralisation is hosted by altered andesitic Siluro-Ordovician Gidginbung Volcanics. A central zone of sericite-pyrite alteration (containing higher grades of mineralisation) is surrounded by a zone of sericite-chlorite-magnetite-albite alteration (MacCorquodale, 1997). Discontinuous zones of pyrite alteration (and acid-generating potential in the regolith) extend beyond the zone of Cu mineralisation.

Mineralisation was discovered by Gold Mines of Australia when drilling aeromagnetic geophysics-defined targets as part of a regional reconnaissance program. The deposit is overlain by 30 m of in-situ regolith and 50 m of alluvium containing quartz, lithic fragments, kaolinitic clays and minor amounts of Fe-oxides. The upper 70 cm of the profile contains discontinuous carbonate-rich patches (mainly magnesian calcite). Recent drainage lines, with narrow zones of alluvium accumulation, contain slightly lower K values, as indicated by the regional airborne radiometrics dataset, than the surrounding areas.

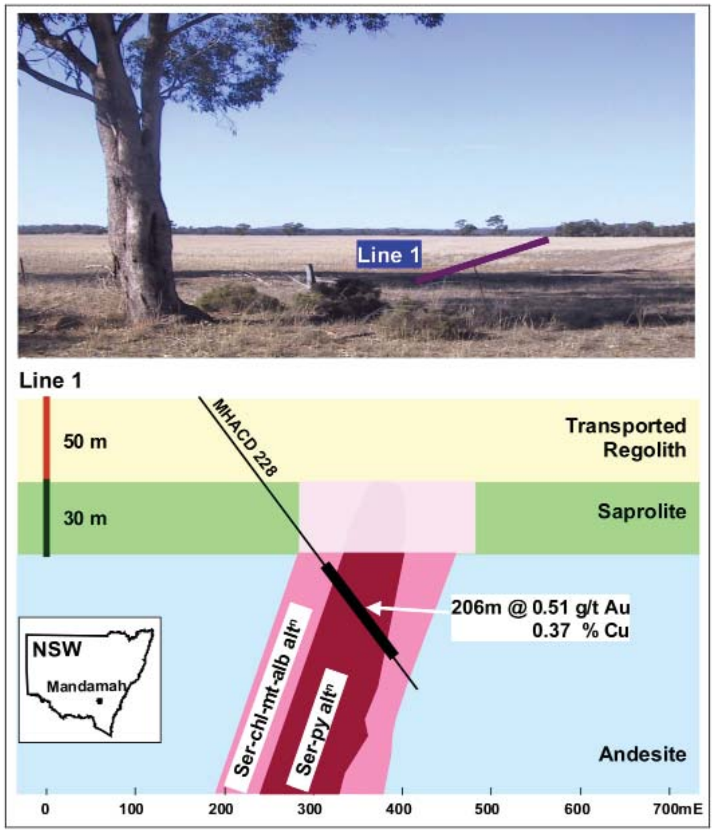

Figure 1. View across the Mandamah site in central NSW, Australia, with geological and regolith profile below Line 1.

Methods

AurionGold completed an extensive reverse circulation exploration drilling program, analysing aqua regia-extractable Cu, Au and other elements at 2 m intervals from surface to ~100 m depth (Fig. 2). In the current study, various soil physical and geochemical parameters were measured on more than 550 regolith samples collected from a series of 1.5 m deep pits and 1.8 m soil cores, along two traverse lines crossing the zone of buried Cu mineralisation (Figs. 3 & 4). Samples from 20-cm increments down the cores and pit faces were subjected to both ammonium acetate (pH 5)

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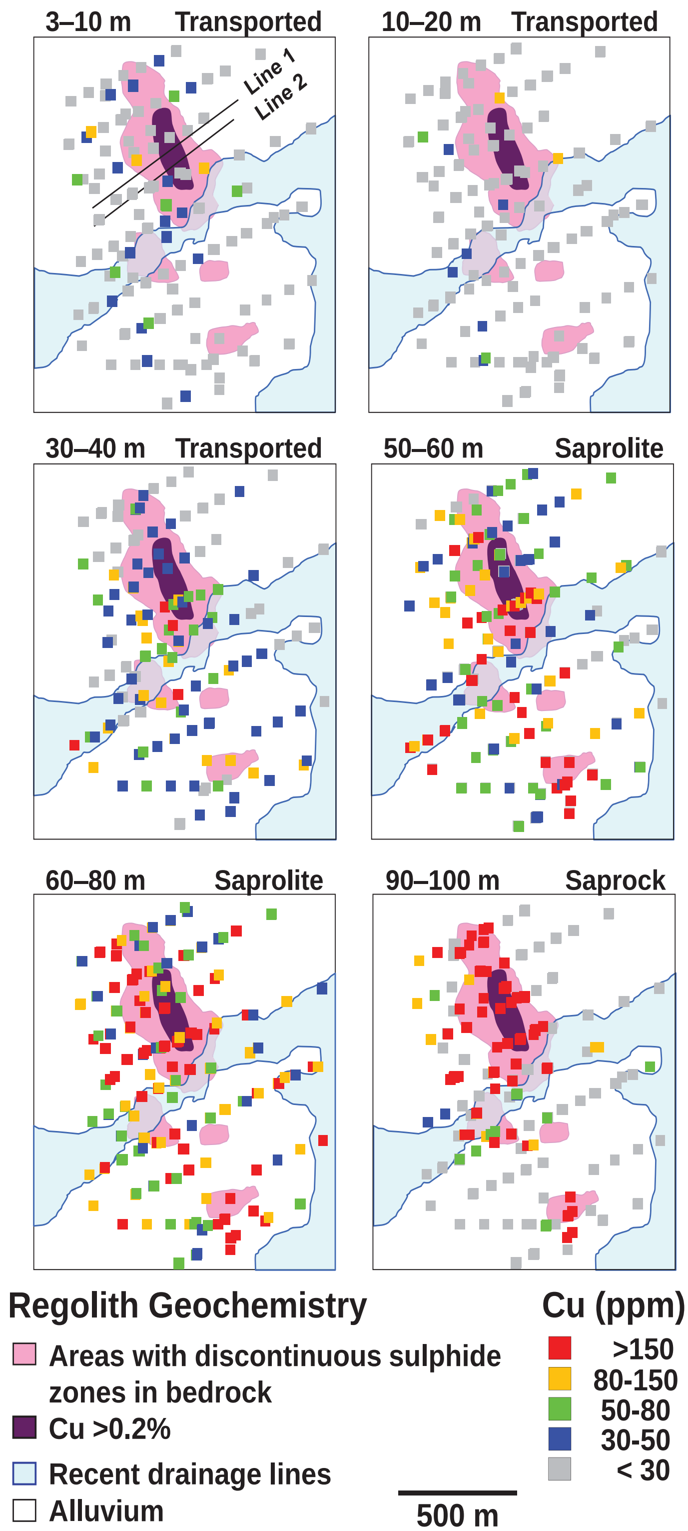

Figure 2. Location of deeply buried sulfide mineralisation and spatial variation in aqua regia Cu contents of various intervals within residual and transported regolith at Mandamah.

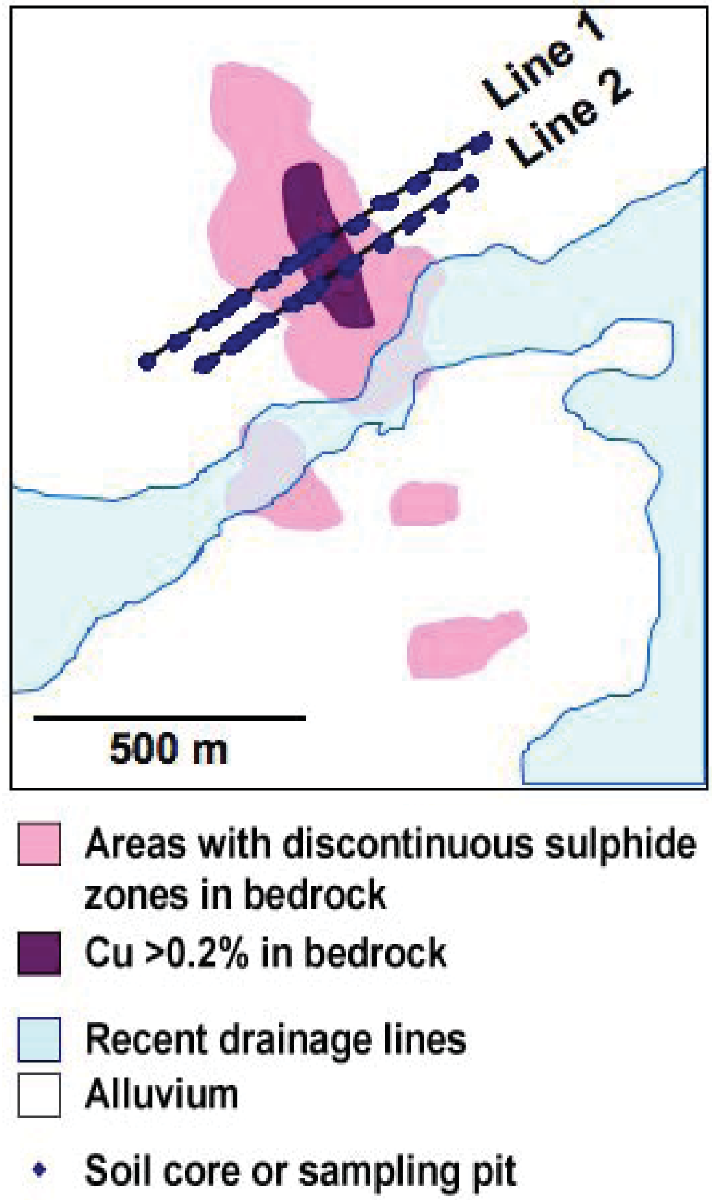

Figure 3. Location of soil core and sampling pit sites along Lines 1 and 2.

and aqua regia digestion followed by ICP-MS analysis, as well as measurement of slurry pH, EC and methylene blue cation exchange capacity (CEC). The shallow EM response was measured at 10 m spacing along both traverses using a Geonix frequency-domain EM-38 device, that provides around 1.5 m penetration in vertical dipole mode and 0.75 m in horizontal mode (Fig. 4). Following a study of the scale of variation in the EM data, this survey was subsequently extended to examine patterns across the property, based on a series of 5,000 measurements taken every 10 m along 30 traverses with 25 to 50 m line spacings. This second phase of the EM mapping followed a 2-year dry spell where just 450 mm total rain fell across the period 2006-07, compared with 910 mm across 2004-05, and corresponded with a reduction in the average conductivity of the soil (though similar patterns in conductivity variation along lines re-sampled in phase 1).

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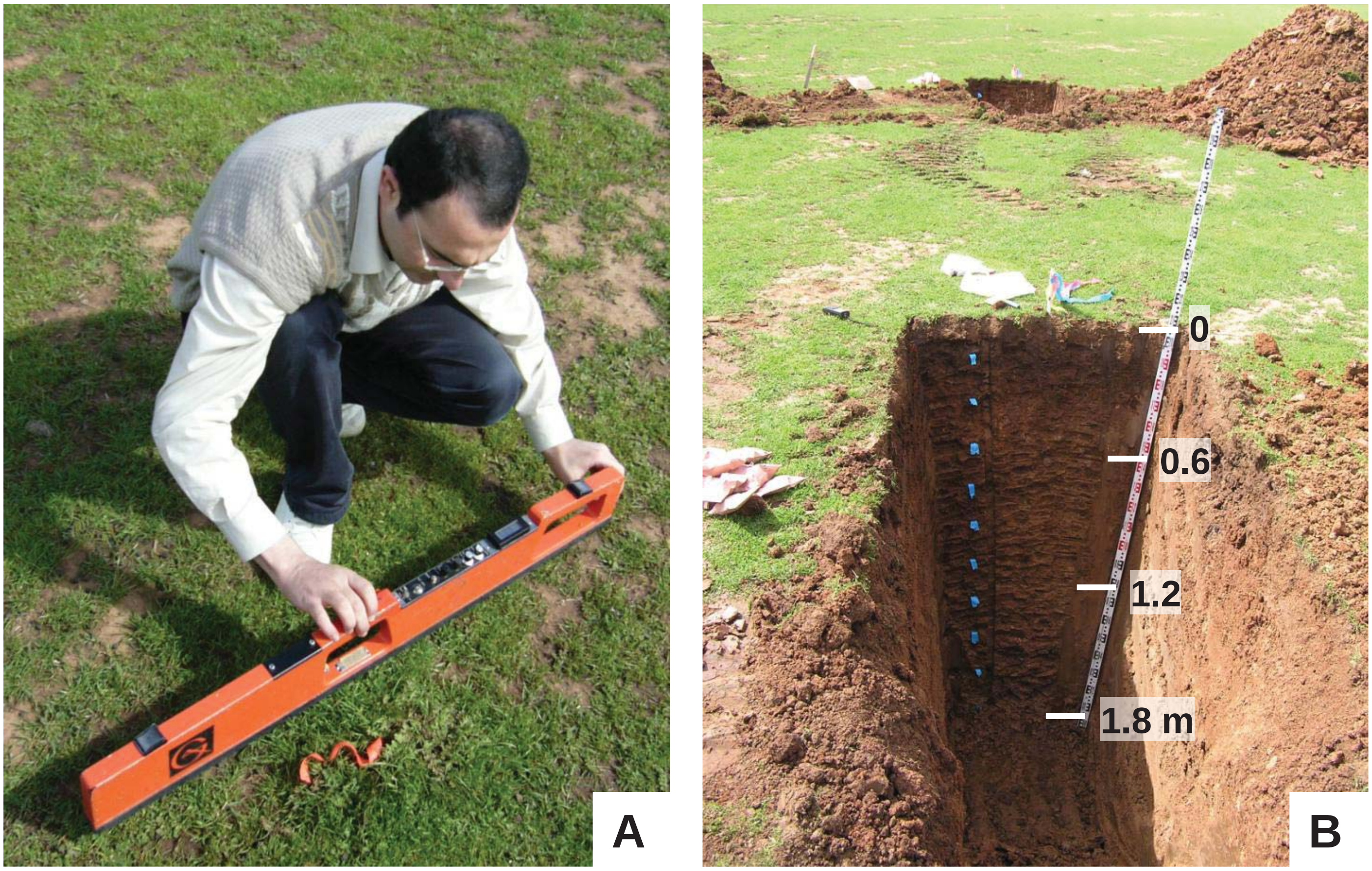

Figure 4. (A) Measurement of shallow EM measurements using a Geonix EM38. (B) Example of typical profiles through the upper 1.5 m of transported regolith at Mandamah. The upper 30 cm is disturbed by ploughing and displays near-neutral pH. Between 30 cm and ~70 cm depth there is carbonate accumulation and the pH is 9 to 9.5. Below 70 cm the regolith displays pH 5 to 6 and Fe mottling.

Results

Elevated total Cu values (>80 ppm) in the saprock are generally restricted to the zone directly overlying the zones where Cu values exceed 0.2% (Fig. 2). There is substantial lateral dispersion in the overlying saprolite and the base of the transported regolith cover. The upper 20 m of transported cover contains a few slightly elevated Cu values above and to the west and southwest of the underlying mineralisation. On Line 1, both the vertical and horizontal mode EM configurations display a discontinuous zone of low conductivity above the eastern (and high grade) section of buried mineralisation (Fig. 5). A similar EM response to that of Line 1 is observed on Line 2, although there is a slight (50 m) shift between the centre of the low-conductivity zone and underlying mineralisation (Fig. 6). Above mineralisation on both lines, the variation between the magnitudes of responses in the different modes is lower than areas away from mineralisation. These vertical patterns cut across the horizontal mineralogical and pH zonation in the upper 2 m of the regolith in the area.

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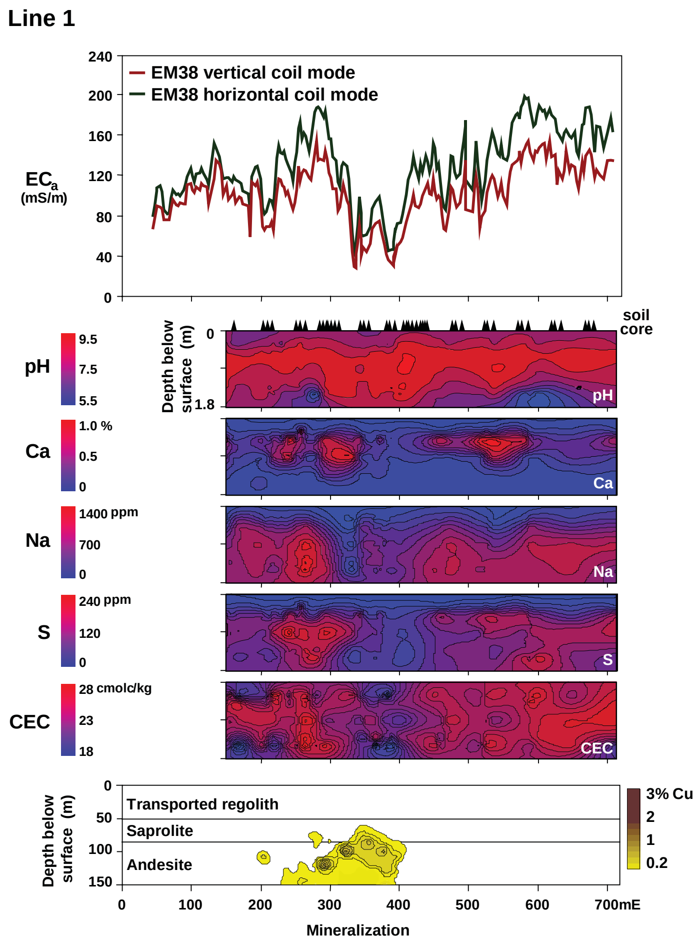

Figure 5. Comparison between surface EM response and profiles for pH, CEC and aqua regia Ca, Na and S in the upper 2 m regolith profile across mineralisation on Line 1.

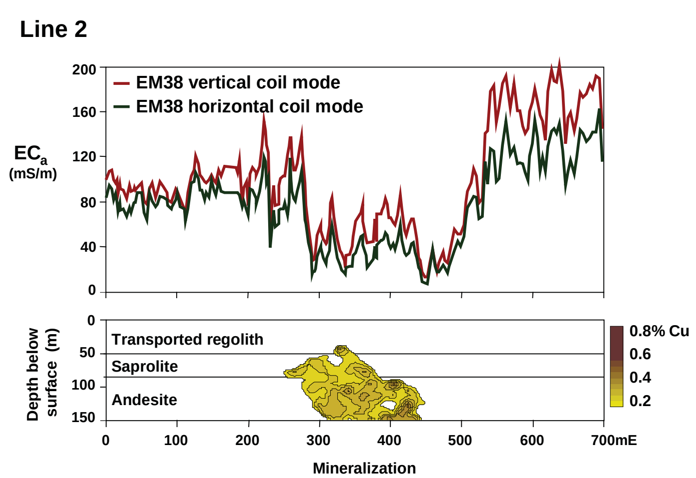

Figure 6. Shallow EM response within the upper 2 m regolith profile across mineralisation on Line 2.

Chemical analysis of the transported regolith shows that electrical conductivity is correlated with CEC and aqua regia-extractable Na and S contents. Calcium concentration displays a classic "rabbit ears" anomaly pattern with accumulations of magnesian calcite either side of the low conductivity zone. The high pH zone on Line 1 does not, however, correspond with elevated pedogenic carbonate concentrations. Aqua regia and ammonium acetate-extractable trace elements patterns in the upper 2 m of regolith do not indicate detectable mass transport of ore-related elements (e.g. Cu, Mo, Au) from mineralisation into the upper part of the overlying transported regolith.

The results of the shallow EM mapping are presented in Figure 7. At the scale of a few metres, there is a high degree of variability in the EM response in the southern part of the property and central part of the western side related to formation of "gilgai" structures produced by swelling clays in the soil (particularly in the northern part of the area). When the effects of local variation on the scale of tens of metres are measured using the absolute value of the first derivative for the smoothed raw data (Fig. 7B), the zone of higher grade Cu mineralisation is characterized by consistently low variation above the mineralization, but a number of zones displaying high variability around the projected edge of the mineralisation (as also indicated in Figs. 5 & 6). Small zones of low-grade, discontinuous sulfide mineralisation to the south of the main Cu mineralisation zone also display limited EM variation in the regolith above mineralisation and increased variation in some places around their projected edges. It is difficult to define a distinct relationship between the EM variability and the location (and edges) of the low-grade sulfide mineralisation that envelopes the higher grade Cu mineralisation.

Discussion

The EM response across the property is controlled by various factors and at different scales. At the broad scale, shallow-depth regolith conductivity is mainly controlled by the effects of recent landscape-modifying processes. These effects include low-conductivity zones in the areas of recent deposition of alluvium along shallow drainages zones (shown in light blue) and a recently ploughed paddock on the NW corner of the area, with generally elevated values elsewhere on the property (Fig. 7A).

The regolith evolution model being developed for Mandamah (Mokhtari et al. 2009) involves the development of an acidic chimney in transported regolith over oxidizing mineralisation during a period (of unknown duration) of more elevated ground water levels. This also resulted in a leaching of carbonate from at least the upper 2 m of regolith above mineralisation and the acid-induced alteration of clays from a 2:1 to 1:1 structure. With the subsequent Late Miocene onset of aridity and reduction in the amount of acid moving to the surface, an influx of Na and Ca and their exchange with clays generated a shallow zone of non-carbonate soil alkalinity at surface over mineralisation. Broad controls on the shallow EM response (soil conductivity) in the area are dominated by the effects of recent alluvium deposition and flushing of salt out of the upper few m of the regolith along recent drainage lines, and the effects of farming activities. There is however a local trend of low conductivity in the shallow regolith over a number of mineralised zones at the site (relative to the surrounding area) and increased variability at the tens of metres scale at the edge of mineralisation.

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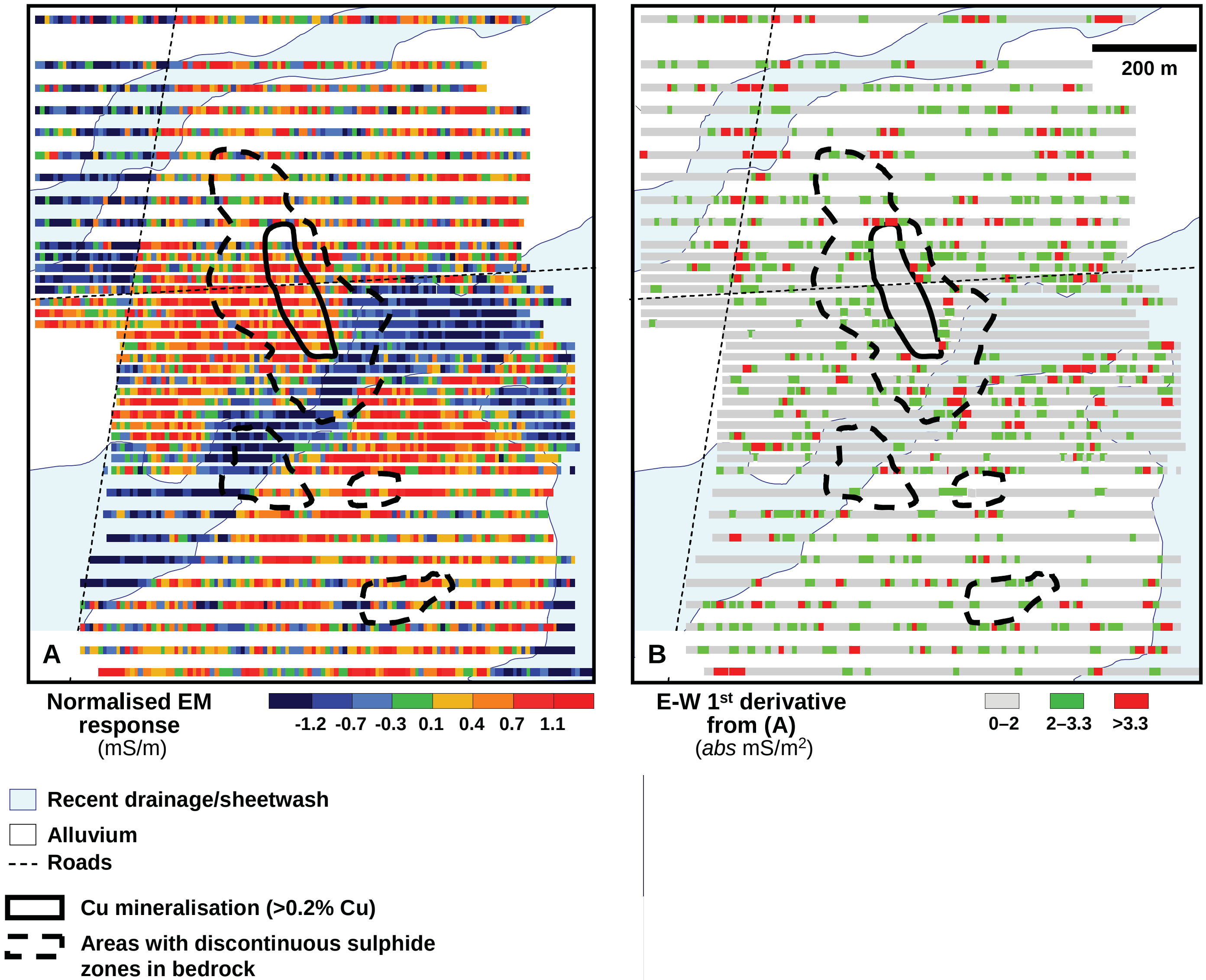

Figure 7. (A) Vertical dipole mode EM response across the Mandamah site, normalised on a line-by-line basis. (B) Absolute value of the first derivative of the vertical mode EM response in the E-W direction.

EM patterns tend to be more strongly developed if preceded by recent rain showers. The EM patterns observed above mineralisation are not unique within the property, and there are other areas at Mandamah with circular to elongate zones of low EM variability. Whether these other zones also display non-carbonate alkalinity is the subject of ongoing research at the site.

Conclusions

Geochemical and mineralogical patterns in the upper parts of transported regolith at Mandamah may be explained in terms of the effects of a (now inactive) acid chimney that developed within transported regolith above buried sulfide mineralisation. Whereas the EM patterns that appear spatially related to the effects of mineralisation on the overlying transported regolith are subtle, and patterns similar to those

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above mineralisation are observed in areas of the property with no known mineralisation, this study should encourage further evaluation of shallow EM methods, in combination with measurement of various soil chemical parameters (mainly pH and carbonate content), to assist in the detection of deeply buried mineralisation.

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References

Cohen, D.R., Kelley, D.L., Anand, R. & Coker, W.B. 2007. Major advances in exploration geochemistry, 1998-2007. In: B. Milkereit (ed), Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration, 3–18.

Govett, G.J.S. 1976. Detection of deeply buried and blind sulphide deposits by measurement of H+ and conductivity of closely spaced surface soil samples. Journal of Geochemical Exploration, 6, 359–382.

Hamilton, S.M., Cameron, E.M., McClenaghan, M.B. & Hall, G.E.M. 2004. Redox, pH and SP variation over mineralisation in thick glacial overburden. Part I: methodologies and field investigation at the Marsh Zone gold property. Geochemistry: Exploration, Environment, Analysis, 4, 33–44.

MacCorquodale, F. 1997. The Mandamah porphyry Cu-Au prospect: new developments in research for ore deposit exploration. Proc of Third national conference of the Specialist Group in Economic Geology. Geological Society of Australia, 44–51.

Mokhtari, A.R., Cohen, D.R. & Gatehouse, S.G. 2009. Geochemical effects of deeply buried Cu-Au mineralisation on transported regolith in an arid terrain. Geochemistry: Exploration, Environment, Analysis, 9, 227-236.

Smee, B.W. 1998. A new theory to explain the formation of soil geochemical responses over deeply covered gold mineralisation in arid environments. Journal of Geochemical Exploration, 61, 149–172.

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