Uncovering the groundwater resource potential of Murchison Region in Western Australia through targeted application of airborne electromagnetics

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SUMMARY

Access to water is identified a key infrastructure need for mining, energy and industry development. In Western Australia, the scale of planned developments linked to current mineral exploration and mining is set to generate significant economic value for the State, but its realisation is dependent on ensuring access to groundwater. To address these issues, The WA Government Department of Water (DoW) has embarked on a series of groundwater investigations to identify and establish long-term water resources in regional areas where agriculture and mining opportunities have the potential for development. The Murchison in northern WA was identified as one of six key priority areas for this initiative. With numerous known mineral deposits having potential for development, locating and securing an adequate, sustainable long-term water supply is a critical consideration if these mineral resources are to be developed further. While it is known that there are significant groundwater resources in the region, at present these are generally poorly understood.

Of particular importance are the palaeovalley aquifers which are known (locally) to contain a significant resource, but which are relatively poorly characterised. To aid an understanding of their extent an airborne electromagnetic (AEM) survey was commissioned and flown in the Murchison extending over an area in excess of ~ 106 000 km^2. Prior studies at a local scale had indicated that airborne EM would be very effective at defining the location and thickness of palaeovalleys in the region. Pilot investigations also determined the most appropriate AEM system to use for acquisition. These studies suggested that the buried palaeovalleys were most likely to be near-coincident with contemporary valley systems developed in a granite/gneiss-greenstone basement. Covering such a large region required a novel approach to survey design to maximize the information relating to their expected spatial variability. Therefore a terrain index (MrVBF) was used with the SRTM 1sec DEM to define the extent of contemporary valleys, and the extent of the AEM survey area. This approach allowed survey acquisition costs to be kept to less than half that of flying a more "traditional" survey over the entire area. It also allowed for the acquisition of data with a closer line spacing than would have been possible otherwise, therefore capturing more of the spatial variability associated with the palaeovalley systems. The results have demonstrated the validity of the strategy adopted and have shown that in the absence of conventional hydrogeological information, geophysical methods are demonstrably a cost and time effective approach to upscaling local hydrogeological information, thereby fast tracking groundwater resource assessments that would otherwise take decades to complete.

Key words: Survey design, Palaeovalley aquifers, airborne EM, AEM systems

INTRODUCTION

Access to water is identified a key infrastructure need for mining, energy and industry development, particularly in remote areas of Australia, where groundwater is the critical resource. However it is generally accepted that in regional Australia there is often an inadequate knowledge of these resources and their capacity to meet the emerging water requirements for industry, whether mining, pastoral or otherwise. In Western Australia, the scale of planned developments linked to current mineral exploration and mining is set to generate significant economic value for the State, but its realisation is dependent on ensuring access to groundwater. There are significant knowledge gaps about groundwater recharge, safe limits of abstraction to ensure a social licence to operate, and water quality characteristics. To address these issues, The WA Government Department of Water (DoW) has embarked on a series of groundwater investigations, supported by ground and airborne geophysical methods, to identify and establish long-term water resources in regional areas where agriculture and mining opportunities have the potential for development.

The Murchison in northern WA was identified as one of six key priority areas for this initiative. In this region, the mining industry is currently the largest user of groundwater. Until recently there were more than 30 operating mines using groundwater for mine development and ore processing, with numerous known mineral deposits having potential for development. Locating and securing adequate, long-term water supply is a critical consideration for this to happen. While it is known that there are significant groundwater resources in the region at present these are generally poorly understood. Of particular importance are the palaeovalley aquifers which are known locally (e.g. Aquaterra 2009, Johnson *et al.* 1999, and English, 2013) to contain a significant resource, but which are not well characterised. Prior studies, at a local scale, had indicated that airborne EM would be very effective at defining the location and thickness of palaeovalleys in the region (Aquaterra 2009, Munday 2012). These studies also suggested that the buried palaeovalleys were most likely to be near-coincident with contemporary valley systems developed in a granite/gneiss-greenstone basement (Figure 1). This paper describes some additional work designed to confirm these observations. It also reports on a novel approach in survey design to maximize the information relating to palaeovalley thickness and variability that builds on this knowledge base. Results from one of the most extensive AEM surveys undertaken to support groundwater assessments in regional Australia are described.

METHODS

Characterisation of palaeovalley systems using AEM

Aquaterra (2009) described the use of helicopter time domain EM systems to map the extent of the palaeovalley aquifer across the current bed of the Murchison River near the Jack Hill's Fe-ore mine in the northern Murchison. They described results from a 2007 25Hz RepTEM helicopter borne, time-domain electromagnetic system survey which was used to orient a groundwater resource drilling program targeting the palaeovalley system near the mine. Subsequently CSIRO commissioned a TEMPEST fixed-wing time domain EM survey over the same area (Munday 2012), with the aim of understanding the value of this technology for mapping the Murchison palaeovalleys. Both data sets were inverted using AarhusInv (Auken *et al.* 2015) and results presented in Figure 2 for a single coincident line of data (flight line orientation and location is shown in Figure 1). The conductivity-depth sections for both systems are comparable at the coarse scale, indicating that both map the lateral extent of what is interpreted to be a conductive valley fill sequence.

Survey Design

Conventional AEM survey design for the area covering the expected distribution of the Murchison palaeovalleys might yield something like that shown in Figure 3 (left panel). In this map the survey covers an area of 106 283 km², and if data were acquired at 4km line spacing in a N-S orientation, the total line kms required to cover the area would be 26 578km. Previous investigations (e.g. Aquaterra 2009, English *et al*. 2012), have determined that the buried palaeovalleys are generally coincident with broad valley systems that characterise the contemporary landscape. With that in mind, and with results from the trial lines of AEM data over the contemporary valleys in the northern part of the survey area, a terrain index – MrVBF (Gallant and Dowling 2003) derived from the 1sec SRTM elevation data was used to delimit contemporary valleys or low points in the landscape, and define the extent of the area actually required for geophysical data acquisition (Figure 4). MrVBF is a topographic index designed to identify areas of deposited material at a range of scales based on the observations that valley bottoms are low and flat relative to their surroundings and that large valley bottoms are flatter than smaller ones.

DISCUSSION

An analysis of trial lines of AEM data in the vicinity of Jack Hills (northern Murchison) showed that both the RepTEM and TEMPEST systems identified a thick conductive unit associated with valley fill sediments beneath the contemporary valley system, but noted that contemporary drainage channels did not directly reflect the orientation of the buried drainage systems. Drilling results described by Aquaterra (2009) revealed that the conductive units comprised permeable strata at varying depths within the palaeovalley sedimentary sequence. They also identified an upper calcrete aquifer and a lower sandy clay aquifer with moderate to good yields (>50m^3/hour). The inversion results also suggested that the RepTEM system struggled to resolve the boundary between the conductive fill and the resistive basement where the sediment fill was thickest (Figure 2).

The system ultimately selected for the AEM survey was the SkyTEM^{304}, with acquisition focussed over the low flat areas in the contemporary landscape areas (Figure 3 (right panel) and Figure 4). The reduced size of the area deemed necessary for acquisition enabled a survey to be completed with a 4 km line spacing, with infill over select areas recognised as important groundwater dependent ecosystems (GDE's). The requirement of detailed near surface information over these GDE's also influenced the choice of system for the survey. The actual number of line kms acquired in the AEM survey undertaken in mid-2015 was 14 069km. The reduced size of the survey area ensured that survey acquisition costs stayed within the budget available, with less than half the total number of line kms necessary compared with a comparable (from a line spacing perspective) survey over the entire area. The smaller area also allowed for the acquisition of data with a closer line spacing than would have been possible otherwise, therefore capturing more of the spatial variability associated with the palaeovalley systems.

A coincident line of SkyTEM^{304} data was also inverted in a similar way for comparison with earlier AEM survey data (see Figure 2). Both the TEMPEST and SkyTEM data sets appear to resolve the base of the channel fill, although the smaller footprint of the helicopter system provides more detail on the geometry of the interface with the resistive basement. The DOI for both would suggest that in the deepest parts of the valley system, the resolution of the boundary may be more uncertain (Figure 2). A gridded map of palaeovalley thickness for a subset of the study area, derived from inverted SkyTEM data, is presented in Figure 5. The image suggests the valley fill sequences are spatially complex.

CONCLUSIONS

An adaptive approach to AEM survey design, built on an understanding of where the Murchison palaeovalleys lie in relation to contemporary topography was developed to maximise information on palaeovalley extent and variability within a fixed budget available for data acquisition. This involved an analysis of elevation data for the proposed survey area, using terrain indices, and existing geological and hydrogeological data from particular type areas across the region. This knowledge was combined with acquisition of several trial lines of AEM data from different systems, undertaken prior to commissioning the full survey. This helped inform their suitability for mapping the extent and thickness of a valley fill that was known to be conductive. It also determined their suitability for defining near surface detail associated with groundwater dependent ecosystems in the region. The approach taken reduced the survey extent (number of line kilometres flown) to less than half of that which might have been undertaken with a more conventional acquisition method. A reduced line spacing that resulted from the targeted acquisition of AEM data ensured that the variability in the palaeovalley systems of the region was better defined. The results have demonstrated the validity of the strategy adopted and have shown that in the absence of conventional hydrogeological information, geophysical methods are demonstrably a cost and time effective approach to upscaling local hydrogeological information, thereby fast tracking groundwater resource assessments that would otherwise take decades to complete.

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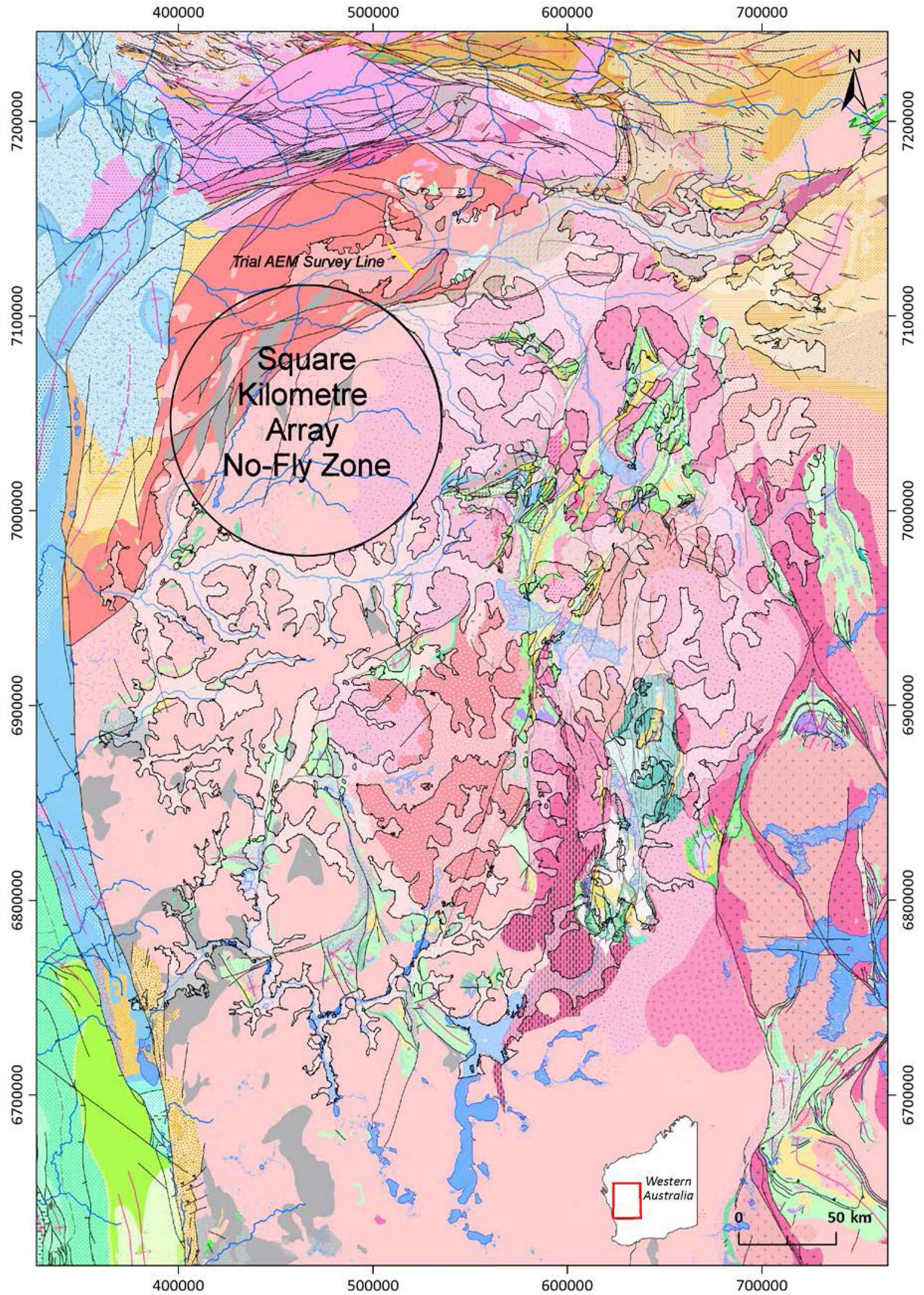

Figure 1: The location and extent of the study area in the Murchison where palaeovalley sedimentary aquifers were expected. The extent of the alluvial/colluvial cover associated with contemporary valley systems is depicted as a semi-transparent overlay on the basement geological map of NW Yilgarn Craton (Source: GSWA 2015). The contemporary drainage and distribution of salt lakes is also shown. Location of trial AEM survey line (Figure 3) is also indicated.

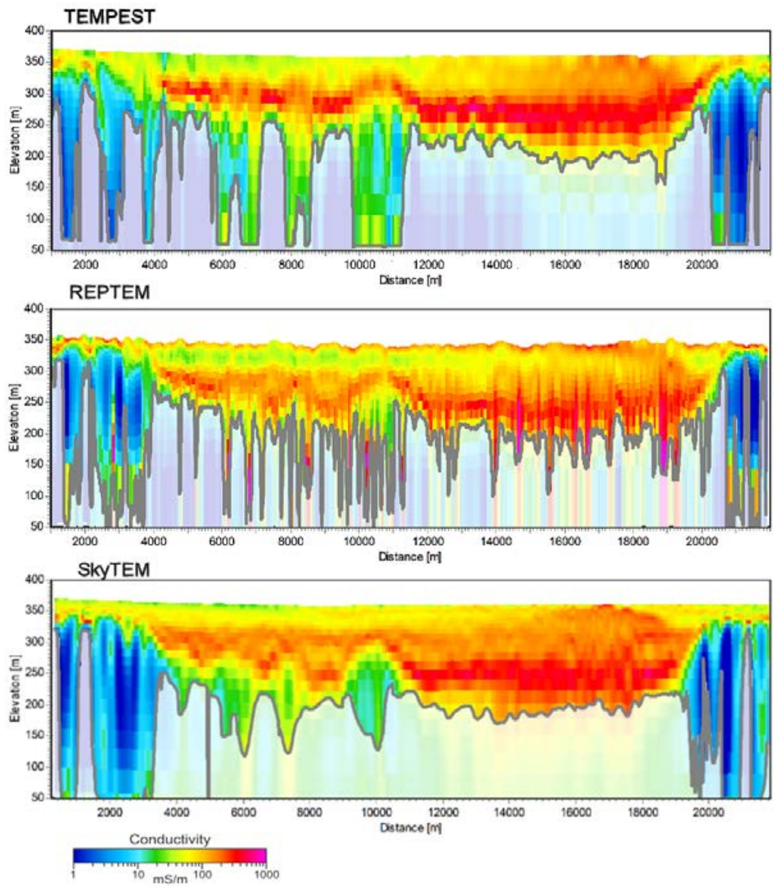

Figure 2: Smooth-model 1D LEI conductivity-depth sections from three different time domain AEM systems for the same survey line in the northern Murchison (see Figure 1 for location). The conductive unit represents sedimentary palaeovalley fill (> 100m thick in places) overlying a resistive basement. Data have been inverted with a common inversion kernel – AarhusInv (Auken *et al.,* 2015). The top panel shows data, from the TEMPEST fixed wing AEM system. The middle and lower panels are results from REPTEM and SkyTEM[304] helicopter time domain EM systems respectively. The calculated depth of investigation (determined by the method described by Christiansen and Auken 2012) is shown by the semi-transparent overlay near the base of each section.

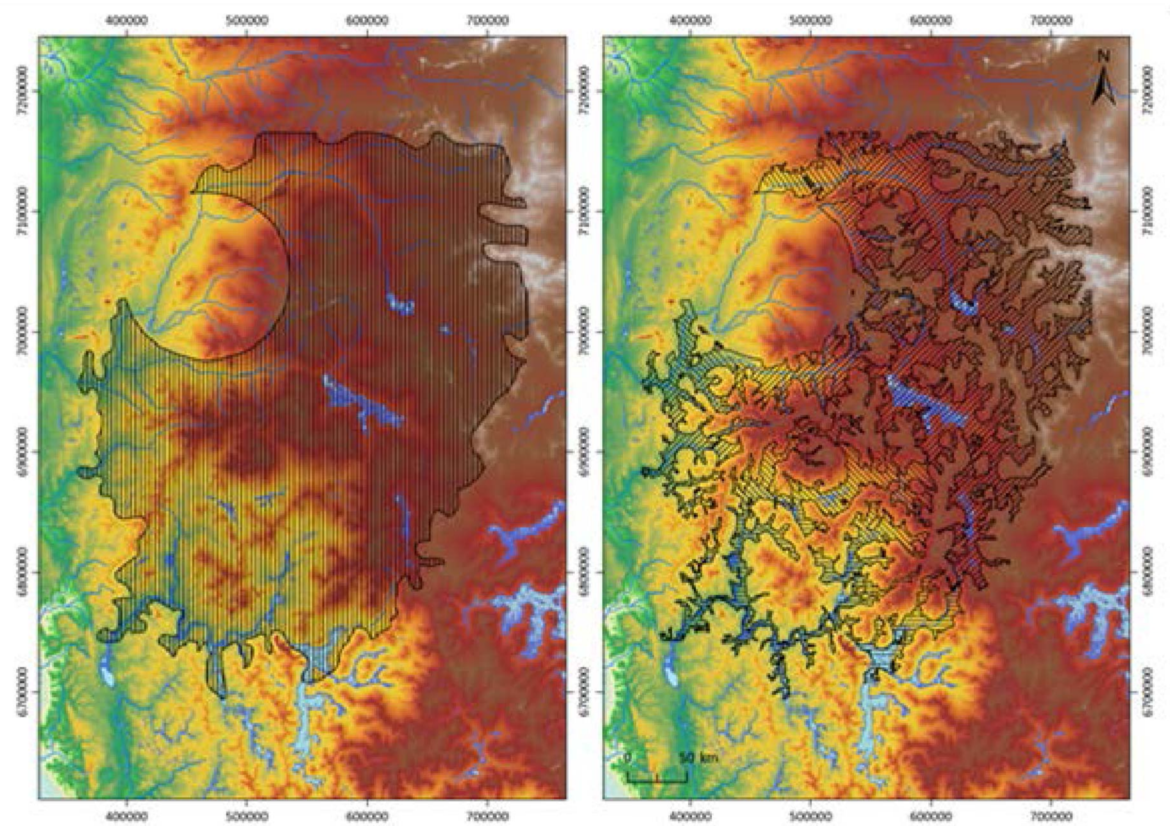

Figure 3: Comparison between a "conventional style" survey acquisition plan (left panel) versus a targeted survey approach (right panel) as was adopted in the Murchison region. The maps show survey extent and proposed AEM survey lines at 4km line spacing draped on SRTM 1 sec DEM. The total area covered by the bounding line in left panel is 106 283 km². The actual area flown (right panel) was 51 284 km².

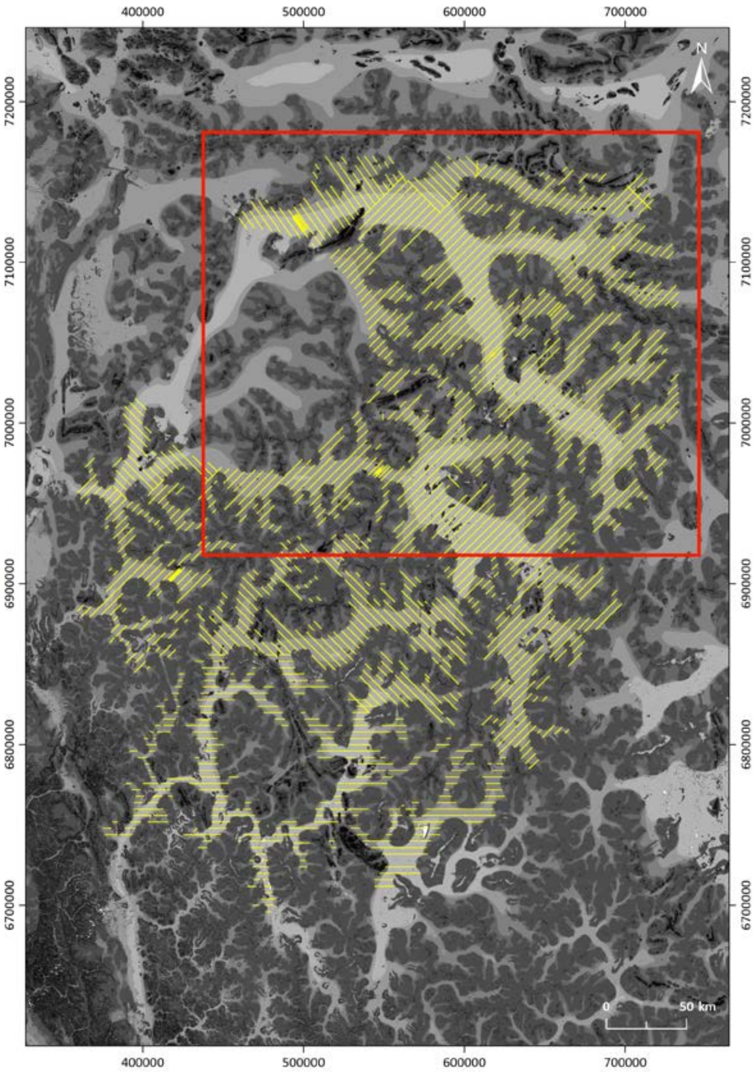

Figure 4: Final flight line orientation map for the Murchison AEM survey. Survey lines are overlain on a MrVBF map derived from the SRTM 1 sec DEM. The Flight lines were orientated, where possible, perpendicular to the expected orientation of the buried palaeovalleys that were expected to occupy the low, flat parts (pale grey areas) of the contemporary landscape. Total number of line kms acquired over the area was 14 069, comprising 1096 lines.

The red rectangle covers the area depicted in Figure 5.

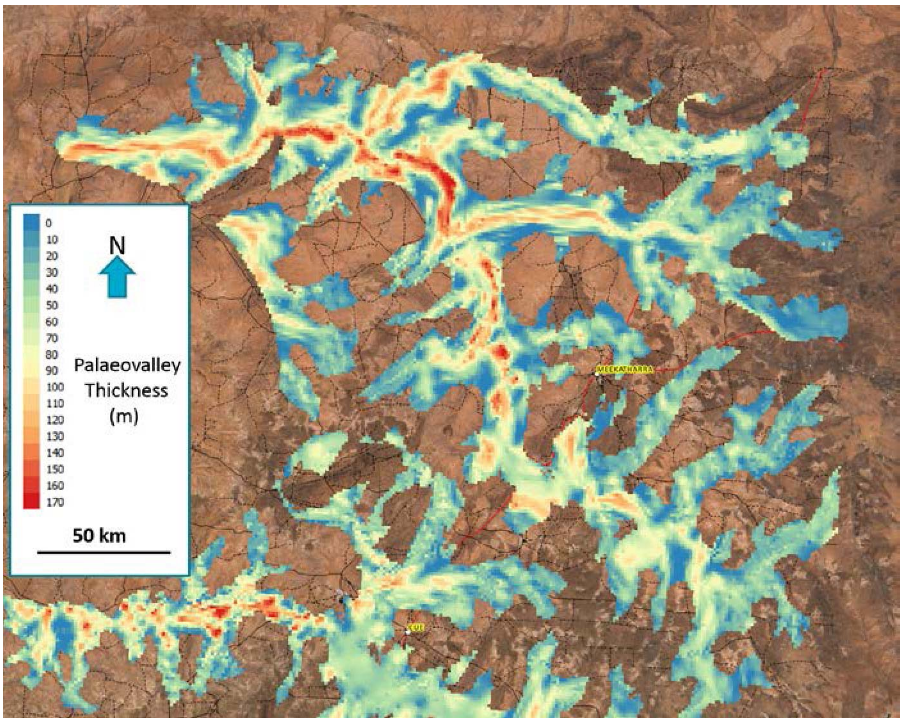

Figure 5: Palaeovalley thickness map for northern part of Murchison survey area derived from a 1D LEI of SkyTEM data acquired across the region. The thicker sequences of valley fill are mapped in reds and yellows.