

Electro-Seismic Survey System

M. du Preez

ABSTRACT: The electro-seismic survey can be used with great success in geophysical surveys where the aim is to site groundwater. The presence of water in the porous rock media is directly responsible for the generation of electro-seismic signals. An analysis technique developed through a quantitative approach produces satisfactory results from survey data sets. These include possible water strike positions as well as layer interface information. Two case studies are presented in this paper to illustrate the capabilities of the current system used for electro-seismic surveys.

1 INTRODUCTION

Geophysical techniques have been employed for many years to locate groundwater in South Africa. Magnetic airborne surveys are very useful in the structural mapping of an area, particularly to determine the dominant direction of tectonic movement, and the location of features such as faults, dykes and fracture zones. The majority of geophysical surveys (magnetic, electromagnetic, electric and gravitational) can yield valuable information on the global geometry of an aquifer. The results are also often ambiguous especially in Karoo aquifers with its numerous layers of mudstone and siltstone. In many instances it is necessary to use a combination of these techniques to overcome these ambiguities. High resolution radio and seismic tomography are two methods that have shown some promise for groundwater investigations in the Karoo formations.

The majority of the geophysical methods focus on obtaining information concerning the rock matrix and subsurface structures. The electro-seismic effect on the other hand is a direct result of relative movement of an electrolytic fluid with respect to the rock matrix. Thus the presence of water in the porous rock media is directly responsible for the generation of electro-seismic signals. This has huge cost saving implications due to the fact that the presence of water could be determined before any drilling has taken place.

This paper discusses the theory surrounding the electro-seismic effect and finally two case studies are presented to illustrate the interpretation of the electro-seismic survey results.

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 & Dietrich, 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 Behavior

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 1.

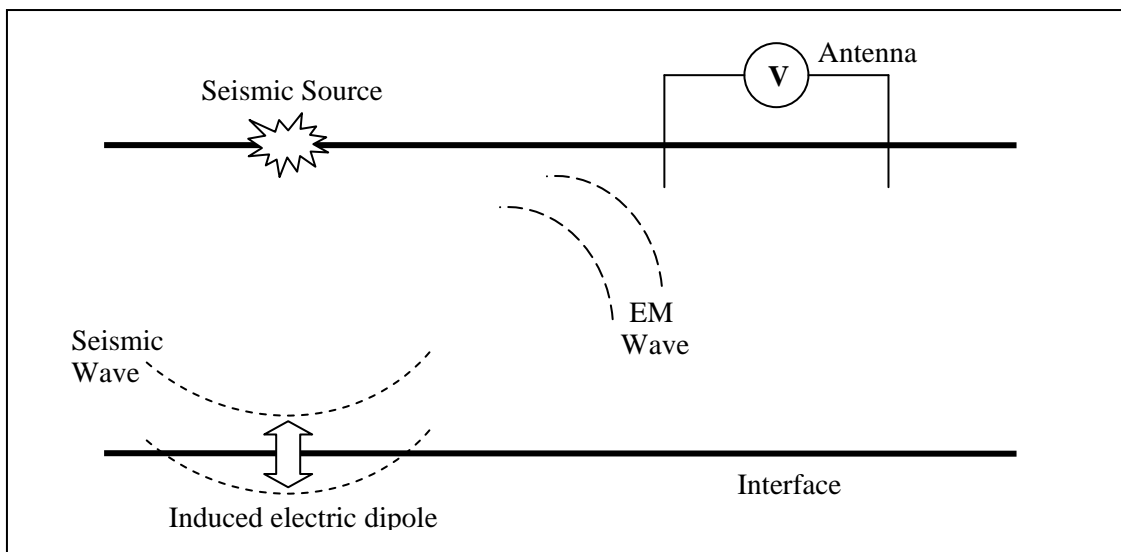


Figure 1. Seismic wave crossing an interface generating an electromagnetic wave.

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 2.

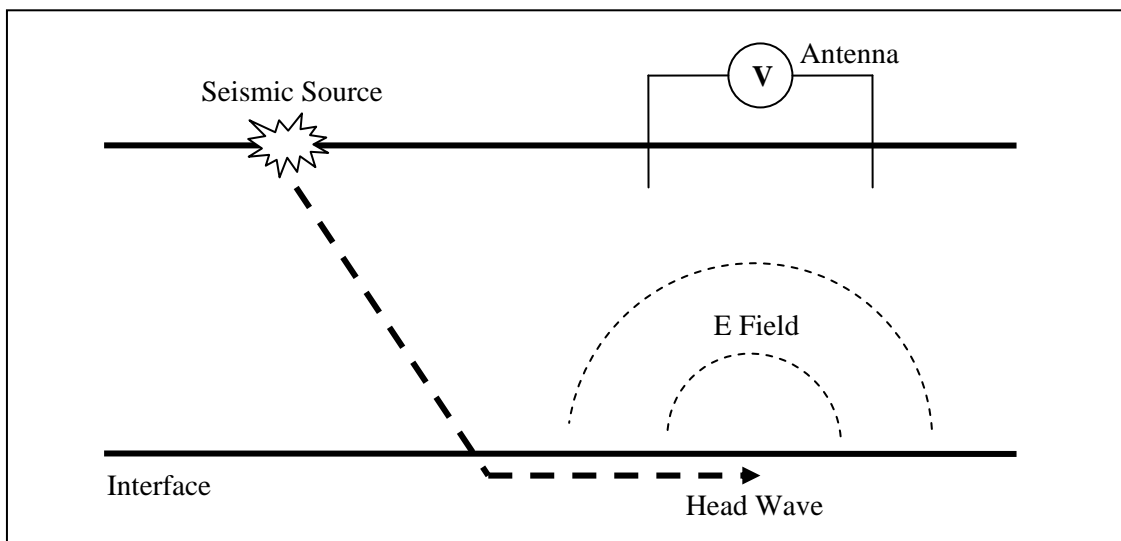


Figure 2. Head wave traveling along an interface generating an electric field.

3 SYSTEM DESCRIPTION

The Electro-Seismic Survey (ESS) system consists of a probe, a trigger and base units. The probe unit is a low noise amplifier connected to a 16-bit A/D converter. A horizontal dipole antenna is connected to the input of the amplifier. The seismic source used is a hammer and plate. The hammer is connected to the trigger unit. An inertia switch is fitted to the hammer and acts as the physical trigger. The base unit is connected to a laptop via the serial port. Custom software has been developed for data acquisition and processing. The probe and trigger units interface to the base unit via a wireless link to reduce external noise coupling into the system. The recorded data set represents 200ms which translates roughly to 200m at the slowest seismic velocity for subsurface media. Practical results indicates an average maximum penetration depth of 150m when using the hammer and plate seismic source.

4 METHODOLOGY

Two methods are used to analyse recorded data. These methods are discussed in the sections below.

4.1 *Numerical Model*

The first approach in analysing the recorded signals was to setup a numerical model that simulated the electro-seismic effect. A ray path model, using the generalized matrix method to solve the governing equations, was setup for this purpose.

Problems experienced were the instability of the model for certain inputs and the fact that there was little correlation between the simulated and recorded data.

4.2 *Quantative Approach*

The second approach taken was a quantative one where surveys were done before drilling took place without making any recommendations with respect to the ESS survey results. After drilling all borehole logs and water strikes were recorded. By doing this the authors could gather enough data to develop an analysis technique that provides accurate results.

5 CASE STUDIES

In this section two case studies are presented. The first is to illustrate that the principle of electro-seismic surveys does work and the second case study illustrate the current capability of the system used.

5.1 *Shallow Water Pipe*

A shallow concrete water pipe was chosen to illustrate the electro-seismic effect. The water pipe is 1m below the surface with a diameter of 20cm. A profile was done across the pipe in a direction perpendicular to the pipe with a station spacing of 0.5m. The result of the survey is shown in Figure 3.

From the results it is clear that the position of the pipe is correctly determined when the velocity of the seismic wave is estimated as 5000 m/s. Typical seismic velocities lie in a range of 1500 to 6800 m/s depending on the medium.

Contours indicate activity beneath the pipe, but this could be a result of reflections because of the close proximity of the surface or due to the free movement of water in the pipe as opposed to water moving in a rock matrix.

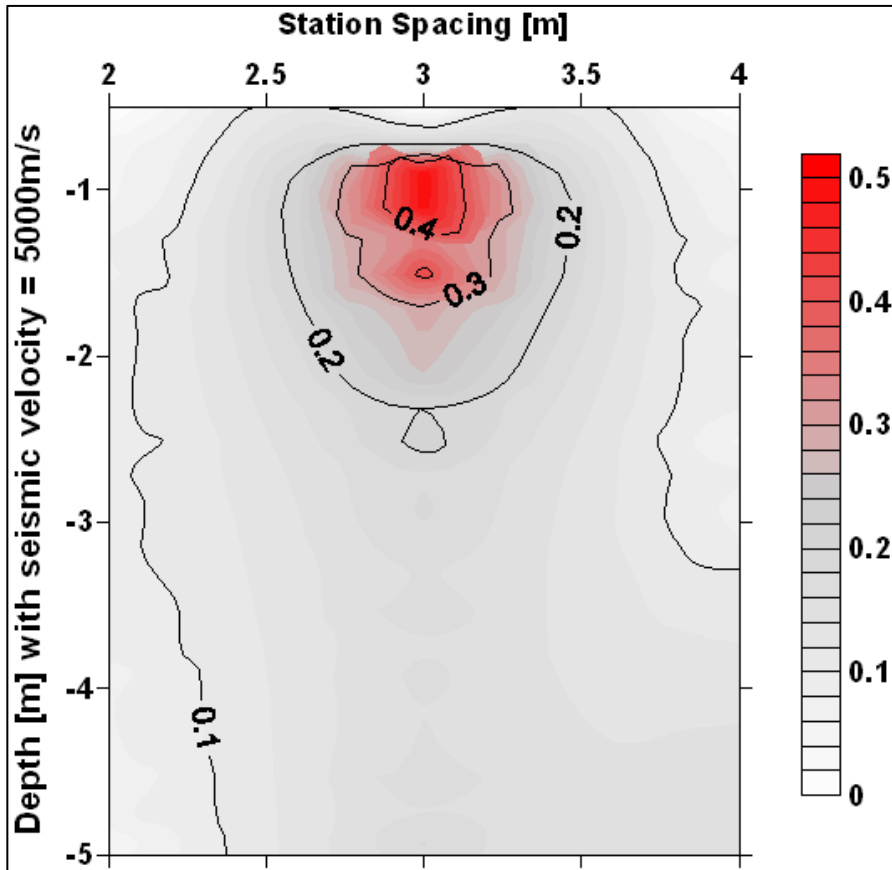


Figure 3. Results of pipe survey.

5.2 Borehole in Layered Media

For this case study a profile was done across the area of interest and the results of the possible water strike positions together with the layer information are shown in Figure 4. Firstly consider the graph on the left hand side. After the survey was completed this contour plot is produced to determine possible water strike positions. The depth of the water strikes is dependant on the seismic velocity used to do the depth scaling. For this particular survey an average seismic velocity was used that was calculated from a borehole about 200m away where the borehole log was available. The difference between the predicted and actual water strike was 3.5m. If no information is available prior to drilling a guesstimate is made regarding the average seismic velocity. The contour plot will still indicate the line with the best response although the estimated water strike could be inaccurate.

At a first glance it would seem that the main water strike is at 20m below the surface but this is not necessarily the correct assumption for the following reasons:

- The seismic wave attenuates with depth as it crosses interfaces.
- The type of geological interface has an influence on the response generated.

Currently the analysis technique used is not capable of indicating the main water strike as related to possible yield estimation.

Now consider the layer plot on the right hand side of Figure 4. Before drilling starts the layer interfaces can be visualized from the data set obtained but the layer types can not be identified until after drilling has taken place and a geological log is available.

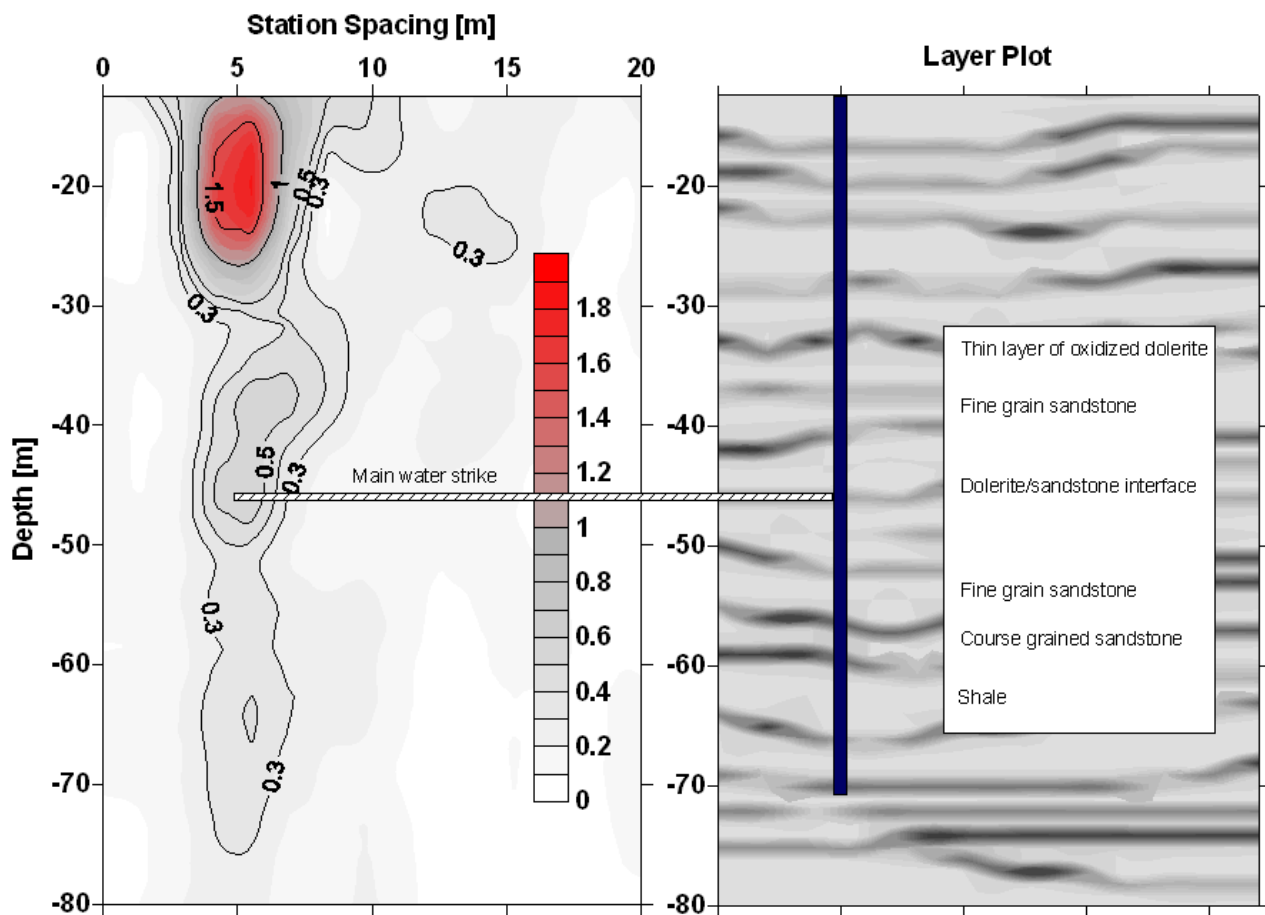


Figure 4. Possible water strike positions and layer information of the layered media survey.

The main water strike was found at roughly 47m below surface on a dolerite-sandstone interface and a blow yield of 4L/s was measured. Very good correlation exists between the borehole log and the layer plot. Only a few layer types are shown on the layer plot for illustration purposes.

6 SYSTEM LIMITATIONS

The system is very susceptible to power line noise which makes the data analysis difficult due to the fact that the 50 to 60Hz noise and the associated harmonics fall within the bandwidth of the electro-seismic response. Various filtering schemes (notch filters and sinusoidal subtraction) have been tested with limited success because valuable data gets lost during the filtering process. Data stacking has provided the best results to date of all schemes tested. For very noisy data 50 point stacking gives good resolution otherwise 10 point stacking is used in the surveys.

The analysis technique employed does not account for the attenuation of the seismic signal with depth and this could lead to the misinterpretation of the data because the strongest signal response does not necessarily indicate the main water strike.

The current analysis technique does not lend itself to yield estimation and further research on this topic needs to be done to determine if it is feasible or not.

Accurate depth of features is dependant on the seismic velocity used to do depth scaling. In most instances this information is not available before hand although good results have been obtained in areas where the average seismic velocity has been determined from existing borehole logs.

7 CONCLUSIONS

From the results it is clear that the electro-seismic survey does provide accurate results if the correct seismic velocity is used for depth scaling. The electro-seismic survey provides valuable information regarding possible water strike positions and physical layering of the media but no successful yield estimation could be done to date. Results indicate a localized response from the electro-seismic effect which is in contradiction to articles written regarding this subject. Further research is needed to fully understand the electro-seismic effect and the application thereof.

8 REFERENCES

Garambois, S. and Dietrich, M. (2002). Full waveform numerical simulations of seismoelectromagnetic wave conversions in fluid-saturated stratified porous media. *Journal of Geophysical Research*, 107 (B7).

Oleg, V. Mikhailov, O.V., Haartsen, M.W. and Toksoz, M.N. (1997). Electro seismic investigation of the shallow subsurface: Field measurements and numerical modeling. *Geophysics*, 62(1): 97 – 105.

Pride, S. R. 1994. Governing equations for the coupled electromagnetics and acoustics of porous media. *Phys. Rev. B*, 50(15): 678 – 696.