Geophysical Research Abstracts, Vol. 7, 05889, 2005
SRef-ID: 1607-7962/gra/EGU05-A-05889

Unraveling the electrical conductivity signatures of sediments from downhole electrical conductivity logs

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INTRODUCTION

In natural resource and environmental investigations, obtaining and interpreting subsurface information is crucial for the understanding, quantifying and modelling of the physical and chemical processes across a landscape, ranging from sub-catchment to basin scale. Downhole geophysical information such as electrical conductivity has been routinely collected for this purpose, with the resultant data allowing the rapid assessment of the physical attributes of subsurface materials.

As part of the South Australian Salinity Mapping and Management Support Project (SA-SMMSP), helicopter airborne electromagnetic (HEM) data of the Riverland and Tintinara East were acquired to map subtle conductivity variations in near surface materials ($\sim$ 1-10 m below the surface) at a high spatial resolution as an aid to better managing the salinisation of the Murray River system (Riverland) and a deep groundwater resource (Tintinara East) (Cook *et al.*, 2004; Leaney *et al.*, 2004). Borehole electrical conductivity logs were collected and the information was used to validate products derived from the inversion of the HEM data and reducing ambiguity in their interpretation (Tan *et al*., 2004a; Tan *et al*., 2004b).

This paper presents a summary of some results obtained from the analysis of these borehole logs and aims to define and, where possible, quantify the relationships between electrical conductivity and its associated attributes, namely: water content, pore fluid salinity and clay abundance.

METHODS

A total of 19 boreholes were selected to target specific electrical conductivity responses observed in the HEM data (at 25000 Hz) at the Riverland and Tintinara East study areas (Tan *et al.*, 2004a; Tan *et al.*, 2004b). Downhole induction and gamma logs were recorded for 18 of the bores. The cores and drill chips were logged and samples at various depths were analysed for gravimetric water and chloride contents, grain size distribution (using laser diffraction technique) and mineral composition (using X-ray diffraction method). Water content was measured by drying 100 g of sample in an oven and a weight percentage was derived based on the dry to moist sample weight ratio.

Downhole conductivity logs were obtained using Auslog-Scintrex A34 as the logging tool. Conductivity is measured in milli-Siemens per metre (mS/m) and the instrument was calibrated using calibration rings of 100, 300 and 1000 mS/m prior to logging. A polynomial function was utilised by the software AUSWIN to transform the calibrated values. Two sets of logs were recorded as the probe was lowered, then retrieved, at a speed of 5 m per minute and values were recorded every 0.05 m (5 cm) interval. The best set of logging data (with no/least anomalous artefacts) was then used for interpretation (Jones and Henschke, 2003).

RESULTS

Rhoades et al. (1976) demonstrated that the apparent conductivity of a material is the weighted summation of the electrical conductivity of liquid and solid phases (Equation 1).

$EC_a = EC_w \theta \tau + EC_s$(1)

where EC_a is the apparent conductivity, EC_w is the pore water conductivity, θ is the volumetric water content, τ is the tortuosity and EC_s is the solid phase conductivity.

In the absence of massive sulphides, conductivity is dominantly attributed to the liquid phase, which is in turn driven by the volumetric water content and the electrolyte (mainly sodium and chloride) ion concentration in the pore water. The product between the water content and salt concentration is termed salt loads, and in this case, chloride is used as a surrogate for pore fluid salinity. Plots of electrical conductivity against salt load show good linear correlation for the Riverland and Tintinara dataset (Equations 2and 3 respectively).

$EC_a = 0.148\ \Phi_{Cl} + 8.18\ r^2 = 0.81$ (2)

$EC_a = 0.148\ \Phi_{Cl} + 59.7\ r^2 = 0.82$ (3)

where EC_a = apparent electrical conductivity (mS/m); Φ_{Cl} = salt load using chloride concentration (mg/kg) as a surrogate for total dissolved solids (TDS) in a sodium-chloride dominated system.

The water content exerts a greater influence on conductivity than pore fluid salinity concentrations. At low water content (< 5 wt %), increasing the pore fluid salinity barely influences the observed EC_a (Equation 4). This accord with the findings of Emerson and Yang (1997) who suggested that sensible measure required clays and sands to have at least 10 % degree saturation. Thus, for a clay sample with 60 vol % porosity, the minimum water content needed is 6 vol % or approximately 4 wt %. Increasing the water contents from moderate (10-15 wt %) to high (25-30 wt %) result in a significant rise in EC_a with a moderate increase in pore fluid salinity. The relationships between EC_a and chloride concentrations at a given range of water content are illustrated in Equations 4, 5 and 6.

At < 5 wt % water, $EC_a = 0.001\ Cl + 43.5$ (4)

At 10-15 wt % water, $EC_a = 0.015\ Cl + 41.3$ (5)

At 25-30 wt % water, $EC_a = 0.049\ Cl + 54.6$ (6)

where EC_a = apparent electrical conductivity (mS/m); Cl = chloride concentration in mg/l.

Clay ($< 4\ \mu$m) abundance has a causal relationship with EC_a via water content and pore fluid salinity. In the unsaturated zone, in general, clay-rich materials have higher water content than sand. Thus, EC_a is found (Riverland data) to be positively correlated to clay abundance (Equation 7). At Tintinara East however, the presence of wet sand interbedded with moist sandy mud has resulted in the data plotted away from the regression line (graph of EC_a against clay abundance). Similarly, an elevated or anomalously low pore fluid salinity also resulted in the data not falling on the regression line for a given clay abundance.

$EC_a = 11.8\ \Psi + 11.6$ $r^2 = 0.9$ (7)

where EC_a = apparent electrical conductivity (mS/m); Ψ = clay ($< 4\ \mu$m) abundance in volume %.

CONCLUSIONS

Results from an analysis of drill cuttings and downhole induction logs in the Riverland and Tintinara East areas in southeastern South Australia suggest that electrical conductivity variations resulted from a combination of textural effects acting together with moisture and high chloride contents. The recorded electrical conductivity is linearly related to salt load, which is a product of water content and pore fluid salinity. However it is the link between clay abundance and water content in the unsaturated zone that result in the clay having higher observed electrical conductivities than sand.

ACKNOWLEDGEMENTS

This work was conducted as part of the South Australian Salinity Mapping and Management Support Project funded by the Commonwealth's National Action Plan in collaboration with the Government of South Australia. This paper is published with the permission of the CEO's of CRC LEME and Geoscience Australia.

REFERENCES

Cook, P.G., Leaney, F.W. and Miles, M. 2004. Groundwater Recharge in the North-East Mallee Region. CSIRO Land and Water, Technical Report No. 25/04. 80 pp.

Emerson, D.W., and Yang, L., 1997, Effects of water salinity and saturation on the electrical resistivity of clays: Preview, 68, 19-23 pp.

Jones, G. and Henschke, C. 2003. South Australia Salinity Mapping and Management Support: Jamestown drilling Report – A draft report to the technical committee: Bureau of Rural Sciences. 16 pp.

Leaney, F.W., Barnett, S., Davies, P., Maschmedt, D., Munday, T. and Tan, K. 2004. Groundwater Salinsation in the Tintinara Highland Area of SA: revised estimates using spatial variation for clay content in the unsaturated zone. CSIRO Land and Water, Technical report 24/04. 62 pp.

Rhoades, J.D., Raats, P.A.C. and Prather, R.S. 1976. Effects of Liquid-Phase Electrical Conductivity, Water Content, and Surface Conductivity on Bulk Soil Electrical Conductivity: Soil Science Society of America Journal, 40, 651-665 pp.

Tan, K.P., Munday, T.J. and Leaney, F.W. 2004. The validation of RESOLVE Helicopter EM data: mineralogical and Petrophysical results from field investigations in the Riverland area, South Australia. CRC LEME Open File Report 179. 61 pp.

Tan K.P., Munday, T.J. and Leaney, F.W. 2004b. The validation of RESOLVE Helicopter EM data: mineralogical and Petrophysical results from field investigations in the Tintinara East, South Australia. CRC LEME Open File Report. 51pp.