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Peeling back the cover on an ancient landscape – AEM in the Musgrave Province, South Australia.

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SUMMARY

A thick and complex regolith cover hinders exploration through the Musgrave Province, a region of Mezo-Proterozoic crystalline basement, in the north of South Australia. The area is prospective for magmatic Ni-Cu-PGE and IOCG mineral systems, but a lack of knowledge about the variability and extent of the cover sequences increases the risk and cost of exploration.

Through the application of deterministic inversion of two regional-scale AEM surveys and an approach based on an attribute-guided regression technique called Smart Interpretation (SI), a map of regolith cover thickness and complexity has been generated. The palaeovalleys present in the region have been defined and the geometry of the pre-Pliocene landscape determined.

Key words: AEM, Smart Interpretation, machine learning, regolith thickness, palaeovalleys.

INTRODUCTION

The presence of a thick and complex regolith cover across many parts of Australia represents an impediment to effective and efficient minerals exploration. This is exemplified in the Musgrave Province, located in the far north west of South Australia (Figure 1), which is a region of Mezo-Proterozoic crystalline basement, consisting mainly of the amphibolite and granulite facies gneisses intruded by mafic – ultramafic dykes and granitoids, and dolerite dyke intrusions. The area is highly prospective for magmatic Ni-Cu- PGE and IOCG deposits (Woodhouse and Gum 2003). However, outcrop in the region is limited (Figure 1) with the Province having experienced at least one phase of intensive deep weathering and erosion prior to the deposition of clastic sediments of the Mesozoic Officer and Eromanga Basins along its southern and eastern margins. During the Neogene, rivers incised up to 150m into the older cover sediments and the basement rocks. These deep valleys were subsequently filled with Pliocene to Pleistocene clastic sediments and more recently covered with Quaternary sand dunes. Although the deep palaeovalley system is known to be present throughout the area from limited drilling, its extent and the geometry of these palaeodrainages is poorly understood. This presents a particular challenge to explorers.

Understanding the character, in particular the thickness and variability of cover materials in this region is the focus for this paper employing regional-scale AEM survey data acquired by the Geological Survey of South Australia and the Goyder Institute. Through the application of deterministic inversion of the AEM data and an approach based on an attribute-guided regression technique called Smart Interpretation (SI) (Gulbrandsen et al., 2017), we have attempted to derive a map of regolith cover thickness and understand the nature of the pre-Pliocene landscape as a means of assisting exploration through the region, but also as an aid to determining the potential groundwater resources present. The buried palaeovalleys are known to contain groundwater of varying quality (Watt and Berens, 2011).

METHOD AND RESULTS

AEM Surveys

For the State Government regional AEM data acquisition, two different AEM surveys were planned with a relatively wide line spacing of 2km, wide enough to cover a large region, whilst being close enough to provide useful information about the variability of cover, including the location and geometry of the major palaeovalley systems known to be present in the area. Both surveys were flown with a line spacing of 2km in a north-south direction. The western survey was flown with the TEMPEST high moment (HM) system, and the eastern part with the SkyTEM312 system (Figure 1). Both systems are time domain airborne EM systems, one being of a fixed wing configuration (TEMPEST), the other being helicopter borne (SkyTEM).

Rationale for different AEM systems

The rationale for selecting two different systems for the survey was linked to cost and to the need to acquire spatial information at scales appropriate to the targets of interest. In the western region, the aim was to acquire information relating to basement geology and cover, the latter being of an undetermined thickness and conductivity. The presence of the Lindsay palaeochannel (Alley and Lindsay 1995), interpreted as a sediment-filled major trunk drainage system that runs through the Musgrave Province from north to south was also a target, although little was known of the thickness of the cover within it, or its conductivity. The serendipitous targeting of deep conductors was also considered in the choice of systems. With these points in mind, the fixed-wing TEMPEST high moment (HM) AEM system was selected, potentially providing good signal to noise in areas of conductive cover, whilst also providing the moment required to explore deeper.

In the eastern region, the focus was on acquiring information on the aquifer systems present, particularly in the vicinity of the indigenous communities. For this reason, the SkyTEM312 AEM system was selected.

Processing and Inversion

The processing and the subsequent inversion of the TEMPEST and SkyTEM312 data was carried out using the Aarhus Workbench processing and inversion software (Auken et al. 2015). The processing procedure applied to the two datasets differed due to the nature of the provided raw data. For the purposes of this study, a 30 layer model was used for the inversion of both datasets. The first layer thickness was chosen to be 3m with logarithmically increasing thicknesses to a depth of 300m which is the depth of the last layer boundary.

We applied a laterally constrained inversion (LCI) (Auken and Christiansen 2004; Auken et al. 2005) to the two datasets with the spatial constraints, defined for adjacent soundings, allowing prior information (e.g., the expected geological variability of the area) to migrate along the flight lines.

Results were presented as conductivity-depth intervals below the ground surface, elevation slices and as conductivity–depth sections, thereby providing a spatial picture of changes in ground conductivity across the survey area. Figure 2 shows an interval conductivity (50-60m) for the combined TEMPEST and SkyTEM surveys. The more conductive linear zones are interpreted as being associated with a conductive sedimentary fill (related to saline groundwater) sitting in palaeovalleys incised into the basement.

Smart Interpretation

The Smart Interpretation (SI) algorithm employed here is described by Gulbrandsen et al. (2017), and is based on a linear regression technique developed for geological layer modelling. The method is based on a two-step approach with the first requiring a geologist or geophysicist (“the expert”) to define a physical interface such as the boundary between two lithological units, or in this study the interface between an un-weathered basement and regolith cover. This definition is initially done by manually “picking” this surface or interface on a conductivity-depth section of inverted airborne electromagnetic (AEM) data (Figure 3) within the GeoScene3D modelling package. While the expert is doing this manual picking, the algorithm tries to learn the relationship between the manually interpreted points and multiple available attributes associated with those points or picks. These can include the conductivity around the point, and/or the elevation of the point.

Specifically, the relationship is defined by the coefficients of a polynomial that are determined through linear regression, and attributes include any quantifiable piece of information such as the conductivity values, geographic coordinates, and elevation. After a few picks, when the algorithm has learnt the interpretation points attribute relation, it then, as a second step, proceeds to predict what the expert would interpret throughout the rest of the survey. This is simply done by applying the relationship learnt in the first step, to the rest of the survey on a line by line basis.

Results from the application of the SI across data from the deterministic inversion of the SkyTEM data are presented in Figure 4. The SI picked interface between the basement and the overlying regolith is plotted as an elevation surface (elevation of basement). The regolith thickness product (Figure 4 middle surface) is derived as the difference between the elevation of the contemporary landscape and the elevation of the basement. Thicker sequences of regolith are interpreted to sit within the incised palaeovalleys.

DISCUSSION

A map of regolith cover thickness across the areas covered by the regional AEM data sets was generated, providing a framework for continued exploration in the Province. In generating estimates of regolith thickness from the regional AEM surveys over the Musgrave Province, we have assumed that the initial “expert” picks account for the variations in modelled conductivity representative of the base of weathering or sedimentary (transported cover) fill. We have also assumed that the regolith, where present, is significantly more conductive that the unweathered basement, an assumption backed up by prior petrophysical studies of regolith settings/materials across Australia (e.g. Emerson et al. 2000). The absence of deep drilling, coupled with a fractured and deeply weathered basement, limits the more thorough assessment of the SI approach for cover mapping in the Musgrave region, but the results presented are consistent with observations made in local water bore and exploration drilling programs.

At this stage, it is more appropriate to consider the derived models of regolith thickness as representing *regional trends* in cover. Finer scale variability is known to be present, and can be similar in magnitude to the range of cover thicknesses observed in the derived products produced in this study. These fine scale differences cannot be resolved with data acquired with a line spacing of kilometres. This should be borne in mind when planning a drilling or sampling program in the region.

CONCLUSIONS

The cover of the Musgrave Province, being more conductive than the underlying basement rocks provides a good basis for using AEM data as a means for mapping its extent and thickness. Fast, automated and objective methods which employ machine learning approaches, such as the SI method used here, have application for defining the basement morphology, and the regolith thickness. The results are aimed at assisting the explorer or hydrogeologist, but caution is required in their interpretation given the wide line spacing of the survey. The results only provide an indication of trends in cover variability.

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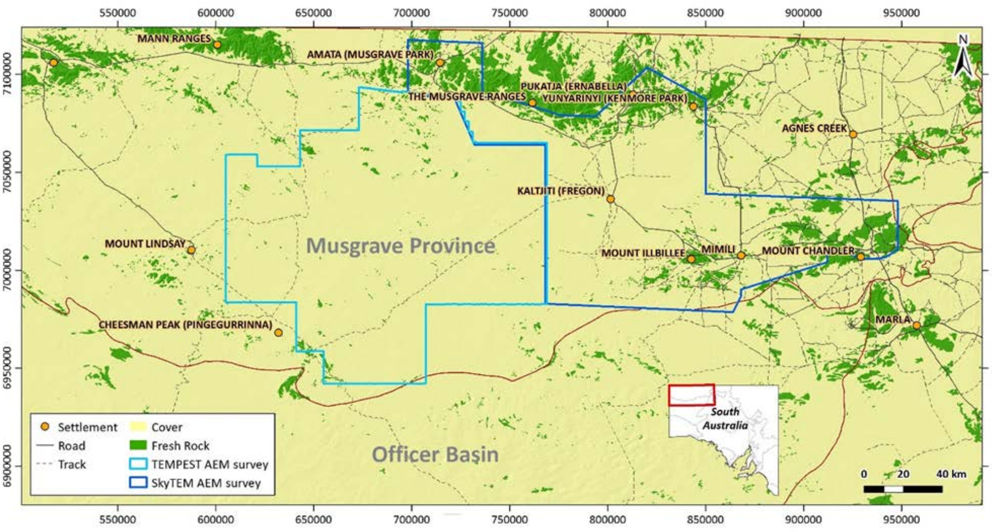

Figure 1: Map of the extent of regolith and sedimentary cover across the Musgrave Province in South Australia. The extent of two regional AEM surveys are outlined with the TEMPEST High Moment survey covering the western area, and a SkyTEM 312 survey the east.

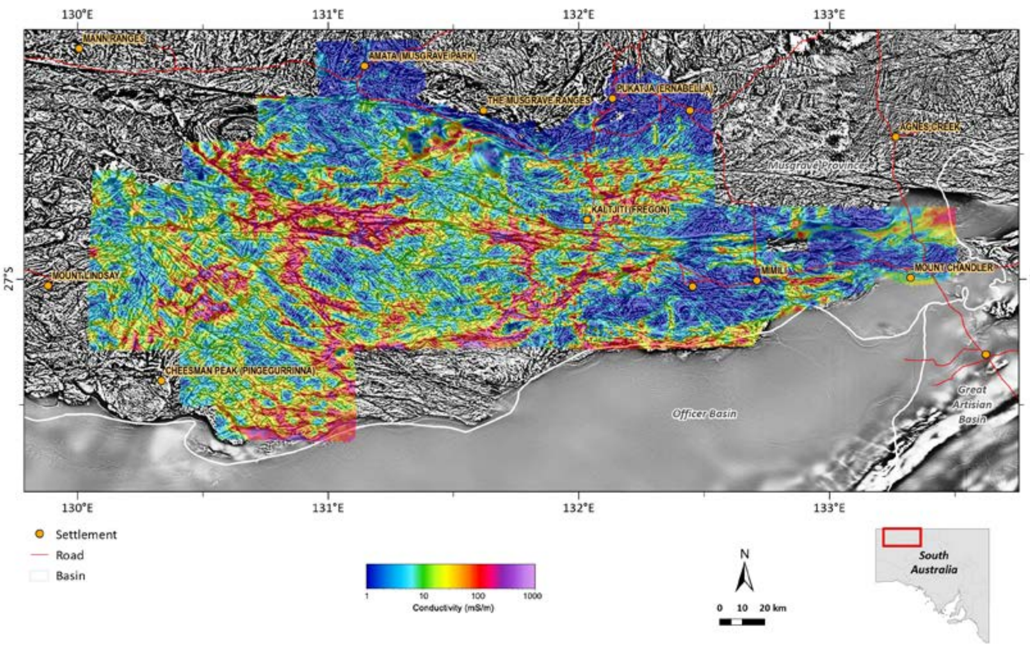

Figure 2. 50-60m interval conductivity image for the combined SkyTEM312FAST and TEMPEST HM AEM surveys overlain on 1st VD magnetic greyscale image. The more conductive areas shown in the combined images are commonly associated with a conductive transported fill sitting within deep palaeovalleys that have incised along and across a predominantly E-W

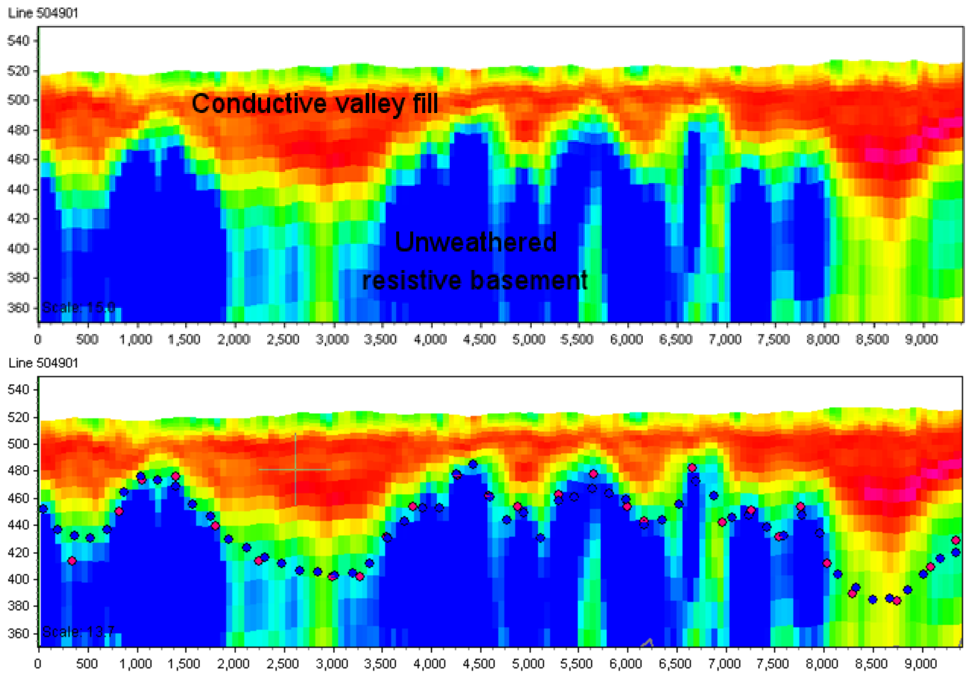

Figure 3. A conductivity-depth section (top) from part of line (504901) of SkyTEM312 data in the study area. The conductive parts of the section are interpreted to be the regolith cover, comprising a mix between transported sediments and *in-situ* saprolitic materials, which overlie a resistive Proterozoic Basement. The expert picks, representing the interface between cover and the basement are identified in the red dots (lower section) . The algorithm then predicts what the expert would have picked and populates the section with a predicted set of "picks" (blue dots in lower section).

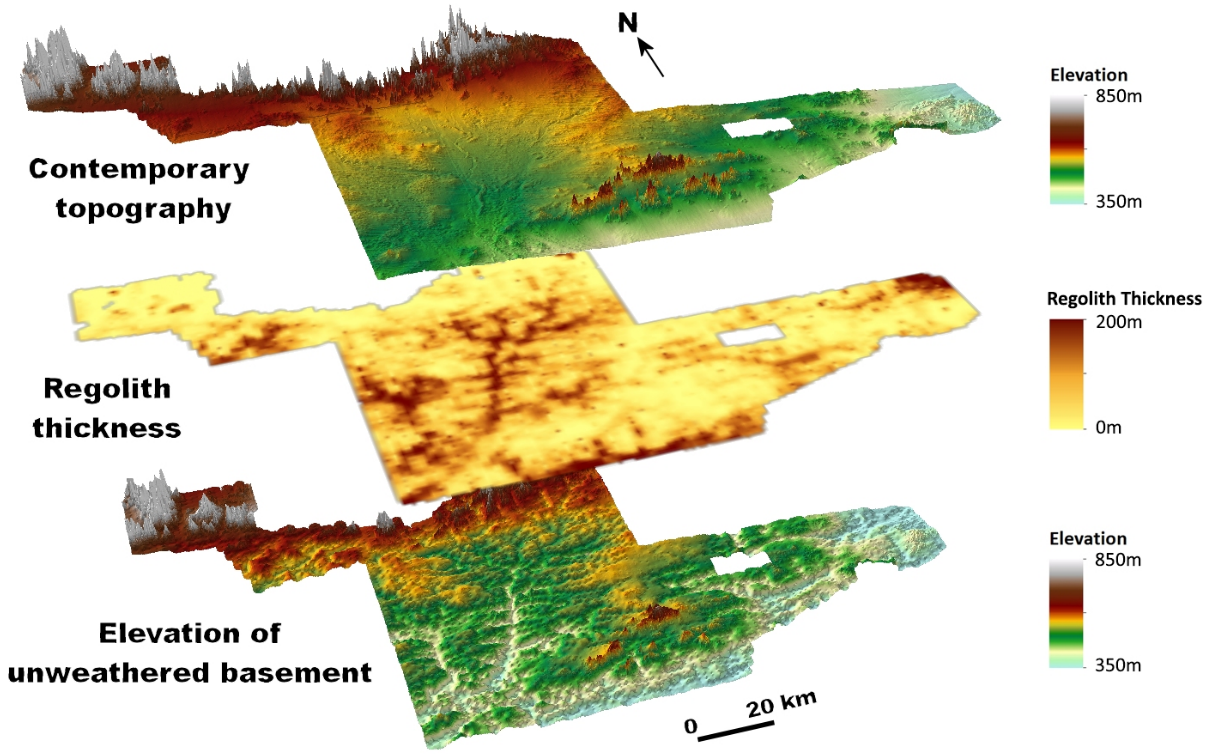

Figure 4. Perspective view (looking from the south to the north) of the area covered by the SkyTEM312 survey in the eastern part of the Musgrave Province (see Figure 1 for location). Top view is the contemporary topography, with a regional slope from the Musgrave Ranges in the north towards the Officer Basin in the South. The middle map is the regolith thickness derived from the application of a Smart Interpretation across the SkyTEM survey data set. Lower image defines the elevation of the unweathered Proterozoic Basement indicating presence of deep palaeovalleys