Seismoelectric acquisition in an arid environment

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SUMMARY

Most seismoelectric surveys to date have been acquired on a small scale in temperate regions. Our objective was to establish if seismoelectric data could be acquired on a large scale in an arid environment.

In April 2011, we acquired over 21,000 traces of 2D seismoelectric data at an arid site in Abu Dhabi, United Arab Emirates. The test also included seismic measurements made using WesternGeco's UniQ single-sensor acquisition system. The source used for the acquisition was an 80,000 lb tracked Desert Explorer vibrator, the largest hydraulic Vibroseis source ever used for seismoelectric acquisition. This large source was used to attempt to overcome the low signal to noise issues inherent in seismoelectric acquisition that have been exacerbated in the past by the use of low energy sources.

We successfully acquired high quality data with coseismic signal present to the limits of our acquisition (420 m offset and 2 s record length). Our current equipment is, however, ill-suited to rapid deployment, having far too many components.

The acquisition of large seismoelectric datasets, such as that described here, enables the data to be viewed in the common receiver domain enhancing data processing and bad trace identification.

Key words: seismoelectric, vibroseis, electrokinetics

INTRODUCTION

The generation of electric signals from seismic energy is referred to as the seismoelectric effect. The signals produced are a result of the electrokinetic effect. The contact between electrolytic fluid and the surface of rock grains causes the development of electrical double layers around the surface of the grains. The electric double layer consists of two parallel layers of ions. The first is the surface charge which can consist of either cations or anions (depending on the charge of the rock) that have become bound to the grains surface and become effectively immobile. The second layer, known as the diffuse layer, consists of mobile charged ions that carry a net charge relative to the surface charge of the grain to which they are attracted. As a seismic wave propagates through the rock this charged fluid is disturbed and thus creates a small electric field. This resulting field can then be measured at the surface.

The strongest electromagnetic arrivals are the coseismic field, which is caused by streaming currents in the propagating seismic wave disturbing the ions at the double electric layer of rock grains as it passes. Another source is the interfacial response which was first observed by Martner and Sparks (1959). It is produced due to an asymmetrical charge distribution resulting from the propagating seismic wave encountering interfaces of differing material properties, and can be measured at the surface before the first seismic wave arrival (Dupuis, Butler and Kepic). This electrical field essentially emulates an oscillating electric dipole, orientated normal to the intersected interface (Butler, et al. 1996).

The electric field is measured by monitoring the voltage between two electrodes, usually metal rods. The electrodes are connected to a pre-amplifier which is then connected to a standard seismic system and recorded as if it were standard seismic data.

Most seismoelectric surveys have been experimental in nature and employ receiver spreads, typically limited to 24 channels, and low energy sources, usually sledgehammers. The largest published surveys are those of Thompson and Gist (1993), who recorded 26 channels, Dupuis, Butler and Kepic (2007) who recorded a 300 m traverse with 24 channels and Dean and Dupuis (2011) who recorded 40 channels. Thompson and Gist (1993) used 0.5 kg of explosives while Dupuis, Butler and Kepic (2007) used a 40 kg accelerated weight drop. Dean and Dupuis (2011) described the successful use of large hydraulic vibrators as sources for seismoelectric surveys.

The experiment described in this paper had two objectives:

1. We wanted to examine the feasibility of acquiring seismoelectric data on a large, quasi-commercial scale. We wanted to determine if the acquisition methods and equipment we have developed are suited to something more than simple experiments.
2. We wanted to determine if the seismoelectric method is suited for use in arid environments. A significant proportion of land-seismic activity takes place in deserts. Given its reliance on pore fluids, is the seismoelectric method likely to succeed?

We begin by describing the equipment we used to carry out the survey, the survey location and the survey parameters...

EQUIPMENT

The equipment used for the survey was a combination of specially developed seismoelectric instruments and standard seismic equipment.

Specialised seismoelectric equipment consisted of the electrodes and pre-amplifiers. For the electrodes we used 50 cm lengths of 3 cm diameter stainless steel tubing with a small handle welded on the end to make it easier to pull them out (Figure 1a). Tubing was used rather than solid rods to improve the contact with the ground. To further improve the electrodes coupling to the dry surface fluid mixed with washing-up liquid was used to water them in. To improve the weak seismoelectric signals we used specially constructed amplifiers. Each amplifier consisted of a small circuit and a battery housed inside a small metal box (Figure 1b).

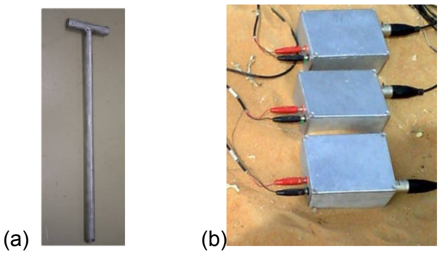

Figure 1. A stainless steel electrode (a) and the pre-amplifiers (b) used for test.

A 48-channel geometrics geode system was used to record the seismoelectric data. Seismic data was recorded simultaneously using WesternGeco's UniQ single-sensor acquisition system.

The source used was the largest ever employed for a seismoelectric survey, an 80,000 lb peak-force tracked Desert Explorer vibrator (Figure 2).

Figure 2. The 80,000 lb tracked Desert Explorer vibrator used as the source for the experiment.

The configuration of the acquisition system is shown in Figure 9. The first take-out on the cable was used to record the pilot from the vibrator controller via a direct cable connection. When the vibrator was on the west side of the spread the cable was connected to the western-most take-out, when the vibrator moved to the east side of the spread the cable was connected to the eastern-most takeout.

SURVEY LOCATION

The data was acquired in early April 2011, at an aquifer storage and recovery (ASR) site (Black, et al. 2008), on the north-eastern side of the Abu Dhabi Emirate in the United Arab Emirates (UAE) (Figure 3). The site is located approximately 70 km southeast of Dubai and 8km southwest of the town of Shwaib, near the Oman border. The area is covered in low-relief (~30 m high) sand dunes and certainly meets the requirement of being arid (Figure 5).

The near surface sediments of the site are comprised of four main groups. The upper two make up an unconfined aquifer with an unsaturated zone above underlain by the saturated sediments, at a water table depth of between 40-60m, consisting of unconsolidated Aeolian and fluvial sands. The following two sediment groups below the aquifer are an Upper and a Lower Fars unit. The Upper Fars unit consists of claystone with interbedded dolomitic marl, limestone and siltstone and the Lower Fars is comprised of mudstone and evaporite (Muller-Petke, et al. 2011).

Figure 3. Location of seismoelectric acquisition at the ASR test site near Shwaib, UAE.

As a result of past deformation a linear feature, interpreted as a NNE-SSW striking thrust fault from a gravity survey (Bradley, et al. 2007), has been interpreted to be crossing through the area.

SURVEY PARAMETERS

The seismic receiver line was 1,200 m long and consisted of 1-C Geophone Accelerometers (GACs) every 6 m and 3-C GACs every 12 m. The main source line was ~3,600 m long, extending 700 m west and 1,700 m east of the receiver line (Figure 4). A secondary source line was located approximately 200 m north. The majority of the source points were acquired with 12 m spacing while those near the receiver line were acquired with 4 m spacing (Figure 4).

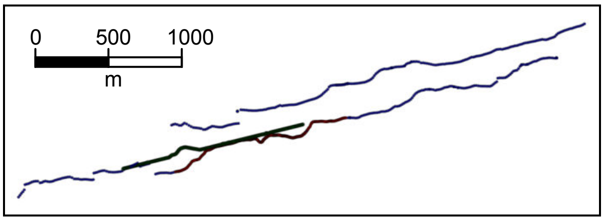

Figure 4. Map showing the seismic receiver line (in green), the 12 m spaced source point (in blue) and the 4 m spaced source points (in dark red).

Seismoelectric data was recorded into three separate spreads. Each spread consisted of 49 electrodes 4 m apart, each dipole sharing an electrode with the adjacent dipoles. Although the recording systems operated independently seismoelectric and seismic data was recorded simultaneously. The first two spreads were adjacent and situated at the eastern end of the receiver line while the third spread was positioned directly over the near-surface structure of interest (Figure 6). There was considerable overlap between the source lines acquired into each spread allowing us to combine those records to increase the total receiver offset distance.

Overall we acquired 451 shots using 47 live channels for a total of 21,197 traces. To put this into perspective, using the typical seismoelectric survey configuration of a 12-channel system and 100 blows/source-point using a sledge-hammer (which is a tiny fraction of the energy transmitted by a vibrator) would require over 175,000 records to be acquired, which at 30 s/record would take over two months of continuous acquisition.

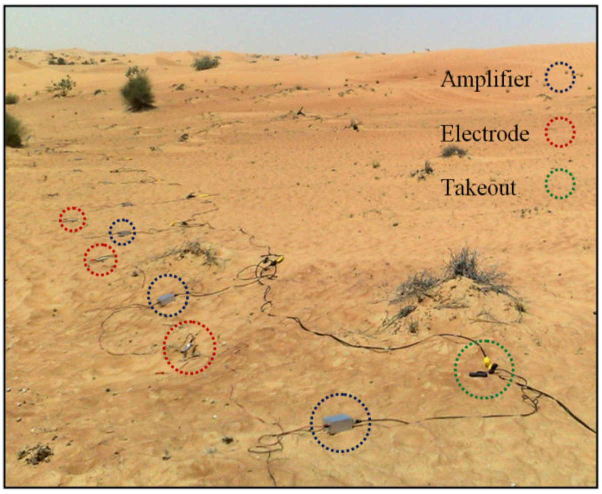

Figure 5. Annotated photograph of the seismoelectric line.

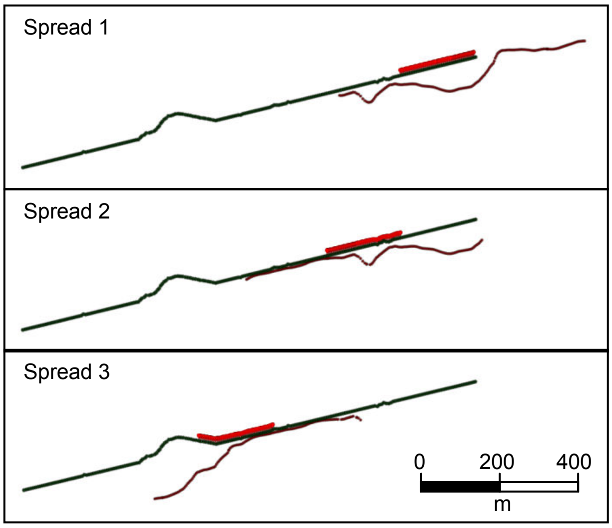

Figure 6. Positions of the seismoelectric spreads (in bright red) and seismic receiver spread (green). The source points acquired into each seismoelectric spread are shown in red.

DATA PROCESSING

As with most seismoelectric surveys the first step in processing was to remove the noise from power lines. We achieved this by applying a single frequency (50 Hz) adaptive noise cancellation routine (Figure 7).

When the cable used to record the vibrator pilot was adjacent to some of electrodes cross-talk occurred between the two. We experimented using adaptive-subtraction, both pre- (using the pilot as the model) and post-correlation (using the Klauder wavelet) to remove the noise but neither were sufficiently effective. Instead we simply muted the top 50 ms of the affected traces. After applying the mute there was no recognisable difference between contaminated and uncontaminated traces.

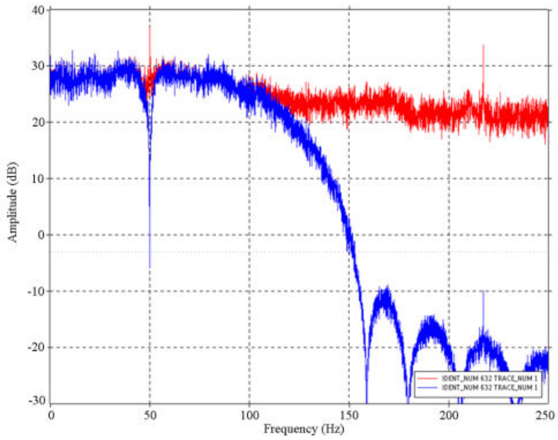

Figure 1. Power spectra before (red) and after (blue) the application of a high-cut filter and power line noise removal.

Although the electrodes were watered in there was still considerable variation between the self-potential (20 to 130 mV) of the dipoles in the spread. This was manifested in some channels recording significantly more noise. As there was large amplitude variation between channels it was difficult to observe the signal by viewing the traces in the common-shot domain.

Unlike most other seismoelectric experiments the sheer scale of our acquisition (at least 146 shots/receiver stations) meant that we could sort our data into the common receiver domain. In this domain the amplitudes of the traces were fairly constant making it easier to recognize signal and identify weak or noisy receivers. We could then apply further noise processing or exclude the traces from the analysis (given the extremely large number of traces we could afford to be quite ruthless).

RESULTS AND DISCUSSION

The quality of the seismoelectric data acquired can be seen from common receiver gathers in Figure 8, the seismoelectric data and the GAC data being indistinguishable. The seismoelectric data is more consistent with the horizontal components than the vertical component, a result consistent with that of Garambois & Dietrich (2001). Data was clearly visible up to our maximum offset of just over 420 m and our effective maximum record length of 2 s.

CONCLUSIONS

Our experiment has shown that seismoelectric data can be acquired on a large scale. We found, however, that the current equipment configuration is ill-suited to rapid spread rolling, each movement of the spread took nearly an hour with eight people assisting. The time taken was due to the amount of equipment required for each station, including cables between the amplifier and the electrodes and between the amplifier and the seismic takeout as well as all the reasonably heavy amplifiers (due to their self-contained battery). Similar large-scale experiments should be acquired using purpose-built cables where the amplifiers are built into the cable and powered from a single battery. Due to the sandy terrain planting the electrodes was not overly time consuming.

Although not detrimental to our data the cross-talk we observed between the pilot cable and the dipoles could be avoided using a radio link or a fiber optic cable similar to that used for impulsive sources (Kepic and Russell 1996).

The high-quality data we acquired (Figure 8) clearly shows seismoelectric data can be acquired in arid environments and confirms the work of Dean and Dupuis (2011) that hydraulic vibrators are an effective source for seismoelectric surveys.

The acquisition of large seismoelectric datasets enables the data to be viewed in the common receiver domain. This has the advantage of improving our ability to filter and identify poor quality traces. While high quality data was acquired further processing needs to be undertaken to establish if we can identify interfacial signals

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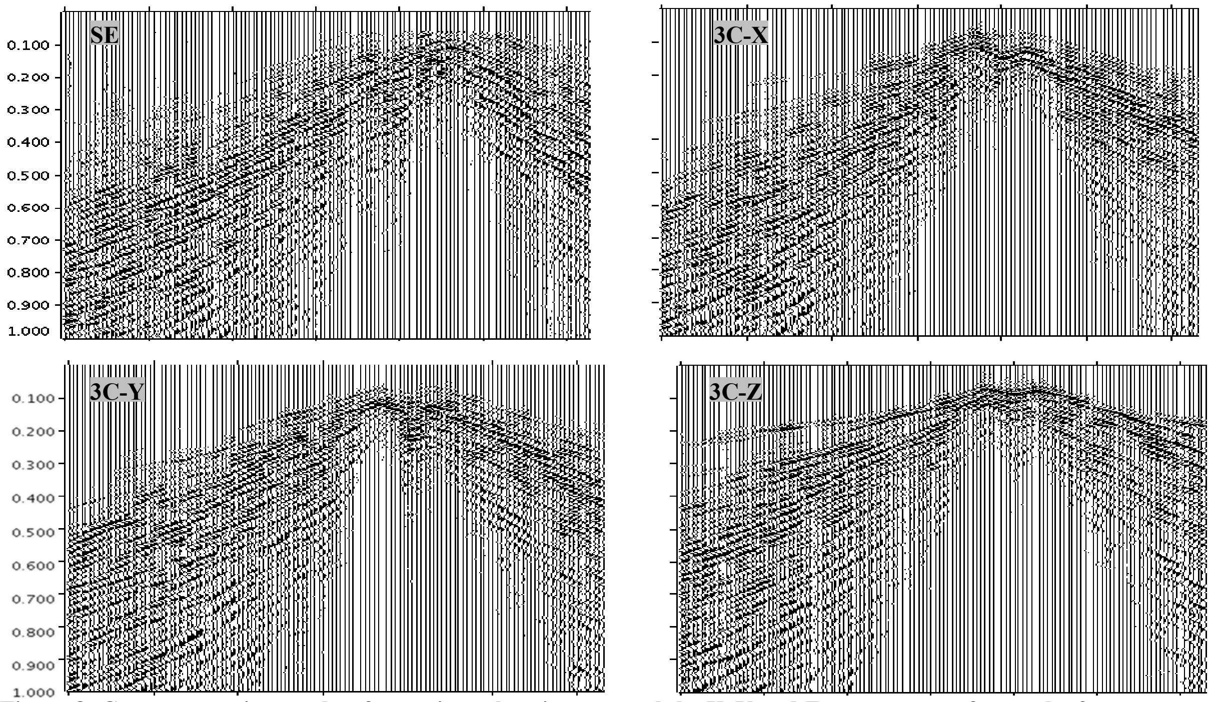

Figure 8: Common receiver gather for a seismoelectric trace and the X, Y and Z components of a nearby 3-component GAC.

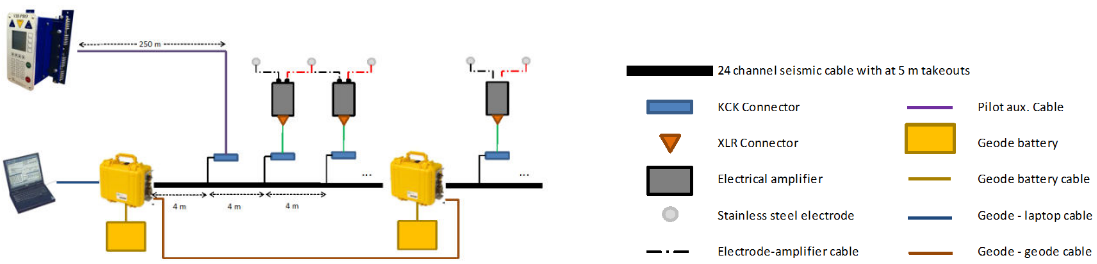

Figure 9: Seismoelectric recording system schematic.