INTERPRETING AND APPLYING AIRBORNE ELECTROMAGNETIC INFORMATION (TEMPEST™ AEM SYSTEM) FOR REGOLITH AND ENVIROMENTAL STUDIES

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INTRODUCTION

The application of any tool or technique depends on the scale and issues one is trying to resolve. In the extensive landscapes of Australia variation in sedimentary environments, depth of weathering and weathering processes have combined to produce a regolith layer that is thick and complex, especially in the low lying areas. Conventional surveys such as soil and surface hydrology are used to define surface regolith-landscape models and the hydrology of the vadose zone, and provide valuable information for various purposes, e.g. agriculture and engineering. However, these models fall short of postulating the three dimensional (3D) distributions of regolith materials at depth and their attributes, such as sedimentary facies and base of weathering. Data from water bores and other drilling can be utilised but are only able to provide a generalised conceptual model except in local areas with high drilling density. Hence, other remotely sensed datasets, e.g. airborne geophysics, are required to fill in the data gap in regolith-dominated terrain.

High-resolution airborne geophysics (magnetic, radiometric, electromagnetic) are interpreted and integrated to map both the surface and subsurface characteristics of the regolith. The size of study areas varies, and in the case of the Geoscience Information for Land Management, Ore Research and Exploration (GILMORE) project is < 900 km^2 (Barmedman area, Figure 1). The GILMORE project was a pilot study designed to test methodologies and technologies for assessing mineral prospectivity and dryland salinity in areas of complex regolith cover (Lawrie, 1999). Numerous State and Federal agencies recognise the value of these techniques and comprehensive coverages are now being acquired (e.g. Honeysuckle Creek, Victoria). Airborne electromagnetic (AEM) surveying using the TEMPEST™ (time domain) EM systems show the potential of becoming new subsurface mapping tool, especially for revealing saline groundwater systems through establishing the distribution of regolith materials and palaeogeography.

REGOLITH ATTRIBUTES INFLUENCING THE ELECTRICAL CONDUCTIVITY RESPONSE

The electromagnetic (EM) technique effectively measures the electrical signatures of surface and subsurface regolith materials and bedrock. There are several factors affecting the electrical conductivity (EC) of regolith materials, which have been explained by Rhoades *et al.* (1976) using the following mathematical model (under a constant temperature):

$$EC = ECw.\theta.T + ECs$$

where ECw = Electrical conductivity of the liquid phase (a function of salinity)
θ = Volumetric water content
T = Tortuosity
ECs = Electrical conductivity of the solid phase (a function of cation exchange capacity of clay minerals etc.).

While EC is a function of a number of variables, the most important factors controlling it are water content and salt concentrations. The solid phase is not a significant factor in driving the EC response except under conditions of low water content (McNeil 1980) or salinity. Therefore, any attribute that affects the amount of salt would have an effect on the EC. These attributes include porosity, the ratio of phyllosilicates to non-phyllosilicates and the ionic concentrations in pore fluids. For example, weathering of bedrock increases the phyllosilicate abundances, which increases the porosity and hence EC. Similarly, clay-rich sediments have higher porosity compared to silt (mostly quartz) and sand- or gravel-rich sediments. In terms of water-rock interactions, Na^+ and Cl^- are the dominant ions in most saline groundwater and are the main driver for variation in EC (Simon *et al.* 1994).

THE DATA / MODELS OF TEMPEST™ AEM SYSTEMS

The TEMPEST AEM system has improved depth of penetration and conductivity resolution over the older SALTMAP system (George 1998). For the GILMORE project, AEM surveys were flown at 120 m above ground and 150 m line spacings to give optimum resolution and the secondary field was measured (fiducial point) every second along each flight path. More economical surveys can be carried out at 400 m line spacings with a trade-off in resolution. The acquired data has to undergo several steps to remove noise before final datasets are produced. The details of processing raw data are elaborated in Lane *et al.* (2000).

The final data at each fiducial point undergoes computation to generate models of ground conductivity. The Layered Earth Inversion (LEI) model assumes several layers in conductivity structure (usually 3—an upper resistor, middle conductor and lower resistor), and calculates conductivity and thickness for each layer at each fiducial point. In comparison, the Conductivity Depth Inversion (CDI) model calculates conductivities of various depths at each fiducial point (for the GILMORE project, conductivity values were calculated at 2 m vertical intervals). To aid visualisation, the point data from a 3-D space can be combined to give profiles of conductivity along flight lines or maps of conductivity at specific depth intervals. For the GILMORE project AEM data set, the CDI depth slice images are computed at 5 m depth intervals.

ENHANCING CDI IMAGES TO MAXIMIZE INFORMATION EXTRACTION

Interpretation of CDI images to obtain relevant information is based on identifying patterns of similar conductivity values, and the use of high colour contrast across a specific EC range to aid the identification process. Maximum colour contrast of each CDI image can be achieved by changing the data input limits and stretching the look-up table (LUT) histogram using ER-Mapper™ image processing software algorithms. The LUT stretch may include default-linear, equalised histogram, or log-transformed; each type of stretch is useful in enhancing the contrast across specific conductivity range intervals. For example, a log transformation on a normal pseudo-colour LUT will enhance the contrast amongst areas with low EC, whereas the default linear algorithm with fixed input ranges can be utilised across numerous CDI depth intervals to display the changes of EC with depth. The CDI images can then be examined in consecutive order (i.e. from depth to the surface) to derive a preliminary conceptual model of the basement rock and base of weathering, changes in drainage direction and systems and sediment fills and facies.

Depending on the algorithm used, shades of blues, greens and reds can depict various regolith materials or salinity concentrations. In the Barmedman area, palaeo-drainage patterns with coarse texture appear blue whereas clay bodies (include clay-rich saprolite) appear orange to red (using a normal pseudo-colour equalised histogram LUT, Figure 1). Alternatively, a CDI depth slice image using a reverse pseudo-colour histogram can be produced to enhance the coarser palaeodrainage and colluvial sediments, mostly derived from granite sources (Figure 2). In this case the coarser materials appear yellow and red and clays and silts appear blue.

ACHIEVING A ROBUST INTERPRETATION OF AEM INFORMATION AND CAVEATS

Since EC is affected by several attributes, determining the main contributing factor may at times be difficult. For example, patterns depicting palaeodrainage (generally lower EC) are easy to separate from the surrounding higher EC values. In the GILMORE dataset, that includes comprehensive ground-truthing, sediments in the palaeodrainages are commonly coarser grained, which reduces porosity, water content and hence EC. However, if these sediments were conduits to fresher groundwater flows, the pore fluid salinity would be lower and, together with lower water content, contribute to a lower EC. Without the controls obtained from pore fluid chemistries analysed from drill core materials, the salinity could not have been ascertained from CDI images alone. Likewise, in the vadose zone it is a challenge to differentiate between coarse textured sediments, saprock, and sediments with fresh water as all three conditions give rise to low EC. Under such circumstances, the shapes and patterns of similar low EC values may provide some clues. Diffreentiation between clay-rich saprolite and fine-textured sediments is not obvious due to the similar pore volume and hence water content. If salinity remains relatively constant, these different materials will give similar EC response.

The above examples imply that AEM data has to be used in conjunction with other data to achieve robust interpretation of hydrology and regolith information. The range of data needed includes geology, geological structures and soil-landscape relationships. This information can be gathered from maps. Other information can be obtained from airborne geophysics coverages including magnetic (to delineate magnetic drainage patterns and bedrock), radiometric (for identifying surficial materials) and digital elevation models. Ground based data such as drill hole logs (visual texture estimates and stratigraphic unit characterisation), down-hole EC (using EM39) and natural gamma logs are used to constrain the airborne geophysics data (Figure 3). In addition, laboratory analyses such as pore fluid chemistry, water content and grain size distribution (by laser diffraction techniques) of representative drill core materials would provide the detailed information and aid in establishing the causal attributes affecting the EC responses. Equally important is obtaining hydrological information from piezometers, which can provide constraints to the conceptual hydrological model.

APPLICATIONS OF AEM INFORMATION

AEM is a good surveillance technique for gathering near-surface and sub-surface information and, when used in conjunction with other information, has a wide range of applications for geomorphology, mineral exploration, environmental and engineering research. Primarily, the AEM information can assist in the mapping of palaeodrainage patterns and drainage evolution, broad scale 3-D sedimentary facies, palaeogeography and base of weathering. Once the attributes controlling the EC responses (i.e. water content, salinity and texture) have been identified, the salt mobility (along preferential groundwater pathways), salt stores (clay-rich zones) and aquifers (confined or non-confined) can be inferred. However, the identification of groundwater pathways needs substantial hydrological data and other knowledge.

There is a growing demand for hydrologists to determine the hydraulic conductivity of regolith materials to calculate salt export from a basin, and the risk of rising water tables from irrigation. However, to map the hydraulic conductivities of the regolith materials using AEM is still a challenging task. The hydraulic conductivities of representative samples from different materials have to be tested in the laboratory. Anisotropy and heterogeneity of hydraulic conductivity at micro-scale decreases the confidence of estimating the hydraulic conductivity at macro-scale. Hence, information obtained from AEM would only be estimates on a kilometre scale.

Exploring for mineral deposits on a prospect scale is partly dependent on intersecting physical and chemical dispersion haloes, which provide vector to the deposits. Knowing the palaeogeography from AEM data can provide drilling targets and delineate potential sampling medium (e.g. basal sediments of palaeo-valley).

CONCLUSIONS

Modern high-resolution airborne geophysics (magnetic, radiometric, electromagnetic) make these datasets suitable for regolith and environmental studies. Both LEI and CDI models are computed from AEM data, and depth-slice images have been produced to aid in visualisation of conductivity patterns. In conjunction with other knowledge such as geology, soil-landscape relationships and ground truth analyses, a robust interpretation of hydrology (salinity), regolith attributes and palaeo-geography is attainable.

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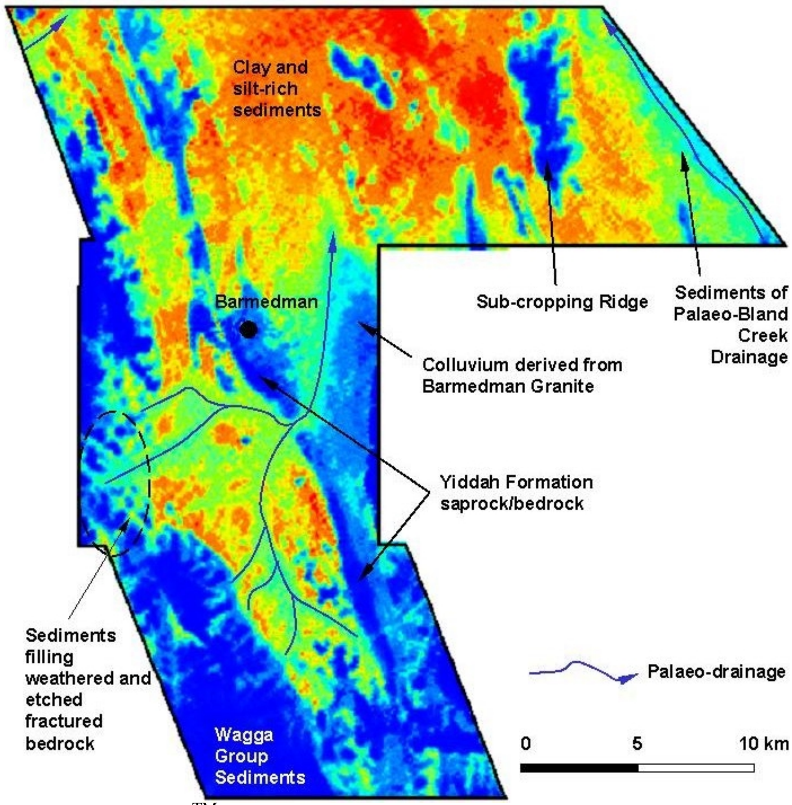

Figure 1: Showing the TEMPEST^{TM} EM survey area, Barmedman region. The area surveyed is < 900 km^2. The normal pseudo-colour equalise histogram LUT is used to generate this CDI depth slice image (20–30 m).

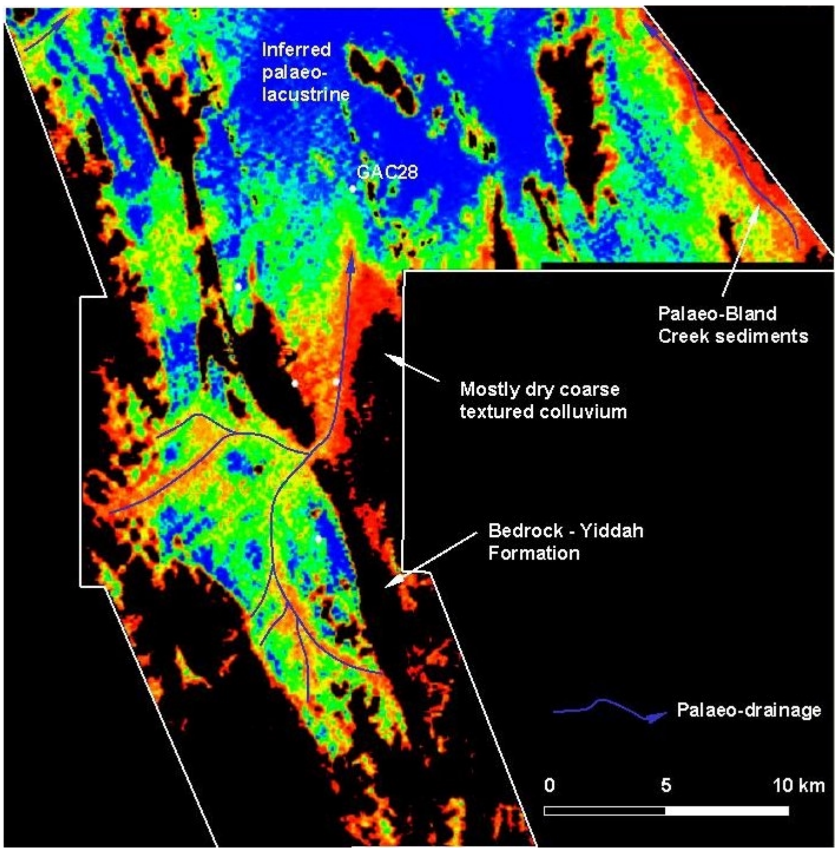

Figure 2: Same CDI depth interval (20–30 m) as in Figure 1 but using reverse pseudo-colour histogram. The yellows and reds denote coarser textured materials whereas the blues depict silts and clay. Areas being masked (black) are bedrock or coarse and dry materials.

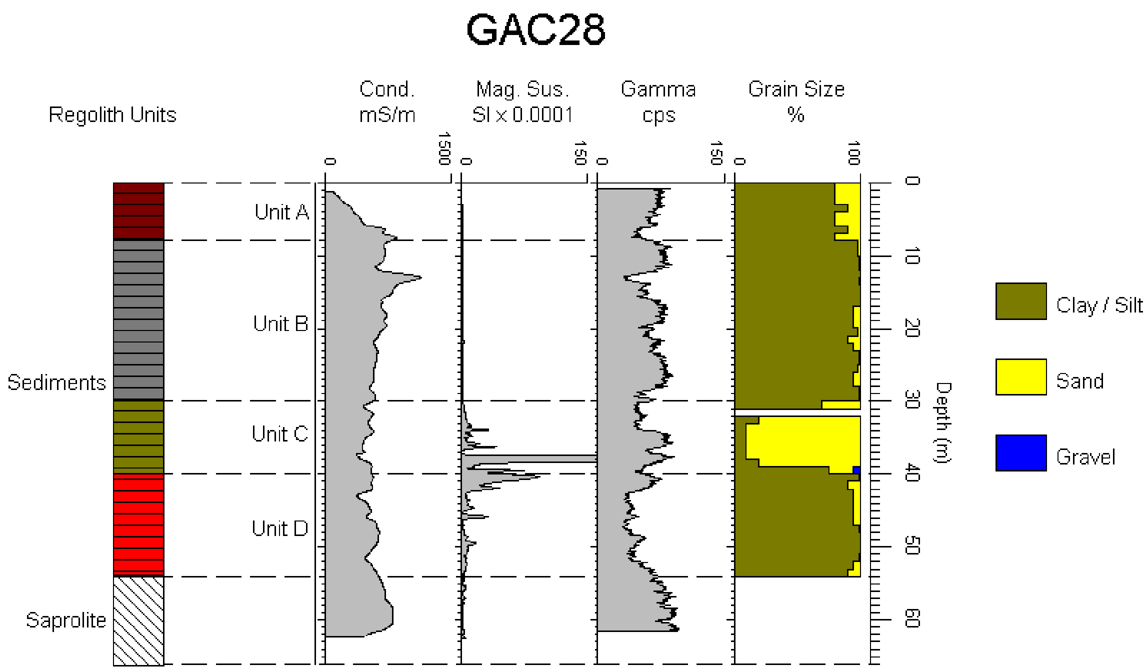

Figure 3: Ground-based geophysics, visual texture estimates and classification of stratigraphic units were used to ground truth the AEM data.