Electro-Seismic Surveyor used in the Kalahari Formation

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ABSTRACT: The electro-seismic surveyor has been used to determine the possible position of the shoulder of Eiseb graben in the Kalahari formations of eastern Namibia. The purpose of the survey was to locate the groundwater reserves in the Kalahari formation, for rural water development schemes. Thus far, only TEM soundings have been found to be effective at locating groundwater reserves in the Kalahari formation. This is mainly due to the deep water table in the area. The electro-seismic data shows good correlation with TEM soundings done over the same graben shoulder. This indicates that the electro-seismic surveyor could be used as an effective tool in locating deep lying groundwater reserves in the Kalahari formations of eastern Namibia.

1 INTRODUCTION

Groundwater reserves have been found to be notoriously difficult to locate in the Kalahari sandstones of eastern Namibia. The main reason for this is that the groundwater table in these formations are usually very deep, between 100m and 150m. This makes geophysical prospecting for these groundwater reserves a very specialised task as many of the standard methods of used to locate groundwater are rendered ineffective. A case study was done in the Eiseb region of the Kalahari that employed the use of TEM soundings on a regional grid to determine the position of the Eiseb graben. The results obtained showed the position of the graben, however there was no extra geophysical information to support the TEM sounding data. This paper shows that Electro-seismic techniques can be used effectively in locating groundwater reserves in the deep lying Kalahari sandstone aquifers. It also shows that Electro-seismic data can be used in conjunction with TEM sounding data to verify the position of the Eiseb graben.

2 ELECTRO-SEISMIC EFFECT

2.1 Background

The electro-seismic effect describes the conversion from seismic to electromagnetic (EM) energy. Several mechanisms are likely to generate couplings between seismic and EM energy in the subsurface (Garambois *et al.* (2002)). The main effects of interest to geophysicists are electrokinetic and piezoelectric phenomena and variations in electrical resistivity.

The macroscopic governing equations were derived from first principals by Pride (1994) which coupled Biot’s theory and Maxwell equations via flux/force transport equations. In this theory the coupling mechanism is explained by electrokinetic effects taking place at pore level.

2.2 Wave Behaviour

A seismic wave propagating in a medium can induce an electrical field or cause radiation of an electromagnetic wave. There are two electro-seismic effects that are considered in this paper (Oleg *et al.* (1997)).

The first effect is caused when a seismic wave crosses an interface between two media. When the spherical P-wave crosses the interface, it creates a dipole charge separation due to the imbalance of the streaming currents induced by the seismic wave on opposite sides of the interface. The electrical dipole radiates an EM wave which can be detected by remote antennas as shown in Figure a.

The second effect is caused when a seismic head wave travels along an interface between two media. It creates a charge separation across the interface, which induces an electrical field. This electric field moves along the interface with the head wave and can be detected by antennas when the head wave passes underneath as shown in Figure b.

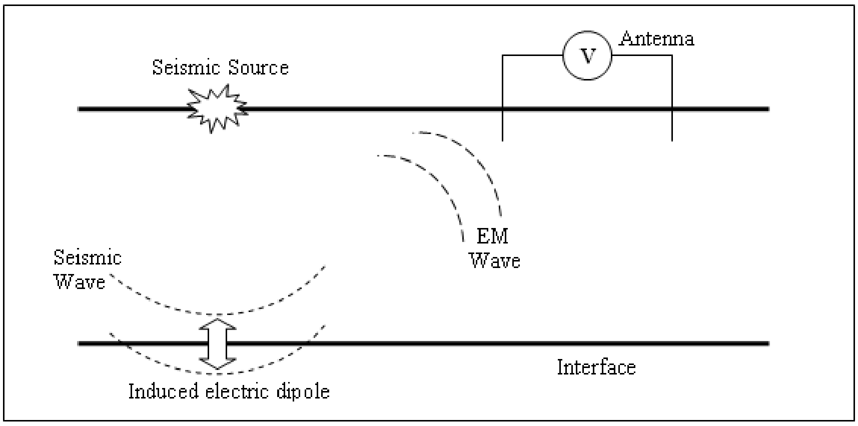


***Figure a**: Seismic wave crossing an interface generating an electromagnetic wave.*

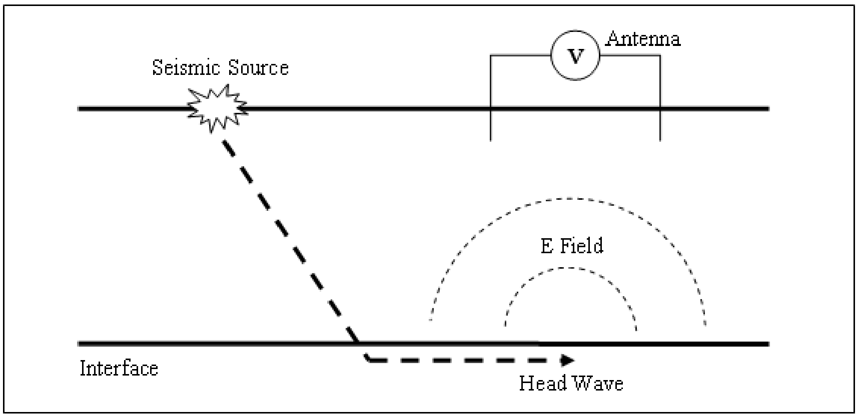


***Figure b:** Head wave travelling along an interface generating an electric field.*

3 METHODOLOGY

The methodology used to gather the field data to determine the position of the Eiseb graben is the same as that used by the TEM sounding method. A regional grid was surveyed using the Electro-seismic method using the exact positions that were surveyed by TEM soundings. This was done to compare the results produced by the Electro-seismic and TEM soundings at a spatial level. The electro-seismic method was applied as a sounding rather than a profiling data set. This was due to the large distances between the surveyed points.

Sounding data was collected by stacking the data recorded by the generation of fifty seismic events at the source point. These seismic events were generated by hitting a 12 pound hammer on a steel plate lying on the ground at the survey point. This stacked data was analysed and interpreted using an electro-seismic model developed and tested by the authors. This analysed data was then compared to the data obtained by the TEM soundings at the same locations. The results of those comparisons are discussed in the following chapters of this paper.

4 CASE STUDIES

A selection of four lines over the edges of the presumed shoulder positions of the Eiseb Graben are discussed in this paper. Lines 1 and 2 were surveyed over the western shoulder of the graben and lines 3 and four were surveyed over the eastern shoulder of the graben.

The positions of the Electro-seismically surveyed points are shown in conjunction with the points surveyed by the TEM soundings.

Figure 1 shows the map of the Eiseb graben and the corresponding TEM sounding lines done across it. Figure 1 also shows the positions of the electro-seismic lines done across the shoulders of the graben. For the electro-seismic lines 1 and 2 these survey positions exactly correspond to the survey positions done by the TEM soundings. For each surveyed line the TEM and electro-seismic data is shown for comparison.

4.1 Eiseb Line 1

ESS Eiseb line 1 was done on the BRG5 TEM Sounding points 1_10, 1_12, 1_15, 1_17 and 1_20. At these points ESS sounding data could be compared to the TEM sounding data, to determine if usable geophysical conclusions could be drawn using these two geophysical methods.

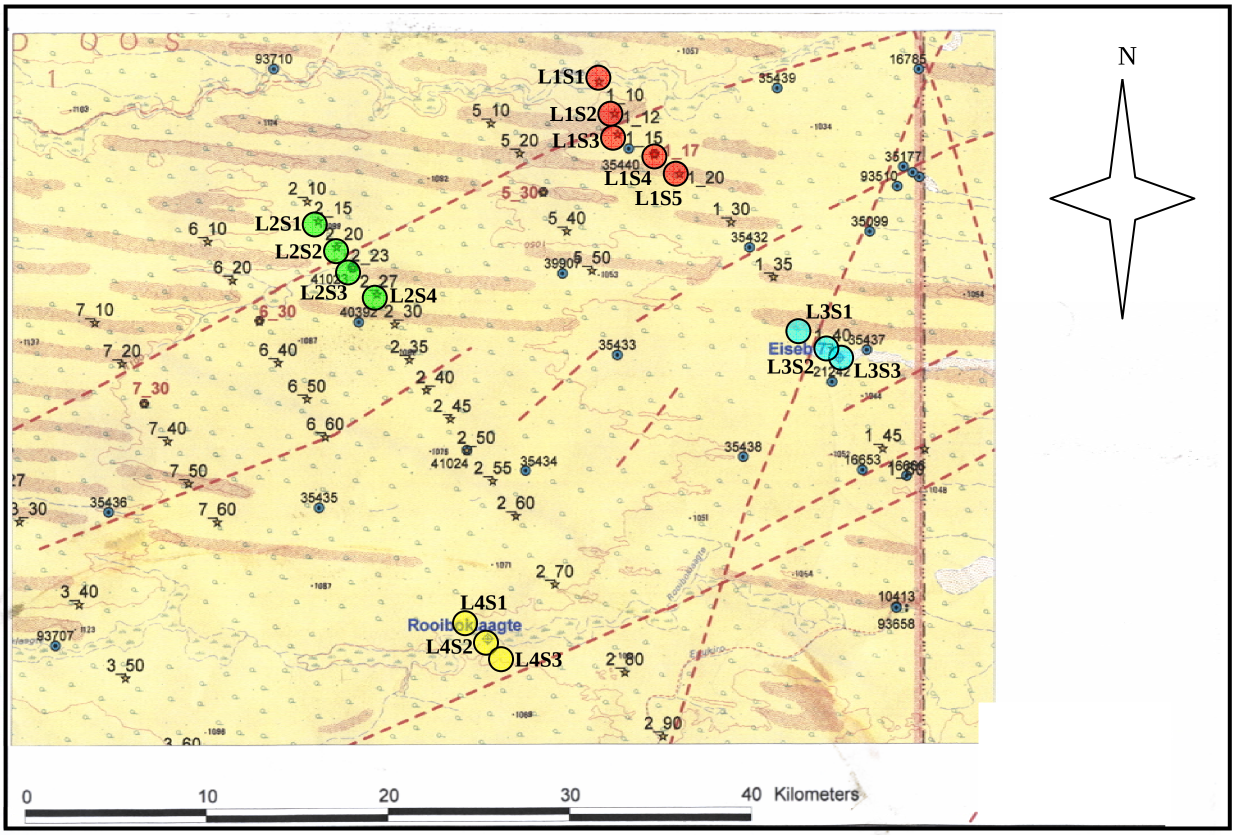
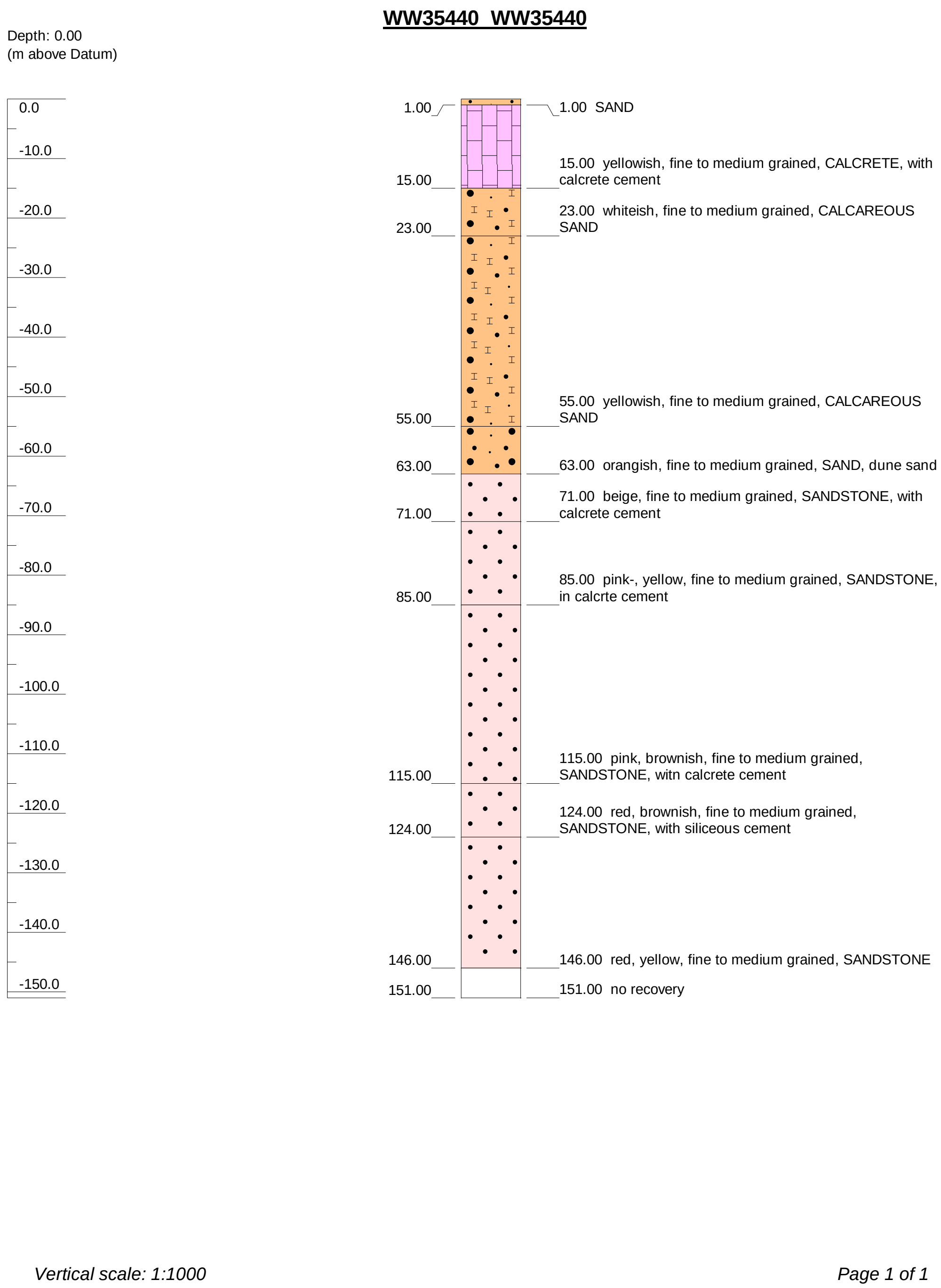


Figure 1 – Eiseb Map of location of ESS line 1,2,3 and 4

Figure 1 shows the positions of the ESS sounding points, in red, and the corresponding TEM sounding points of line 1. The sounding points BGR5 1_10 and 1_12 are expected to be outside the graben and the remaining three are expected to be inside the graben. The drill log for borehole WW35440 is shown on figure 2. It indicates that there is a 15m thick layer of calcrete overlaying a layer of calcareous sand that extends to 63m. This is followed by sand stone. At every one of these interfaces it is possible to receive an electro-seismic response if they are water bearing interfaces.

Figure 3 shows the TEM Sounding data for line 1. The black dashed lines indicate the observed depth of penetration of 200m. This depth of penetration was chosen due to the water strike target zone of 150m to 200m. As seen on figure 3, the topography varies substantially, this must be accounted for as the ESS sounding response plot shown on figure 4, do not account for topography correction. An assumed seismic velocity of 3500m/s was used to generate the ESS profile plots, however this velocity may be slower than expected and could produce depth to strike errors of up to 10m. The Electro-Seismic Relative Amplitude or “ESRA” is the scale that is used to point out the relative ESS anomalies on the ESS response profile shown on figure 4. It is important to note that the *ESRA scale does not give an indication of possible water yield*, it only gives an indication of the position of a predicted water strike. On figure 3, the red circles indicate the ESS response positions as found on the ESS sounding response profile shown by figure 4.

Sounding point 1_10 shows an ESS response at 80m but nothing with depth. This 80m response could be a water saturated change in geology but with a water level in the area of 150m, it is unlikely to be a high yielding water strike. The sounding at position 1_12 does not show any appreciable ESS response and is assumed to be outside the graben as indicated by the TEM soundings. ESS soundings at the points1_15, 1_17 and 1_20 all produce ESS responses between 150m and 200m. This indicates an aquifer at those depths with possible multiple water strikes. This correlates well with the assumed contact position of the graben predicted by the TEM sounding data on figure 3. It also correlates well with the known water level and water strike logs of borehole WW35440.



Project:		
Location point: WW35440		
Client:	Easting (X):	484619
Author:	Northing (Y):	7719437
Checked by:	Ground level:	0.00 m above Datum
Date:	End depth:	0.00 m below ground

Figure 2 – Drill log for WW35440

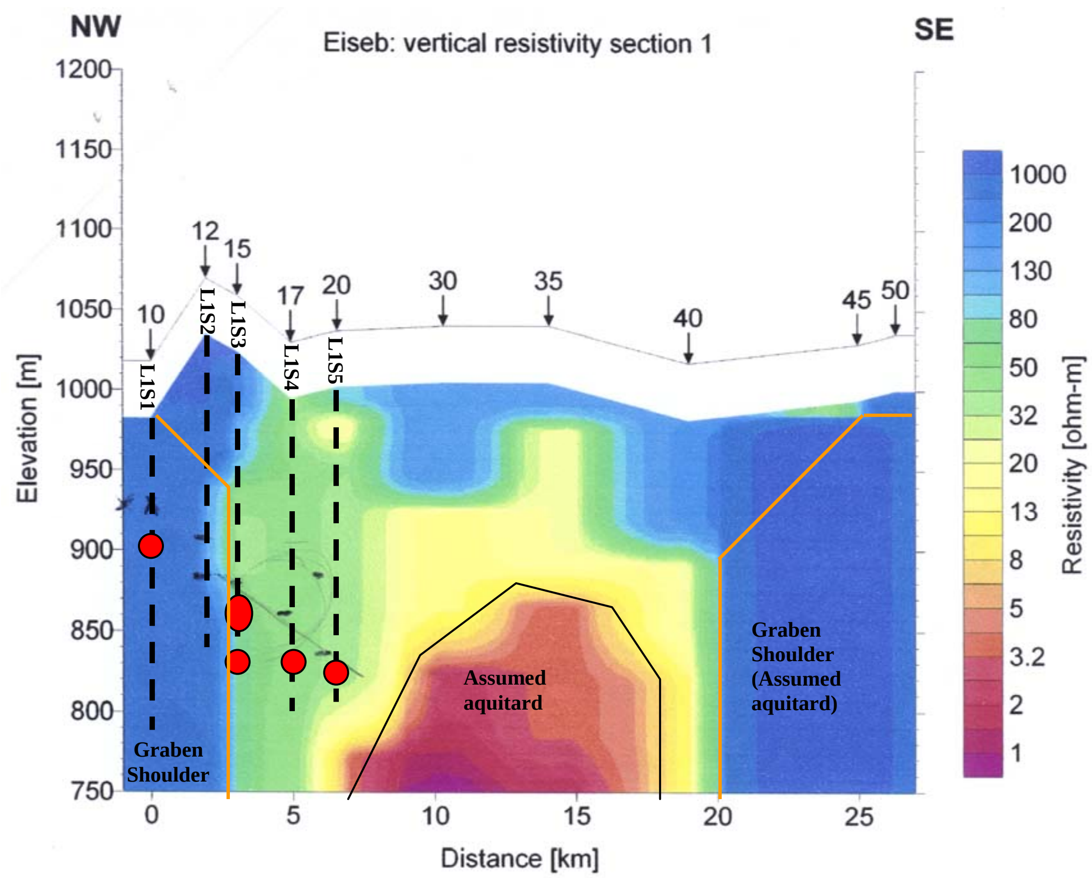


Figure3 – TEM Sounding data for line 1

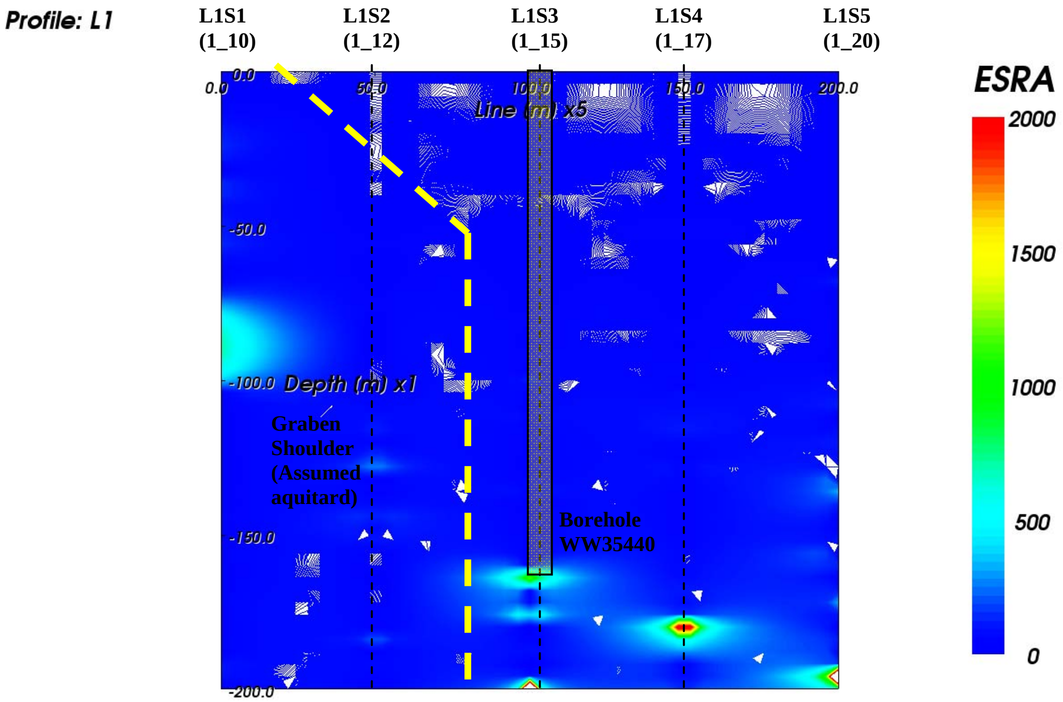


Figure 4 – ESS sounding profile.

4.2 Eiseb Line 2

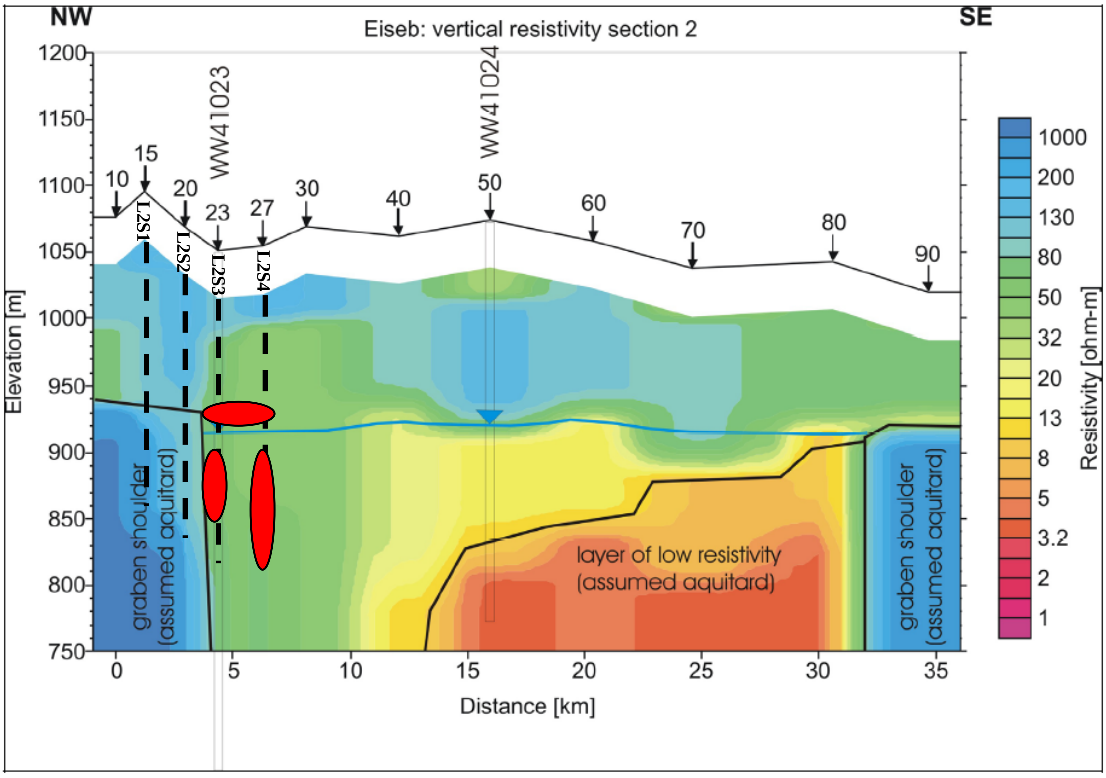


Figure 5 – Line 2 TEM Sounding data

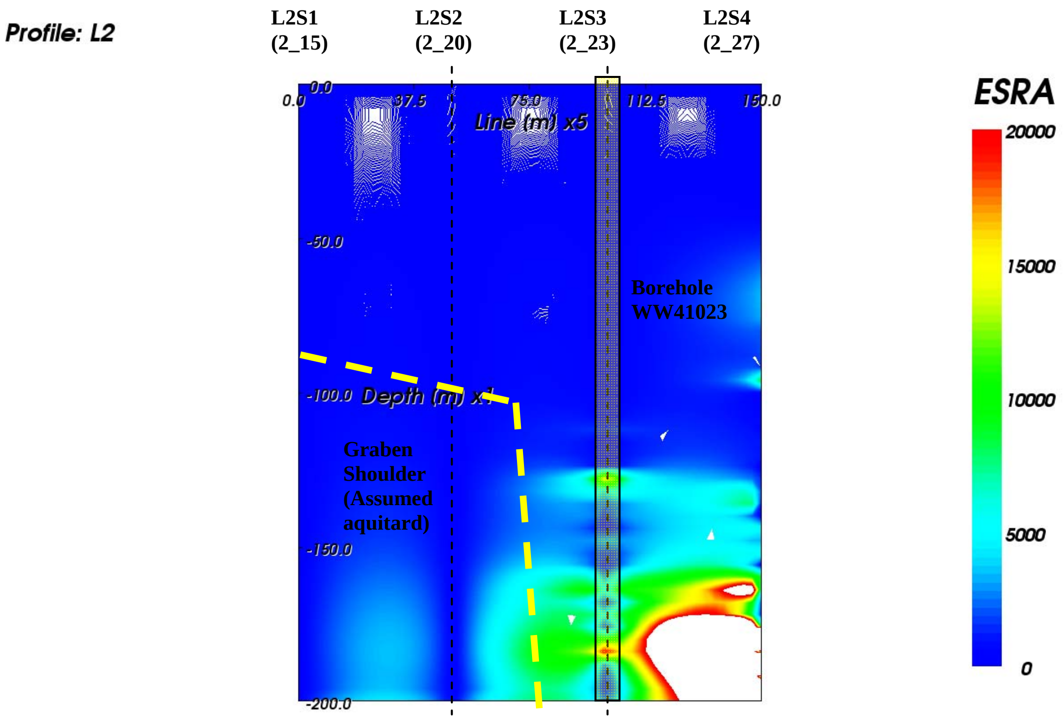


Figure 6 – Line 2 ESS Sounding Data

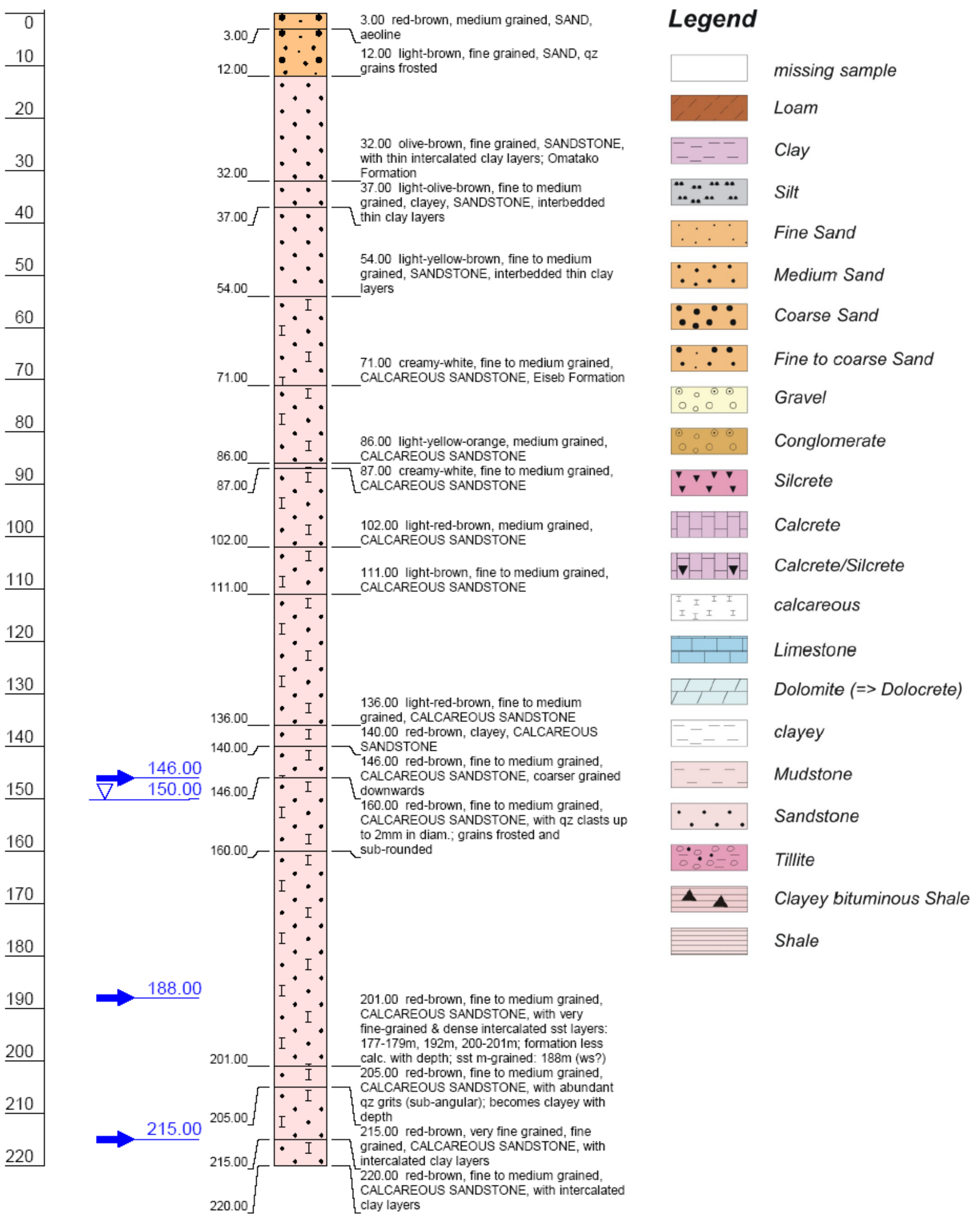


Figure 7 – Borehole log for WW41023

METHOD : Figure 1 shows the position of ESS line 2 sounding points indicated by the green points. These ESS sounding points correspond to the TEM sounding points BRG1 2_15, 2_20, 2_23 and 2_27. These points also cross the shoulder of the graben as predicted by the TEM sounding data in figure 5. As used in the first line, the assumed seismic velocity was taken as 3500m/s. An "ESRA" scale of 20000 was used for line 2.

RESULTS : As expected points BRG1 2_15 and 2_20 produced very little electro-seismic response, indicating the position of an aquitard. This was also predicted by the TEM sounding data and indicates the presence of the graben shoulder. Points BRG1 2_23 and 2_27 indicate large ESS responses at depths between 130m and 200m. This indicates the presence of an aquifer at that depth. The presence of that aquifer is also confirmed by a high yielding borehole WW41023 of which drill log is shown in figure 7. The drill log indicates a water level of 150m with various water strikes between 146m and 220m. This correlates well with the possible strike positions indicated on the ESS sounding data shown in figure 6.

Very large ESS responses are recorded on point 2_27 between 160m and 180m, indicating a well developed aquifer system. At points 2_23 and 2_27 a shallower ESS response is generated at a depth of 130m. This could be due to a saturated underdeveloped or low yielding, aquifer system at that depth or it could be due to an error in the seismic velocity of about 10m.

5 CONCLUSIONS

The ESS data corresponds well with both the TEM sounding data and the borehole logs. This correlation strengthens the findings of the TEM soundings data and clarifies the positions of the possible aquifers. It also strengthens the assumptions made about the geology of the area derived from the TEM soundings.

6 REFERENCES

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Oleg V, Mikhailov OV, Haartsen MW and Toksoz MN 1997. Electroseismic investigation of the shallow subsurface: Field measurements and numerical modeling. *Geophysics*, 62(1): 97 – 105.

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