Evaluation of multifrequency airborne EM for opal prospect definition at Lightning Ridge, NSW

Michael Moore*
NSW Department of Mineral Resources, Australia
moorem@minerals.nsw.gov.au

James Macnae
Department of Applied Physics, RMIT University, Australia
james.macnae@rmit.edu.au

Gary Burton
NSW Department of Mineral Resources, Australia
burtong@minerals.nsw.gov.au

SUMMARY

The NSW Department of Mineral Resources has been evaluating the use of geophysical techniques as a tool to better understand controls on opal formation in the Lightning Ridge district of New South Wales. A detailed study over the Gurley Ridge, approximately 25km southwest of the Lightning Ridge township, commenced in June 2001. This Cretaceous sedimentary ridge hosts the Coocoran Opal Field and includes the productive Allahs and Natelies Dream prospects. Current geological understanding predicts opal occurrence at the interface of clay and sandstone horizons within the sedimentary package. The study included a compilation of historic drill records, detailed surface geological mapping, lithofacies mapping, and acquisition of detailed airborne electromagnetic data. An electrical model of the subsurface generated from previous ground work was used to guide selection of the transmit–receive frequencies employed in the airborne survey. The acquired multifrequency airborne data were inverted and conductivity depth images for each flight and tieline produced. The CDI sections revealed the existence of an ubiquitous conductor located between 10m and 20m below the surface, covering the majority of the ridge area. A ground follow-up program was instigated to investigate the identified conductive zone. Eight high-resolution, detailed transient EM ground lines were acquired coincident with various conductive signatures identified in the airborne data. A small drill program was conducted to ground truth both the airborne and TEM subsurface conductive features. Drill results, downhole geophysical logs, and the detailed ground TEM data have been used to validate and refine inversion of the airborne data.

Key words: HEM, TEM, opal, Lightning Ridge.

INTRODUCTION

Prospecting for opal at Lightning Ridge is dominated by a haphazard drilling approach. Exploration of the prospective claystone to depths of about 30m is achieved through use of either a nine-inch auger or a three-foot Calweld drill rig. Drill locations are sited from either aerial photograph lineaments, local ground knowledge, divining "wires", or other prospector trusted techniques.

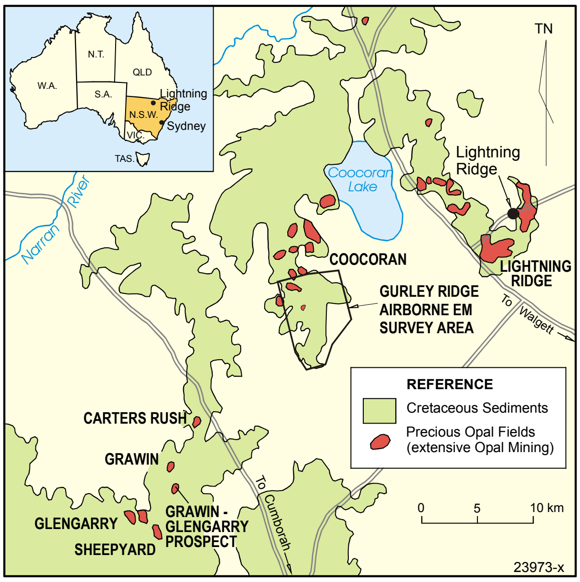

Figure 1. Location of the Lightning Ridge Opal Fields and the airborne EM survey (details in Figure 2).

Favourable indicators in the drilled spoil include the existence of a thick sequence of sandstone and an underlying claystone layer — the opal "level". The ultimate prize is opaline material or "colour" in the drilled claystone material — "opal dirt". If no sandstone, favourable level or opal is encountered, then the next hole is drilled resulting in a sporadic or random peppering of the standard 50 x 50m claim block. While this style of prospecting is probably the most cost effective, it remains very much a hit-and-miss approach. Prospecting in this manner has a greater environmental impact often leading to conflict between miners and coexisting pastoralists.

While geophysical techniques may never directly detect the occurrence of opal, electrical methods have been shown to be effective in identifying the sedimentary host lithologies. Past work has shown that a three-layer electrical model closely approximates the opal-hosting environment.

A pilot-scale heliborne electromagnetic (HEM) survey was flown over a test site in the Lightning Ridge area (Figure 1) as part of continuing efforts by the New South Wales Department of Mineral Resources (DMR) to study the application of geophysical techniques to opal formation and exploration. Initial inversion results suggested the existence of an almost ubiquitous conductive horizon at about 10m to 20m below the surface across the surveyed ridge country. A compilation of historic drill records also indicated the occurrence of clay horizons within most holes drilled across the study area. These drill results, while suffering spatial and geological accuracy, were used to qualitatively confirm the validity of the inverted HEM data. Ground TEM, drilling and downhole logging has been completed in an attempt to further constrain inversion of the HEM data.

GEOLOGY

The Cretaceous rocks in the Lightning Ridge area are interpreted to have been deposited within an estuarine to shallow marine environment. The sediments were derived from a volcanic source, resulting in feldspar-rich sandstones and ash-rich claystones. Widespread weathering episodes in the Late Cretaceous and Early Tertiary caused the kaolinisation and silicification of the sedimentary rocks. Opal at Lightning Ridge is considered to have formed during these deep, chemical weathering events.

The Cretaceous rocks are unconformably overlain by Tertiary gravels, sandstones and claystones. A shielding Tertiary silcrete cap in parts has protected the soft Cretaceous sedimentary rocks from erosion, resulting in the present ridge system. The Cretaceous rocks and Tertiary silcrete are effectively flatlying.

Study Area

Burton (2002) described the Cretaceous rocks of the study area as consisting of interbedded sandstones, claystones and siltstones, with kaolinitic alteration extending to a depth of at least 25m in opal workings. Both sandstone and claystone beds range in thickness from several centimetres to several metres. In drill core, it is commonly observed that sandstones are clayey and some claystones are sandy, indicating compositional overlap. A maximum silcrete thickness of about 4m was observed. Silicification of Cretaceous sedimentary rocks extends to a depth of about 10m, as seen in opal workings and drill records. Significant ferruginisation of the Cretaceous rocks occurs at about 30m below the surface. Surface geology constructed from a combination of photogeological interpretation and field mapping is presented in Figure 2.

Opal Formation

Opal in the Lightning Ridge area occurs as horizontal seams, nodules (nobbies) and as replacements and cast fillings after fossils. It commonly occurs within the upper parts of the Finch claystone facies lenses (Watkins, 1985). Recoverable opal is commonly found within 30m of the surface and is mined predominantly by underground methods. Within the study area opal is found as nobbies.

The most likely explanation for the origin of opal in the Lightning Ridge district involves mobilisation of silica during weathering. This model proposes that deep weathering, leading to kaolinisation of the feldspathic sedimentary rocks, liberated silica into the groundwater, which then migrated downward through permeable pathways until reaching an impermeable barrier. Once trapped, the fluid formed a silica gel, which then precipitated microscopic silica spheres to form opaline silica. Precious opal formed where precipitated spheres of uniform size were packed regularly. Potch or common opal was formed where the spheres were variable in size and unevenly packed.

Recent investigations suggest only anecdotal evidence relating opal occurrence with faulting. However, post-opal deposition faulting most likely resulted in either uplift and erosion, or deeper burial of opal, contributing to the elusiveness of this hard won gemstone (Burton, 2002).

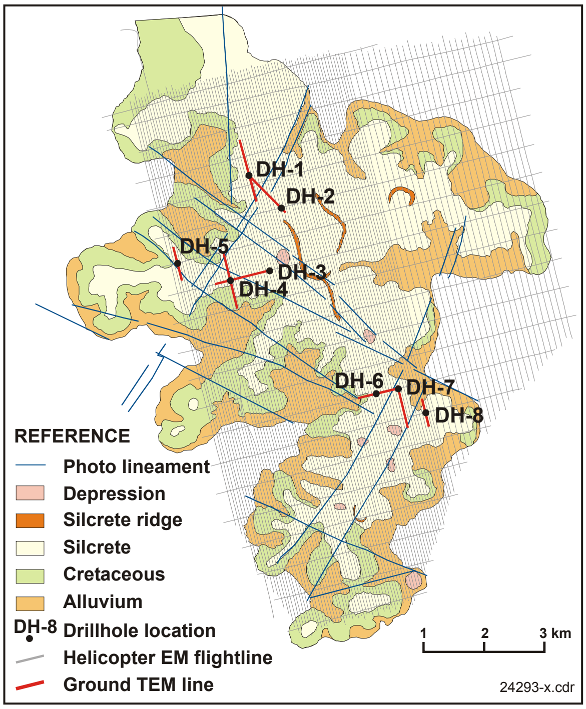

Figure 2. Gurley Ridge airborne EM survey area, showing flightlines, ground TEM lines, drillhole locations and interpreted geology.

GEOPHYSICS

HEM survey

The decision to trial detailed airborne electromagnetic techniques at Lightning Ridge was made on the basis of previous geophysical studies. Based on the results of ground TEM and resistivity trials, Leys *et. al*. (2001) concluded that, the opal-bearing claystone would most likely be detected by a detailed airborne EM survey. The studies found that the opal-hosting sedimentary section could be readily modelled by a simple three-layer electrical section (Whiteley, 1983; Leys, 1987; and Moore 2002). The proposed model consisted of a near-surface highly resistive layer coinciding with surface silcretes, an intermediate layer of intermediate resistivity representing sandstones and an underlying low resistivity layer representing the opal-hosting claystones. Resistivity values of 100-500Ωm, 50-100Ωm and less than 10Ωm were assigned to the three layers, respectively.

The Geotech Hummingbird multi-coil EM system was considered the most appropriate for the trial purposes. This was based on the fact that the Hummingbird system supported five unique frequencies and a combination of both coplanar and coaxially aligned coil pairs (Table 1). Forward modelling of the system configuration and the three layer geoelectrical section confirmed that an acceptable signal to noise ratio would be achieved and that a claystone unit down to a depth of at least 30m would be adequately detected.

In June 2001, approximately 980 line kilometres of HEM and magnetic data were acquired on a combination of 50m and 100m spaced flightlines using a bird clearance of 30m (Figure 2). Standard multicoil frequency EM calibration procedures using a jig, Q coil and phase bar, as well as high-altitude drift control techniques, were used throughout the survey to maintain data integrity. Processing of the field data was predominantly carried out using GEOSOFT's standard, frequency EM processing module. A development version of EMFLOW was then used to generate conductivity depth images (CDIs) for each line of the survey.

Table 1. Hummingbird HEM system specifications

Frequency (Hz)	Coil Separation (m)	Dipole Moment (NIA)
875 coplanar	6.01	200
980 coaxial	6.01	200
6606 coplanar	6.26	150
7001 coaxial	6.26	150
34133 coplanar	4.93	40

Ground TEM

In May 2002, eight lines of ground TEM data were acquired over areas identified for drill testing from field mapping. The majority of these lines were coincident to HEM flightlines so that the results of drilling and ground TEM traverses could be related directly to the airborne results (Figure 2). A fast-sampling NanoTEM system, utilising 20m transmitter loops and 5m centrally located receiving loops, was used to provide high-resolution coverage of the near-surface. The acquired NanoTEM dB/dt magnitude data were converted to resistivity depth sections using Zonge's 1-D smooth-model inversion.

Geophysical logging

Downhole logging was completed on eight strategically placed, 50m diamond drillholes (Figure 2). On completion of drilling each hole was logged for inductive conductivity, natural gamma and magnetic susceptibility. The induction tool provided a measure of the bulk conductivity within a range of 5-3000mS/m and within a zone of 25-125cm from the hole.

RESULTS

As expected, there was a close correlation between the identified stratigraphy and the recorded downhole, electrical conductivity values. Figure 3 shows this relationship for drillhole 7. The electrical conductivity logs revealed:

- the near-surface silcrete and silicified clay units have conductivity values less than about 250mS/m (>4Ωm);
- sandstone units varied between about 50mS/m and 300mS/m (3.3-20Ωm) with some deeper occurrences having higher conductive values around 700mS/m (1.7Ωm) coinciding with increased clay or moisture content; and
- clean clay horizons (ie, non-sandy) were relatively high in conductivity, generally ranging between 600 and 800mS/m (1.25-1.6Ωm).

It is assumed that an observed increase in the interstitial moisture content of the clays at about 15-20m contributed to the higher conductivity values observed in the deeper layers.

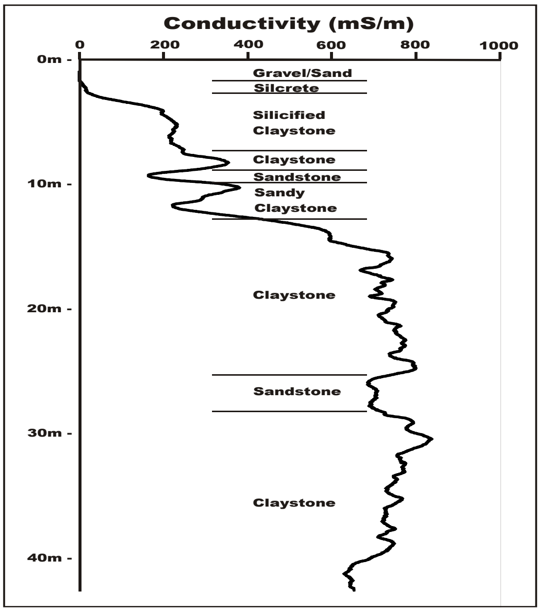

Figure 3. Comparison of the geological and electrical conductivity logs for drillhole 7 (DH-7).

Overall there is excellent correlation between the electrical conductivity logs and results of the ground TEM traverses (Figure 4). This includes both the measured range of conductivity values in the logs and TEM data, as well as the indicated depth to the top of the conductive TEM features. While the log results show a general increase in conductivity with depth, measured near-surface conductivity values are about one order of magnitude less than predicted by the proposed geoelectrical model. This has been attributed to an obvious lack of a well-developed sandstone unit throughout the survey area.

While there is general agreement in the shape of the subsurface conductive layer identified in both the airborne and the ground surveys, conductivity depth sections calculated from the airborne data over determined the conductivity values and in some cases underestimated the conductive layer depth. A highly conductive surface layer defined by the initial CDI process appears to have affected the determination of the depth to the top of the conductive clay horizon on the original HEM sections. Figure 4 compares an extract of ground TEM data with a coincident HEM CDI extract and conductivity logs from two drillholes.

DISCUSSION

Program EMFLOW enables HEM data in parts per million (ppm) at each transmit–receive frequency to be converted into conductivity–depth data using state-of-the-art inversion methodology (Macnae *et. al*., 1998). To obtain accurate conductivity–depth sections, a key requirement is that the calibration and geometry of the EM system be known. As discussed by Fitterman (1998), errors are likely to occur when HEM systems are calibrated in conductive areas. Even though the system had been calibrated in a resistive terrain prior to mobilisation it was clear from the survey data that the highest frequency information was incompatible with the lower frequencies under a layered earth assumption. Hence, with uncertain calibration, a decision was made to scale ppm amplitudes so that the shallowest conductors predicted by the processing were located near-surface (Figure 4(a)). Comparison of the HEM CDI sections with the ground TEM and downhole conductivity data subsequently revealed that scaling parameters used in the initial CDI processing were in error.

The issue of scaling and calibration was revisited to account for the increase in conductivity with depth as displayed in the drill log data. Further research development of EMFLOW had enabled the program to provide additional calibration constraints (Macnae, 2003). In the second pass processing, (October 2002) only the highest frequency data were re-scaled (by a factor of 1.5) so—as to be compatible with the other data. The data were then reprocessed with the constraint that the EM response be 'extrapolated' using a thick conductive layer model. (In the first pass a thin sheet approximation was used.) This 'extrapolation' predicts the HEM response at higher and lower frequencies than those actually measured. The resulting CDI sections are shown in Figures 4(b) and 4(c). The assumption made in Figure 4(b) favoured a high-frequency extrapolation of the data compatible with a uniform conductor starting at surface. Figure 4(c) shows the results when no constraints were placed on the shallow conductivity structure. In Figure 4(c) the near surface has been imaged as being perfectly resistive.

CONCLUSIONS

The application of multifrequency airborne EM at Lightning Ridge was successful in defining a subsurface, conductive layer that appears coincident with the perceived prospective (opal level), clay horizon. Inversion of the HEM data from ppm values to CDI sections was helped markedly by the acquisition of ground control data. Improvements in CDI calculations were also obtained through further EMFLOW numerical algorithm developments.

Opal development requires a thick sequence of sandstone to be present above the prospective claystone horizon. Both the airborne and ground data indicate a probable lack of sandstone throughout the survey area away from the known producing areas.

ACKNOWLEDGMENTS

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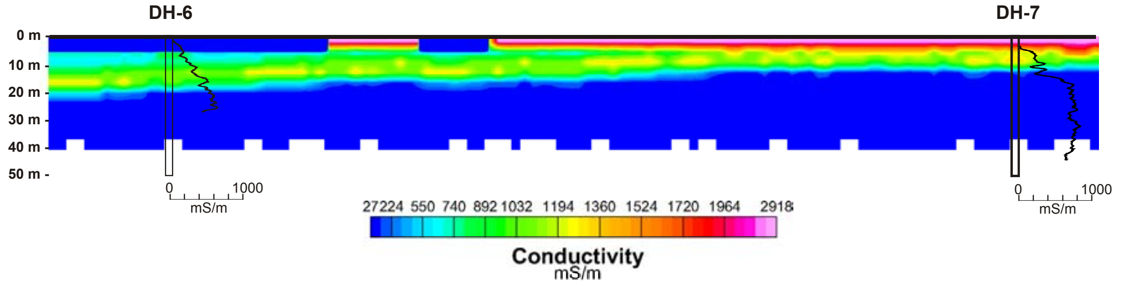
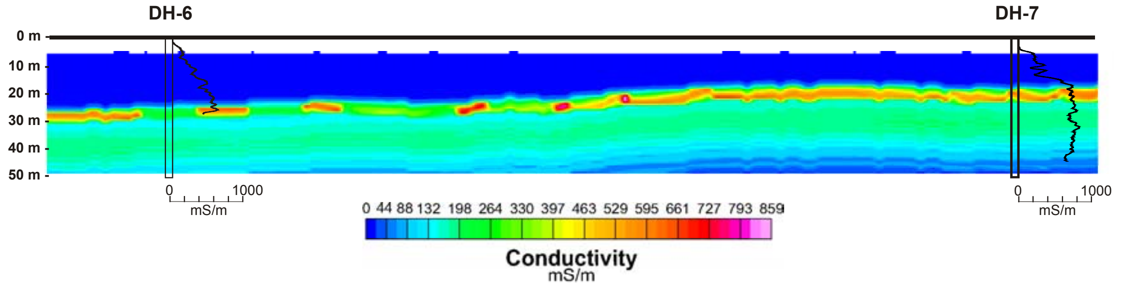
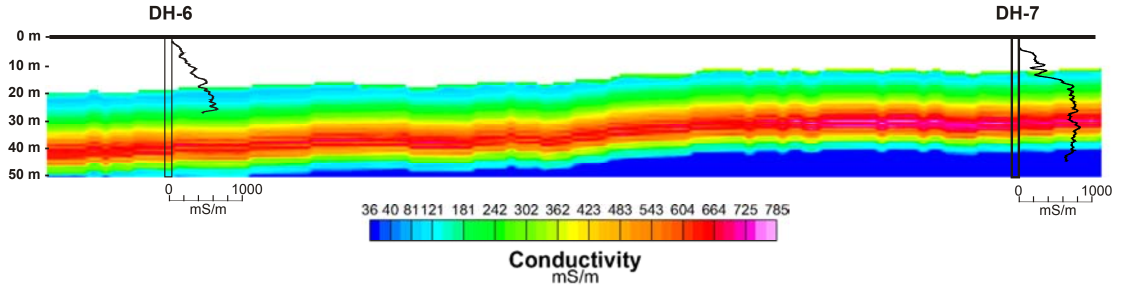
(a) Airborne EM CDI assuming a thin sheet approximation (September 2001)



(b) Airborne EM CDI assuming a thick conductor approximation (October 2002)



(c) Airborne EM CDI assuming a uniform conductor approximation (October 2002)



(d) Ground TEM conductivity-depth section

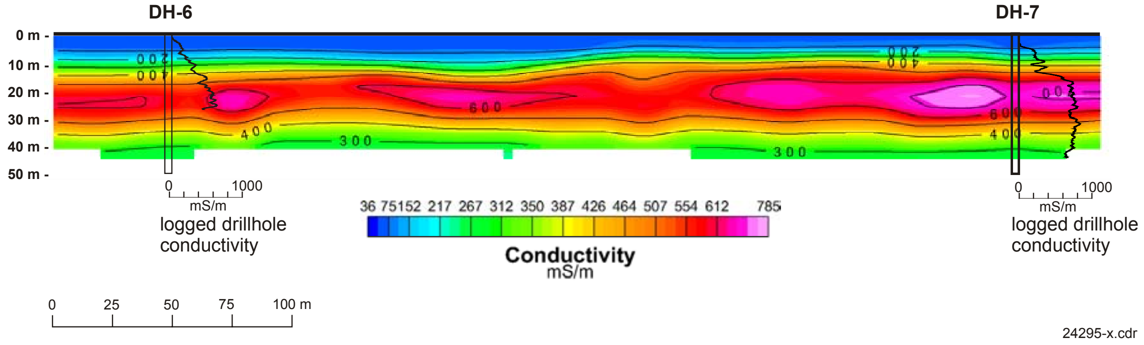


Figure 4. Comparison of CDI processing of HEM data using EMFLOW with ground TEM and downhole conductivity logs. CDI sections were calculated assuming a thin sheet approximation and using ppm amplitude scaling in (a); a thick conductive layer approximation with scaling of only the highest frequency in (b); and a uniform conductive earth approximation with scaling of only the highest frequency in (c). Conductivity values as per the individual, graduated colour bars (a linear colour stretch was used in all four cases).