TRIAL RESULTS FROM A NEW ELECTRO-KINETIC GEOPHYSICAL TECHNIQUE FOR REMOTE MEASUREMENT OF SUB-SURFACE HYDRAULIC CONDUCTIVITY

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ABSTRACT

Field trials of a new geophysical technique called an Electro-Kinetic Sounding (EKS) have been conducted in a range of geological settings, including upper Murray Basin sediments from two sites near Kerang, Victoria, Australia. Successive regressions of the Pliocene coastline (<5 Ma) have formed numerous beach dune strands, which are now buried from 0 – 35 m below the surface. In between the dune sands are finer and less permeable sediments. The different sedimentary facies incorporated in Loxton-Parilla Sands form important near-surface aquifers for the regional hydrological regime, and are host to over 20 titanium and zircon mineral sand deposits, some of which are currently under development. Successful mine development, operation and managing environmental impacts require a detailed understanding of the hydrology.

The EKS geophysical technique has successfully detected and defined the relative depth and permeability of the dune sand systems from the Loxton-Parilla Sands where previously only drilling had been successful. Some of these sand units are recognisable as relict beach dune sands, formed by regression of successive Pliocene strandlines. An example of a similar structure from the Wemen mineral sand deposit, also in the Murray Basin, is shown for comparison (after Mason 1999). The Wemen heavy mineral deposit is well defined by close spaced drilling and detailed mineral analysis. One difference between the two sites is the size. The Wemen dune system is approximately 200 m across, compared with 500 m for the larger of the 3 dune systems detected in the 1200 m EKS cross section at Churchs Road, near Pyramid Hill.

Within the interpreted large dune system there are zones of particularly high permeability. For a beach dune geological setting, high permeability is likely to correspond with coarse sands and high concentrations of heavy minerals. If this inference proves to be correct, EKS surveys will be very useful for heavy mineral exploration. Heavy mineral sand mines also require hydrological models to be constructed to predict the environmental impact of sand mining. EKS data could be used for both purposes, significantly lowering the total cost of exploration and environmental assessment to the operator. Similar strandline beach dune deposits are found throughout the Murray Basin.

Calibration of individual EKS data traces by comparison with geological drill logs and gamma logs, enables selection of a uniform seismic velocity model for processing all EKS data at any location. The survey technique involves collection of a sequence of EKS measurements along a profile line or in a grid pattern. Permeability values inferred from the processed signal may be interpolated to a 3D grid or mesh. These 3D block models are used to aid in the visualisation of the hydro-geology, or as direct input into finite difference or finite element hydrological flow models. Application of the EKS in this geologic environment has significant cost and interpretive advantages compared with the use of drilling alone for hydro-geologic investigations.

INTRODUCTION

A geophysical investigation was undertaken to assess the utility of the Electro-Kinetic Sounding (EKS) technique for mapping shallow aquifer systems in seven areas near Kerang in Northern Victoria (Figure 1). This paper presents selected results of EKS data collected in April 1999, with a comparison between EKS data, gamma logs, bore records and geological cross sections provided by Goulburn-Murray Water. Full results are available in Hankin and Waring (1999).

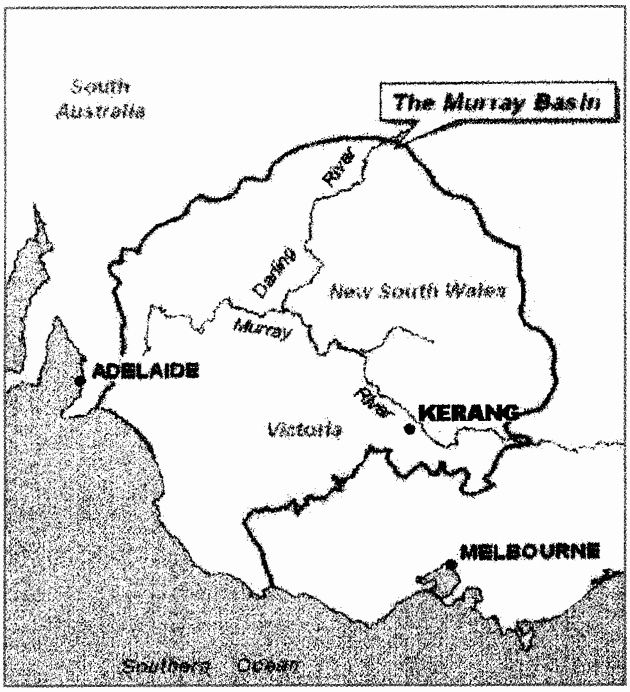


Figure 1. Location of Kerang, Australia (after Macpherson 1999).

EKS PRINCIPAL AND EQUIPMENT

The EKS equipment used in this survey is the commercially available GroundFlow-500 model. GF-500 is based on a relationship first described by Chandler (1981) where a sharp pressure pulse on a permeable rock core sample induces an electrokinetic signal or "streaming potential". The rise time of the electrical signal is inversely proportional to the rock core sample's permeability.

Groundwater contains dissolved ions, which are attracted to the walls of cracks and pores in the rock. When pore water moves in response to a seismic pulse, negative ions travel further and more easily than positive ions, so that an electric potential develops which is proportional to the applied pressure (Millar, 1997). This potential is typically 30-60 millivolts per atmosphere in a wide range of rock types. The amplitude of this effect is controlled by changes in the pore fluid resistivity. Also, the rise time of electrical response is a direct measure of how quickly flow is generated by a given pressure, or the permeability of the rock.

In practice, a 4 electrode array of 2 independent channels records small electrical signals which are induced by the passage of a seismic pulse through water saturated porous permeable rock and unconsolidated sediments. Proprietary algorithms built into the EKS hardware and software interpret the electrical signal from each channel into a hydraulic conductivity vs depth trace (dependent on selected seismic velocities).

EKS DATA PROCESSING

The data was inspected on a site by site basis, and the best quality data was selected from each site for further processing. This requires inspection of each sounding to assess quality of data due to variability in seismic source, electrical properties at each electrode, possible recorder triggering delay and electromagnetic noise. Some soundings may be corrected or omitted at this stage, to prevent introducing noisy data into the visualisation. Where suitable, a stack of the data was applied to obtain improved signal to noise ratio.

Calibration of individual EKS data traces by comparison with geological drill logs and gamma logs, enables selection of a uniform seismic velocity model for processing all EKS data at any location. The data is then reprocessed using the new seismic velocities. A uniform depth to water table of 1.5 metres was selected for all areas and a seismic velocity of 0.5 m/ms used for the unsaturated zone. Depth corrections due to topographic effects were not necessary due to the flat topography of the survey areas. The selected data was then truncated to a depth of 100 metres below ground, and de-sampled to 20% prior to griding.

DATA VISUALISATION

The linear permeability scale processed data from each site was interpolated to produce a cross section of EKS calculated permeability. Due to the high amplitude response of the EKS signal in the unsaturated zone, the natural logarithm of EKS permeability is presented in the cross sections. The logarithmic scale representation helps to enhance visibility of lower amplitude structures below the water table. All vertical coordinates are presented as metres below ground. Note that varying degrees of vertical exaggeration are present in different cross sections and that varying colour scales have been used. All horizontal coordinates are presented on an arbitrary local grid coordinate system in metres, relative to the position of hydrological bores on site. Key bore positions are labelled on the cross sections. The position of EKS soundings is shown as a thin black line.

Individual bore comparison diagrams are presented for EKS soundings that coincide with hydrological bores. These diagrams allow direct comparison of the EKS signal with the interpreted soil and sediments. The coloured bar and black line represents the magnitude of natural logarithm of EKS permeability in meters/day, with the surrounding hatched area representing the logged soil and sediments. Graphical display of soil and sediments is obtained from drill logs and gamma logs supplied by Goulburn-Murray Water. Where suitable, the depths of sand layers indicated in the drilling logs were manipulated to more closely match the corresponding gamma log, before being applied to the comparison diagram. For these diagrams, the EKS data is not desampled, and only the top 30 metres of the EKS sounding is presented, as most of the hydrological bores extend to less than this depth. The horizontal position of the bores in relation to each other is not conserved in all cases.

Figure 2 shows a comparison between a gamma log and drill log supplied by Goulburn-Murray Water and the EKS log permeability. In each, an EKS high is visible at approximately the same depth as a low in the gamma log. High EKS values are also present in parts of the section, without significant low values in the gamma log.

Direct correspondence between these data is not expected because they measure different sub-surface parameters. The particular lithological classification of the drill logs makes it difficult represent continuously varying sedimentary units, and tends to favour representation as discrete narrow bands at subjective depth intervals. All sedimentary units logged as "Sand" are not identical and are defined on the subjective assessment of the person logging the drill hole. Gamma logs have particularly good depth resolution and are usually indirectly proportional to the clay fraction concentration. In this geological setting gamma logs may be ambiguous because some coarse sands with a low clay content contain elevated concentrations of radioactive minerals such as monazite in the heavy mineral fraction. EKS permeability data has the tendency to smear sharp geological boundaries and is unable to clearly resolve discrete narrow geological units, particularly if there is little contrast in permeability. EKS is a remote surface geophysical technique. Comparison with the down-hole equivalent of EKS, Electro-Kinetic Logging (EKL) is likely to greatly increase the depth and permeability resolution.

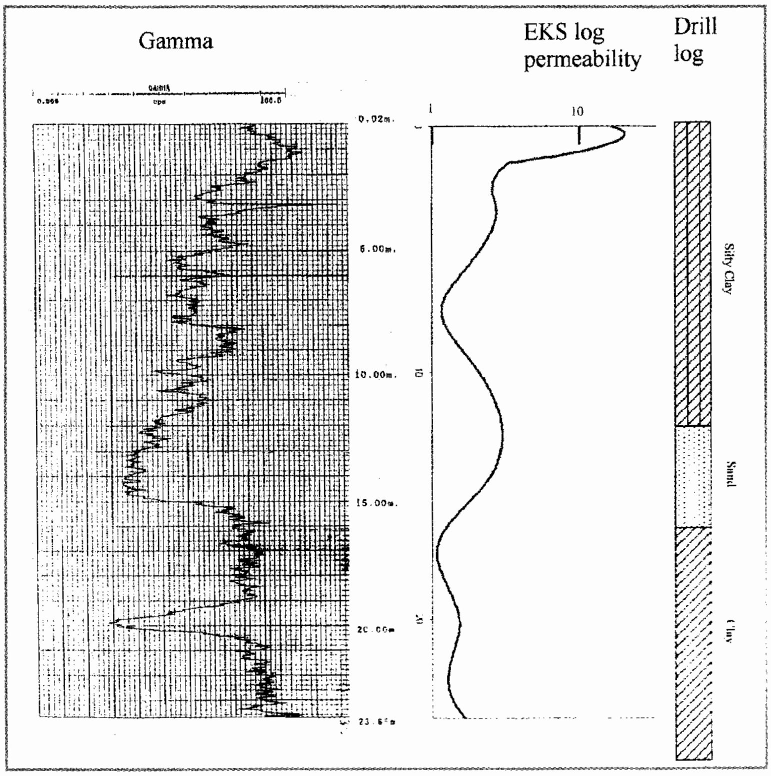


Figure 2. Kow Swamp – Bore KS1. Comparison of gamma log, drill log and EKS log permeability.

GEOLOGICAL SETTING

Successive regressions of the Pliocene coastline (<5 Ma) have formed numerous beach dune strands, which are now buried from 0 – 35 m below the surface forming the Loxton-Parilla Sands. In between the dune sands are finer and less permeable sediments. Loxton-Parilla Sands form important near-surface aquifers for the regional hydrological regime, and host to over 20 titanium and zircon mineral sand deposits, some of which are currently under development.

SITE INTERPRETATION

Interpretation of the cross sections is discussed individually with reference to the associated comparison diagrams. The first five sites described are in the vicinity of Pyramid Creek, and the bore fields form part of the Pyramid Creek Groundwater Interception Scheme.

Kow Swamp

A seismic velocity of 1.7 m/ms was applied in this area. Four bores were selected for EKS comparison. From the bore records, it can be seen in Figure 3 there is an interpreted sand layer at 12 - 15 metres depth. Position of the top of the sand layer slightly increases in depth from KS7 to KS4 to KS1 and then decreases to KS9 for both the geological log and EKS trace. An increase in EKS permeability is visible at approximately the same depth becoming more vague in bores KS1 and KS9. This is more easily seen in the associated cross section in Figure 4. This cross section shows good agreement with established bore records.

Churchs Road

A seismic velocity of 2.0 m/ms was applied in this area. The survey area is a transect across a proposed evaporation basin for the ground water interception scheme. A comparison diagram was not constructed, as little detail is recorded on the drilling logs for this area. Zones of high EKS log permeability are displayed in cross section Figure 5. A more detailed interpolation of the top 30 metres of this section shown in Figure 6, reveals 3 diagonally aligned high permeability zones, bounded by relatively low permeability zones. Note the high level of vertical exaggeration of the section (30 metres vertical by 1200 metres horizontal), and the nugget-like appearance is a product of the interpolation process.

An interpretation of these diagonal features is as relict beach dune sands, formed by regression of successive Pliocene strandlines. An example of a similar structure from the Wemen mineral sand deposit, also in the Murray Basin, is shown for comparison in Figure 7 (after Mason 1999). The Wemen heavy mineral deposit is well defined by close spaced drilling and detailed mineral analysis. Contours shown in Figure 7 are heavy mineral grade outlines. One difference between the two sites is the size. The Wemen dune system is approximately 200 m across, compared with 500 m for the larger of the 3 dune systems detected in the 1200 m EKS cross section at Churchs Road, near Pyramid Hill.

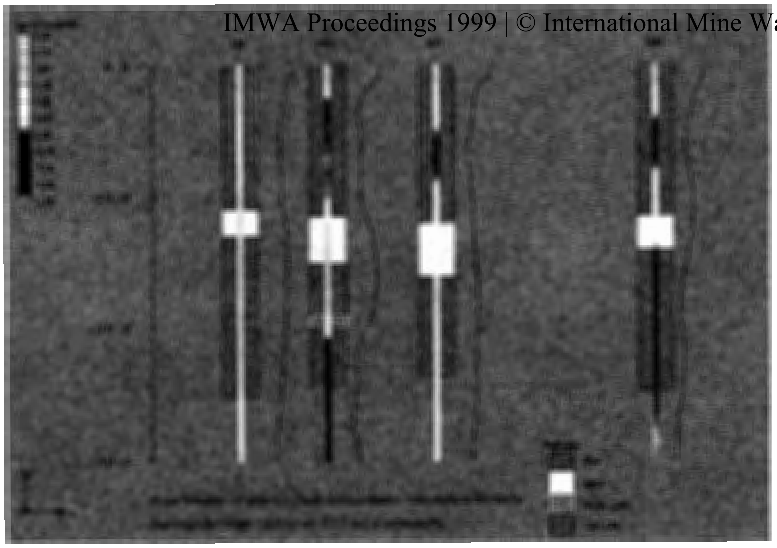


Figure 3. Kow Swamp – Geological Log comparated to EKS Permeability (log scale).

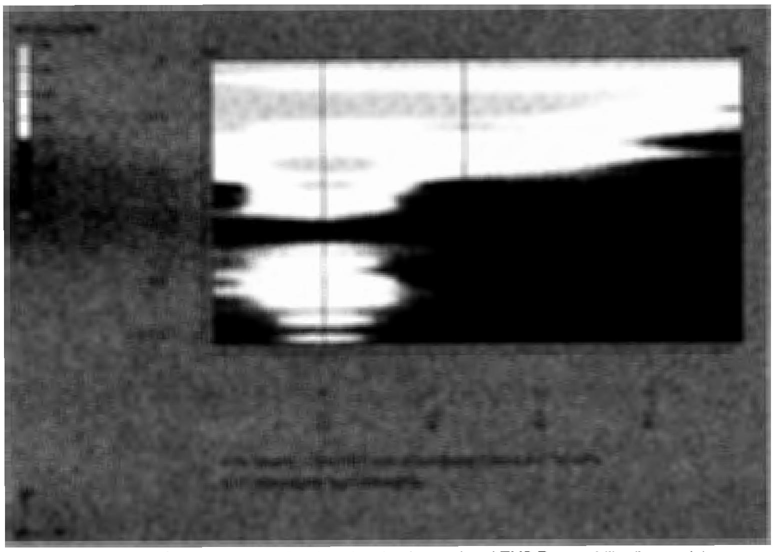


Figure 4. Kow Swamp – Cross Section showing Interpolated EKS Permeability (log scale).

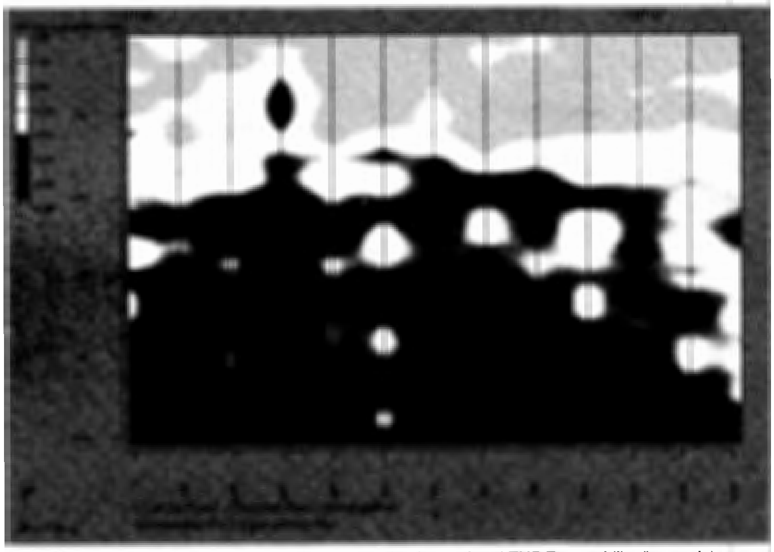


Figure 5. Churchs Road – Cross Section showing Interpolated EKS Permeability (log scale).

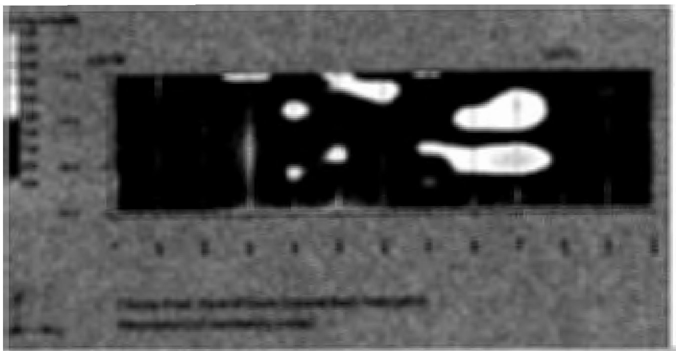
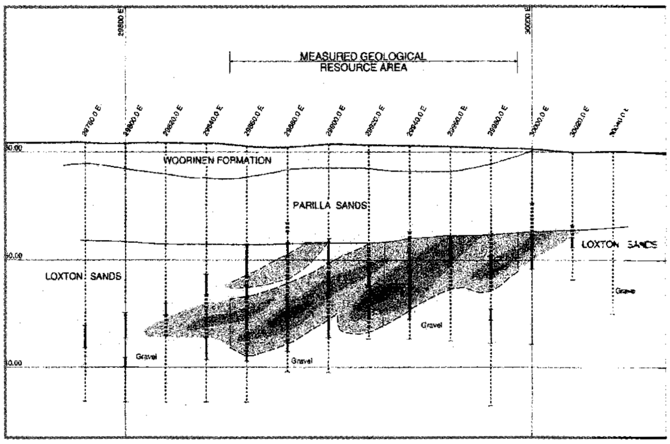


Figure 6. Churchs Road top 30 metres – Cross Section showing Interpolated EKS Permeability (log scale).



Grey shading denotes mineral grade

Figure 7. A cross section through the Wemen heavy mineral deposit showing diagonal structure from beach dunes (After Mason 1999).

Within the interpreted large dune system there are zones of particularly high permeability. For a beach dune geological setting, high permeability is likely to correspond with coarse sands and high concentrations of heavy minerals. If this interpretation proves to be correct, EKS surveys will be very useful for heavy mineral exploration. Heavy mineral sand mines will also require hydrological models to be constructed to predict the environmental impact of sand mining. EKS data could be used for both purposes, significantly lowering the total cost of exploration and environmental assessment to the operator. Similar strandline beach deposits are found throughout the Murray Basin.

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