Enhancing the seismoelectric method via a virtual shot gather
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Summary
The seismoelectric method is a new means of characterizing near surface aquifers and appears to be able to detect significant changes in permeability or pore fluid chemistry. Seismic energy is used to probe the properties of porous media via the electrokinetic effect by measuring the resulting electrical potential on the surface.

Two types of signal are observed in practice: signals recorded simultaneously by many sensors due to the seismic wave encountering a change in sub-surface properties, and signals that are produced when the seismic wave is near a sensor. The first type of signal is the desired response, and the second type of signal is interference. As the second type of signal exhibits move-out with seismic velocities it can be removed with filtering in the F-K or t–p domain. In practice, the limited number of acquisition channels typically available and the strength of these unwanted signals compared to the desired signals limits the effectiveness of these methods.

We propose and demonstrate a solution to this problem by combining shot records from 24 sensors at different shot positions to create a virtual 120 channel shot record that allows velocity or move-out dependent filters to perform more effectively. The application of this method of data collection and processing has allowed us to reliably detect seismoelectric signals originating from depths of up to 120 metres.

Introduction
The seismoelectric method uses a seismic-to-electrical mechanism, the electrokinetic effect, to probe the subsurface for significant changes in aquifer properties. As the seismic wave passes through significant changes in the medium (such as salinity, permeability and seismic impedance) electrical currents are produced at these interfaces (Butler et al., 1996; Garambois and Dietrich, 2001; Rosid and Kepic, 2003; Zhu et al., 2003).

Surface potentials are measured with an array of electrode stakes (dipoles) set into the earth. As electrical disturbances travel much faster than seismic energy when the seismic wave encounters a zone of electrokinetic conversion a signal is recorded simultaneously on all sensors. This is the first type of seismoelectric signal. This type of seismoelectric signal can be converted to a depth if a 1-D earth is assumed and seismic velocities are measured or estimated. Thus, the shot record should allow us to probe changes in formation or aquifer properties with depth. An advantage of using a seismic source is that resolution is not significantly degraded with depth of investigation.

However, the seismoelectric method also suffers from problems similar to the seismic reflection method as ground-roll, guided waves, and refraction related events often obscure the signals of interest (a good example of this can be found in Butler et al, 2002). These are signals of the second type. This type of signal travels with the seismic wave, but the electric fields created decay with distance so rapidly that they are only observed when proximate to the sensor. Butler et al. (1996) provide conceptual models describing these phenomenon with field examples, and Haartsen and Pride (1997) predict via numerical modeling the existence of the two types of signals.

As one type of signal arrives simultaneously (or near enough) and the other propagates outward from the shotpoint with seismic velocities an F-K or t–p filter should be able to isolate and eliminate the interfering signals. However, for such filters to work effectively with such narrow band-pass requirements the spatial sampling of the signal should be relatively dense. As the seismoelectric signal tends to contain relatively wide bandwidth pulses (significant energy from 100 to 500 Hz, Rosid and Kepic, 2003) spatial aliasing can become a problem too. Thus, an acquisition system with a fairly large channel capacity is needed to overcome the problem.

A New Approach to Acquisition
It is generally not cost effective to deploy a 100+ channel seismic system for shallow aquifer studies. However, 24 channel systems are readily available and relatively inexpensive. We propose that a 24 channel system be used with 5 or more shots to produce an single shot record with an equivalent of 120+ channels of data. This is done by moving the shotpoint in the center of the electrode array by small increments to emulate the effect of shifting all of the electric potential stakes closer or further from the array centre. For example, if the ground stakes were set in a staggered array where successive dipoles are offset by 2m then combining data from shotpoints at 0,+0.4, +0.8, -0.4, and -0.8m from the array centre would provide an equivalent to a single 120 channel record. The equivalent record would contain sensors spaced at 0.4m offset increments; thus, giving a high spatial density of data.

This method works on the assumption that the earth has a 1-D structure (ie properties vary only with depth). The seismoelectric signal of the first type is laterally invariant
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with respect to arrival time. However, arrival times of signals of the second type will change with shotpoint-to-dipole offset. A possible weakness with the proposed scheme is if there are significant lateral changes in seismic velocity within the centre of the array then there can be distortion in the created shot gather leading to artifacts. However, it would require extreme near surface changes to create significant artifacts in the virtual shot gather.

Field Data Examples

The field examples come from an area in the south-west of Australia near the town of Nannup. Several seismoelectric soundings were collected near test boreholes for a large water supply scheme for the city of Perth (some 300 km away). The aquifer to be tapped, the Yarragadee formation, is a sequence of sands, sandy clays, and clays that start at a depth of approximately 20 m and continue to depths of 500 m to 1500 m. Water in the Yarragadee aquifer is low in salt (200-400 mg/l) and the formation has a resistivity of the order of 100 to 200 ohm-meters. Overlying the Yarragadee formation is the Leederville formation, which contains weathered materials such as caprock (ferricrete and silicrete) as well as sandy clay and a lower shale unit that forms a seal to produce a perched aquifer. The main water table is within the Yarragadee and is located at a depth of 40 to 70 meters in the test area.

To collect the field data we either used a 48 channel Bison seismograph equipped with 2 x 12 channels of refraction cable, or a 48 channel OYO DAS1 seismograph equipped with a roll box and CDP cables. The electric sensors were 24 grounded dipoles, each consisting of a pair of 50 cm long stainless steel stakes, and were configured so that the shot point was centered in the electrode array (12 sensors on each side). The stakes were driven to approximately 30 cm depth into the ground, and paired to form 4m or 5m dipoles with the positive electrodes closest to the shotpoint. Each dipole was connected, via wire leads, to a battery-powered differential preamplifier located half-way between stakes. The preamplifiers provided an electronic gain of 10 or 30, then the signals are transmitted along conventional seismic cables to the recorder. A sledge hammer and heavy base-plate provided the seismic source. Each actual shot record is a stack of 50 hammer blows.

Figure 1 displays an example of our first efforts in the area using 24 channel data from the OYO system. Even after filtering the record is still dominated by ground-roll related signals except for the far offset sensors at early times. Note that in order to prevent spatial aliasing problems the length of the spread is quite small at less than 30 metres because the dipole offsets are incremented by 1 m. Such a small “aperture” can cause problems when looking for deeper targets as theory and experiment indicate that the seismoelectric signal amplitude is zero near the shotpoint and is at a maximum when the dipole is offset from the shotpoint approximately of the order of the depth to the target (Butler et al. 1997; Garambois and Dietrich, 2001). Thus, to see 10 to 100 m deep we would want our electrode array to span approximately 100 m. To meet this criterion and prevent spatial aliasing requires 100+ channels of data.
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Our second set of trials used our new method of combining five shotpoints incremented at 0.4m intervals (Figure 2 provides an example). This time the data was collected with a Bison seismograph, which had poor quality cables that caused some problems with data quality. An example is seen in Figure 2 where traces at distances 12 to 16 m are from an erratic dipole sensor. Despite such problems we were able to produce interpretable records that contained identifiable seismoelectric arrivals. Two examples of the processed records (Figure 3) show coherent arrivals consistent with known locations of permeable/impermeable interfaces. These records show simultaneous signals up to 60 ms after the impact. This corresponds to depths of more than 120 m.

Conclusions

By using this new method of acquiring the data we have produced interpretable records at all of our sounding locations at the Nannup test area. Previously, we were only able to produce interpretable records when conditions were in our favor, which was at best 50% of our surveys. A greater number of channels in the data allows us to spread the array over a larger area without compromising on spatial sampling of the signal. Thus, more aggressive filtering strategies to remove seismic wave related noise can be used. The end result is that we are now able to routinely detect signals from depths of more than 120 m in the test area with a relatively compact and easy to deploy 24 channel acquisition system.

References


Acknowledgements

We thank CRCLEME for the financial assistance in these and we also thank the Western Australian Water Corporation for supplying the geological data and experiment area for this work.
Figure 3. Two examples of processed data from the Nannup area and comparison with geological logs. Note that the identified arrivals appear to come from the base of permeable sand units. The processing sequence was a high-pass filter (100Hz) followed by AGC with 30 ms window, then F-K band-pass filtered so that only events with very high apparent velocity remain (>20,000 m/s). The processed data has been displayed with the AGC operation (mostly) reversed. Thus, later events are reduced in amplitude as would be expected from deeper target horizons.