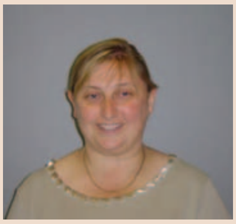
10.1071/PVv2011n150p29

Kombolgie AEM survey images to 2 km



Marina T. Costelloe

Marina T. Costelloe[1,2] and Ross C. Brodie[1]

[1]*Onshore Energy and Minerals Division, Geoscience Australia, Canberra, ACT, Australia.*
[2]*Email: marina.costelloe@ga.gov.au*

Introduction

Airborne electromagnetic (AEM) data are being acquired by Geoscience Australia (GA) under the Australian Government's Onshore Energy Security Program (OESP) in areas considered to have potential for uranium or thorium mineralisation. The surveys are managed and interpreted by members of GA's AEM Acquisition and Interpretation Project. In contrast to deposit-scale investigations carried out by industry these surveys are designed to reveal new geological information at a regional scale. The Pine Creek AEM survey shown in Figure 1 is comprised of three survey areas: Woolner Granite, Rum Jungle and Kombolgie. The TEMPEST™ AEM system was used for the Woolner Granite and Rum Jungle surveys and the VTEM™ system was used for the Kombolgie survey.

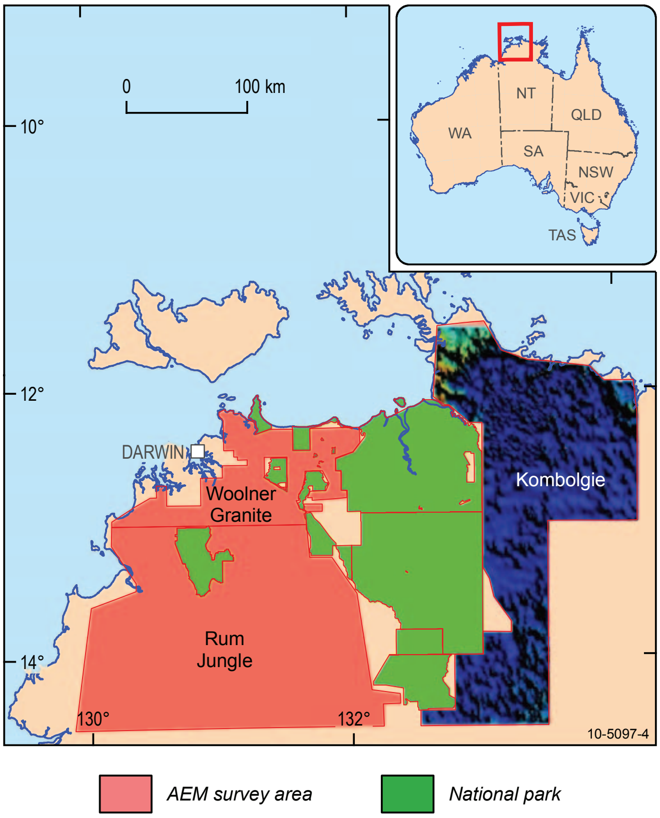


Fig. 1. *Pine Creek Survey boundary locations. The Kombolgie Survey area is highlighted with an image of the estimated conductance to 2000 m. Geoscience Australia funded 5000 m line spacing across the entire Kombolgie survey and an infill area at 1666 m line spacing.*

The Kombolgie survey, in the Pine Creek Orogen of the Northern Territory, covered sections of the Alligator River, Cobourg Peninsula, Junction Bay, Katherine, Milingimbi and Mount Evelyn 1:250 000 map sheets (Costelloe et al., 2009). A total of 8800 line km of VTEM™ data were acquired in 2008, covering an area of 32 000 km^2. In 2009 the processed response data and conductivity estimates to 600 m depth were produced by the survey contractor Geotech Airborne using EM Flow™ (version 3.30) (Macnae et al., 1998; Stolz and Macnae, 1998), and were made available to the public in the GA Phase-1 data release.

In this article we present an enhanced set of conductivity estimates which are now available from the GA website free of charge. These conductivity estimates reveal new geological information to depths approaching 2 km in the more resistive portion of the survey area. They were generated by GA using a more recent version (version 5.23-13) of EM Flow™.

AEM system selection

GA selected the VTEM™ system to fly the Kombolgie survey from the various candidates submitted by members of the Panel of AEM contractors after an assessment of the probability of detecting hypothetical geological targets in the presence of a given background. This assessment was based on a methodology developed by Green and Lane (2003). In this methodology a geological scenario representing the likely background and target conditions is sketched out and then transformed into an equivalent geo-electric model. From forward model responses, with and without the target unit present, an anomalous response is determined. Then, using the estimated system noise levels, the anomalous response is converted to an anomaly-to-noise ratio, from which a probability of detecting the presence of the target can be derived.

While the success of this method is strongly dependent on the assigned conductivities and system noise levels, it does give an objective measure of system suitability for a particular exploration task. The assigned system noise levels for each AEM system were those specified as maximum allowable noise levels in survey contracts. These are determined from sample high altitude and repeat line data (Green and Lane, 2003) provided to GA as part of the requirement of becoming a member of the contractor panel. Geo-electrical models were synthesised from prior knowledge of conductivity ranges for the targeted geological units.

The West Arnhem Land region is highly prospective for uranium mineralisation (e.g. Ahmad, 1998; Beckitt, 2003; Lane et al., 2007). The architectural elements essential for unconformity uranium systems in this area include an

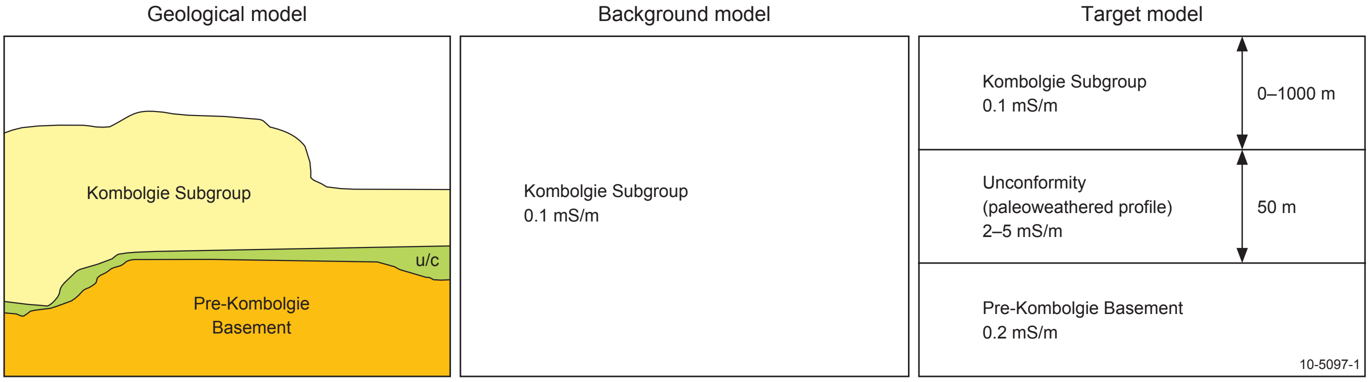


Fig. 2. *An example of a geological scenario and corresponding geo-electric model for the Kombolgie unconformity.*

Table 1. Conductivities used in the forward modelling

Geological unit	Conductivity (mS/m)
Regolith	5
Kombolgie subgroup	0.1
Unconformity (u/c)	2–5
Pre-Kombolgie basement	0.2

unconformity surface, domes/inliers of Archean granite-gneiss; paleo-regolith surfaces and basement faults (Jaireth et al., 2007). The main geological target in the Kombolgie survey area was the Paleoproterozoic Katherine River Group metasediment unconformity. An example geological scenario and corresponding geo-electric model for the Kombolgie Subgroup – Pre-Kombolgie Basement unconformity is shown in Figure 2. The conductivity ranges were compiled from information provided by companies that have tenements in the Kombolgie survey area (Table 1).

The forward modelling of this scenario indicated that two of the AEM systems considered would successfully detect the hypothesised unconformity under 500 m of 0.1 mS/m Kombolgie Subgroup sediments. Further modelling predicted the VTEM^{TM} system would detect the unconformity to 1000 m under a thin (5 m) 5 mS/m regolith overlying 0.1 mS/m Kombolgie Subgroup sediments (Richardson et al., 2008). When all scenarios were deemed of equal relevance, and when other survey factors were taken into account (such as survey logistics, availability, safety, cost, etc.), the VTEM^{TM} system was expected to be more likely to be successful in the Kombolgie survey area.

The new EM Flow^{TM} results

The commercial Version 3.30 of EM Flow^{TM} was used by Geotech Airborne in the generation of the originally released Phase-1 Kombolgie conductivity estimates. Further work has been carried out in order to extract additional value from the electromagnetic data. In this process, Richard Lane (Geoscience Australia) and Professor James Macnae (RMIT) discovered that in parts of the survey area, geologically plausible conductivity estimates could be generated to depths exceeding 1500 m.

The differences between the new Phase-2 Kombolgie EM Flow^{TM} data release and the previous Phase-1 release can be summarised as follows:

(i) Use of the most recent research version of EM Flow^{TM} (v5.23-13) developed through AMIRA project P407b with additional enhancements added by RMIT staff;
(ii) Extension of the maximum depth of conductivity estimates from 600 m to 2000 m;
(iii) A different received waveform;
(iv) Corrections made to the window time definitions and amplitude scaling factors;
(v) A different range of Taus (time constants); and,
(vi) A different range of discrete conductivities.

The research version (Version 5.23-13 – *STEM Flow_FULL523-13.exe*) was used to generate the Phase-2 Kombolgie results. In contrast to the earlier version, the version used for this work facilitates a greater number of discrete conductivities to be employed (250 instead of 20). This enables a wider dynamic range of discrete conductivities to be used, that are more suitable for the survey area, while still allowing for a gradual transition between conductivities.

The later version also allowed for a negative Tau ($\tau = -25\,\mu s$) to be used in the fitting process so that the parasitic capacitance component of the signal could be accounted for (Macnae and Baron-Hay, 2010). This is a relatively new innovation for the EM Flow^{TM} software that has been added by staff from RMIT. Since fitting of the parasitic response is better constrained when early-time data are used, we used all 30 available time windows (beginning at centre-time 62.5 μs) in place of the 27 used by Geotech (beginning at centre-time 99.0 μs).

For this work we used a different waveform to that employed by Geotech Airborne for the Phase-1 Kombolgie data. We chose the waveform that we assessed to be the most representative of the 272 waveforms acquired at high altitude during the survey. After selecting the most representative waveform, recorded by monitoring the time derivative of the transmitter current rather than the actual dB/dT received waveform, we filtered it using parameters supplied to GA by Professor James Macnae. This filtering simulates the effect of the receiver-side electronics and has the effect of slightly delaying and filtering the 'transmitter-measured' waveform so that it more closely represents a true 'receiver-measured' waveform that is actually required.

Figure 3 shows EM Flow^{TM} sections to 2 km for three consecutive 1666 m spaced flight lines proximal to areas where the Kombolgie unconformity has been mapped at surface near the Nabarlek uranium deposit. Surface geology and total magnetic intensity (reduced to the pole) data are also provided at

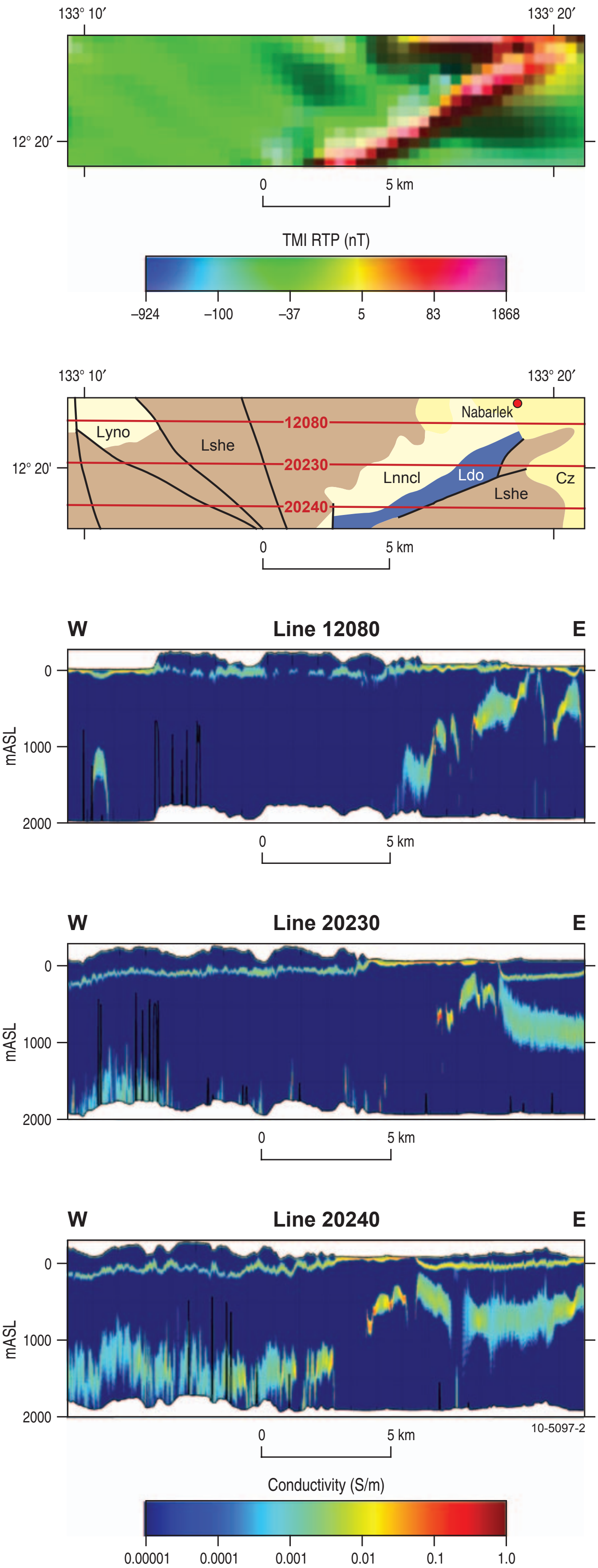


Fig. 3. *TMI RTP, Geoscience Australia Surface Geology of Australia Map, and EM Flow™ sections for three lines near Nabarlek showing conductivity features to 2000 m.*

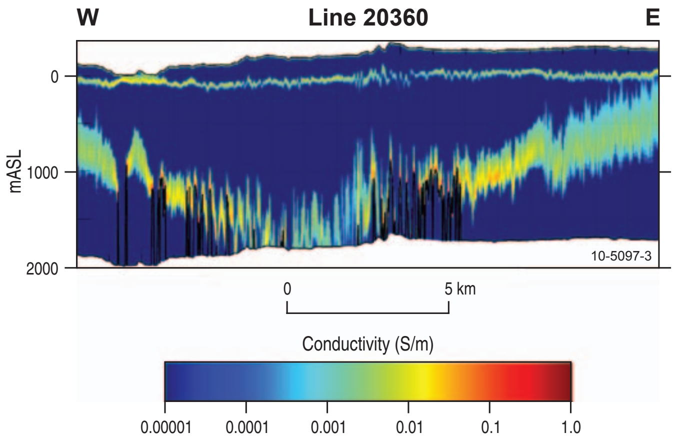


Fig. 4. *Kombolgie survey line 20 360 subsection showing a coherent conductivity feature to 2000 m.*

the top of the EM Flow™ sections. The estimated depth of penetration line depicted in these sections is calculated by EM Flow™. The interpreted Kombolgie – Pre-Kombolgie Basement unconformity appears in the sections as a thin, weakly conductive, sub-horizontal feature mid section. In this resistive area, conductivity estimates relating to basement architecture are coherent below 1500 m (Figure 4). Forward gravity modelling and 3D geological mapping undertaken in West Arnhem Land (Lane et al., 2007) confirms qualitative agreement between the proposed architecture and the conductivity estimates.

Implications for exploration

The outcomes of the Pine Creek AEM Kombolgie survey include mapping of subsurface geological features that are associated with unconformity-related as well as sandstone-hosted Westmoreland-type and Vein-type uranium mineralisation. The products are also suitable for interpretation focussed on other commodities including metals and potable water as well as for landscape evolution studies. The improved understanding of the regional geology to depths greater than 1500 m in selected areas that has resulted from careful application of the enhanced EMFlow software will be of considerable benefit to mining and mineral exploration companies.

The Kombolgie survey results shown here illustrate a significant improvement in mapping conductivity in greater detail and identifying features such as unconformities and major structures at much greater depths than has previously been published.

Acknowledgements

We would like to acknowledge the significant contributions of Richard Lane. We also thank Professor James Macnae (RMIT) who greatly assisted GA through technical advice, provision of the most recent EM Flow™ research version software and help to determine the most appropriate waveform and program settings.

Geoscience Australia would also like to acknowledge the contributions of the following groups: Northern Territory Geological Survey (NTGS); National Water Commission Natural Resources, Environment, The Arts and Sport (NRETAS), in particular Jon Sumner; Cameco Australia, in particular Geoff Beckitt and Tyler Mathieson; and Energy Resources of Australia Ltd for field support as well as land access, access to open bore hole and lithological logs supporting the conductivity logging phase of the program. Subscription companies Crossland Uranium Mines Ltd, Hapsburg Exploration Pty Ltd, Rio Tinto Exploration Pty Ltd, Rum Jungle Resources Ltd (prev. Rum Jungle Uranium), Southern Uranium Ltd, Thundelarra Exploration, United Uranium Ltd, and Uranex NL for their support of the AEM project by funding additional lines, supplying historical data and providing geological support. The Northern Land Council, for granting access to traditional lands. We also thank the Geophysics Group and the Groundwater Group at GA, in particular Camilla Sorensen and Pauline English.

References

Ahmad, M., 1998, Geology and mineral deposits of the Pine Creek Inlier and McArthur Basin, Northern Territory: *AGSO Journal of Geology and Geophysics,* **17**, 1–17.

Beckitt, G., 2003, Exploration for unconformity uranium in Arnhem Land (NT): *Exploration Geophysics,* **34**, 137–142. doi:10.1071/EG03137

Costelloe, M., Sorensen, C., and English, P., 2009, Pine Creek Airborne Electromagnetic Survey Onshore Energy and Minerals, Geoscience Australia: *ASEG 2009 – 20th Geophysical Conference and Exhibition Extended Abstracts*, Adelaide, SA.

Green, A., and Lane, R., 2003, Estimating noise levels in AEM data: *ASEG 2003 – 16th Geophysical Conference and Exhibition Extended Abstracts*, Adelaide, SA.

Jaireth, S., Meixner, T., Milligan, P., Lambert, I., and Miezitis, Y., 2007, Unconformity-Related Uranium Systems: Regional Scale Constraints: Presented in Darwin at *AusIMM – Australia's Uranium Conference.* http://www.ga.gov.au/image_cache/GA10581.pdf

Lane, R., Beckitt, G., and Duffett, M., 2007, 3D geological mapping and potential field modelling of West Arnhem Land, Northern Territory: *ASEG 2007 – 19th Geophysical Conference and Exhibition Extended Abstracts*, Perth, WA.

Macnae, J., and Baron-Hay, S., 2010, Reprocessing strategy to obtain quantitative early time data from historic VTEM surveys: *ASEG 2010 – 21st Geophysical Conference and Exhibition Extended Abstracts*, Sydney, NSW.

Macnae, J., King, A., Stolz, N., Osmakoff, A., and Blaha, A., 1998, Fast AEM processing and inversion: *Exploration Geophysics,* **29**, 163–169. doi:10.1071/EG998163

Richardson, M. L., Brodie, R., Costelloe, M., and Sorensen, C., 2008, Assessment of AEM systems for the Pine Creek survey: Unpublished GA internal report (in-confidence).

Stolz, E., and Macnae, J., 1998, Evaluating EM waveforms by singular-value decomposition of exponential basis functions: *Geophysics,* **63**, 64–74. doi:10.1190/1.1444328

Geoscience Australia Kombolgie AEM survey data releases

Kombolgie Phase-1 VTEM™ data and processing report. The complete VTEM™ data set and processing report are only available from the Sales Centre on DVD due to the size of the files.
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71372

Kombolgie Phase-2 Revised EM Flow™ conductivity estimates to 2 km depth, subsampled along line by a factor of 5, are available for download from the web.
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71371

The complete second generation EM Flow™ conductivity data set for the entire survey is available without any subsampling along line from the Sales Centre on DVD.

EM Flow™ development

The commercial version of EM Flow™ was developed by AMIRA Projects P407 and P407a in CRCAMET during the 1990s. As part of the process implemented in the software, data from an arbitrary AEM system are converted to a time-constant domain by fitting of basis functions contained in an 'aot' file. Since 2001, RMIT and AMIRA project P407b have enhanced the stability and accuracy of the conductivity estimates generated using the EM Flow™ software.

In the P407b project, of which Geoscience Australia was a sponsor, one developed option allowed for the fitting and subtraction of a residual primary field, effectively that part not completely removed in conventional processing. It was possible using P407b EM Flow_FULL523-13.exe software and a text editor to manually replace the primary field 'row' in an 'aot' file with a row consisting of an appropriate (negative) exponential decay, and thus fit and subtract parasitic capacitance effects exactly as the P407b code removed primary field contamination effects.

Confidentiality restrictions on the P407b software developments have now expired. A recent minor amendment to the P407b software was carried out by Professor James Macnae at RMIT to allow the research version of EM Flow™ used in this work (STEM Flow_FULL523-13.exe) to directly fit a rapid decay of negative amplitude in order to approximate the effect of parasitic capacitance without the need to manually edit the 'aot' file.