Signal to Noise Improvements in Seismoelectric Data Acquisition

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Introduction

Electrokinetic and piezoelectric effects induced by seismic waves are of interest in exploration for their sensitivity to targets that are difficult to image with established geophysical methods. Such targets include quartz veins (a common host rock for gold) which can be detected by their piezoelectric response, and highly permeable aquifers and hydrocarbon reservoirs which can be detected by their electrokinetic response to seismic waves (e.g. Thompson et al., 1993; Russell et al., 1997). The electrokinetic mechanism has attracted most of the attention because of its potential for revealing information about the pore fluids and permeabilities of subsurface formations with the relatively high resolution of seismic methods.

Since the early 1990's several groups of investigators have confirmed that the effects are real and measurable in the field and great strides have been made in theoretical modeling. The development of practical applications however, remains a work in progress due to the challenges involved in developing robust instrumentation and methods to allow reliable and interpretable measurements to be made a routine basis. The difficulty in making the measurements relates to an inherently low signal-to-noise ratio (S/NR). In this poster, we present the common sources of noise and strategies that have been developed to combat them. We also present results from a particularly successful set of field experiments conducted over an unconfined sand aquifer near Perth, Western Australia in 2006.

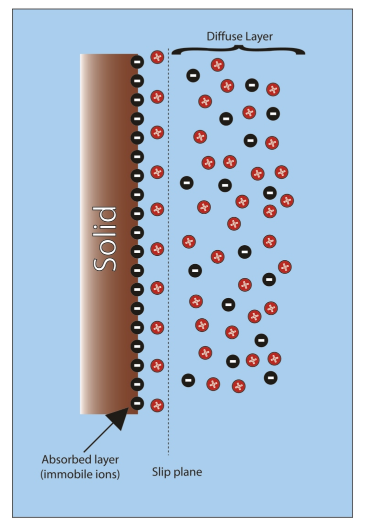
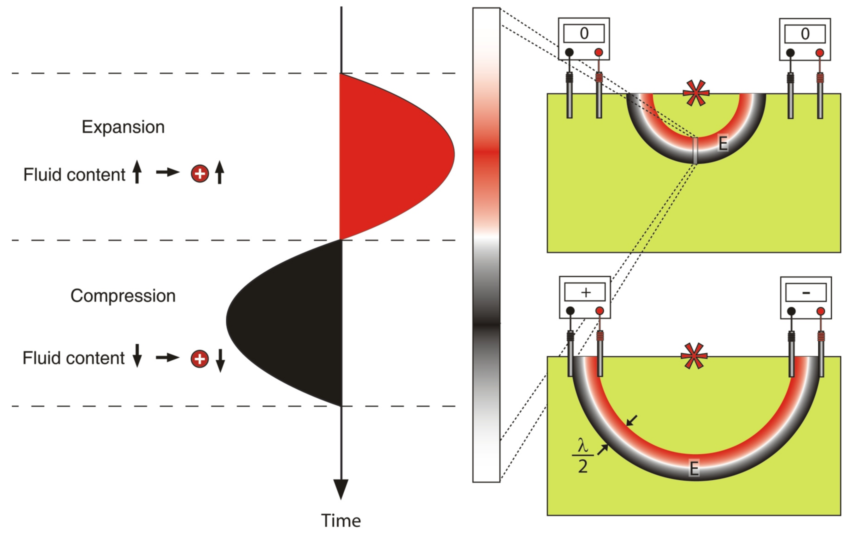


Fig. 1: Electrical double layer

Seismoelectric Effects of Electrokinetic Origin

In poroelastic media, compressional waves cause pore fluid to move relative to the solid matrix thereby moving the excess electrical charge in the outer, mobile portion of the electrical double layer (Figure 1). Charge separations arise between zones of compression and rarefaction (Figure 2). This gives rise to a co-seismic electric field that is confined within the compressional wave.. When a compressional wave encounters heterogeneity such as an interface that changes the streaming currents and distorts the resulting charge distribution (Figure 3), it generates an unbounded electric field, which we call an interfacial seismoelectric effect. These effects propagate as electromagnetic signals and therefore appear nearly simultaneously at widely separated receivers with an arrival time essentially equal to the one-way seismic traveltime from shotpoint to interface (Figure 4).

Figure 2:
Coseismic Seismoelectric signal, its origin and time progression in a homogeneous half-space



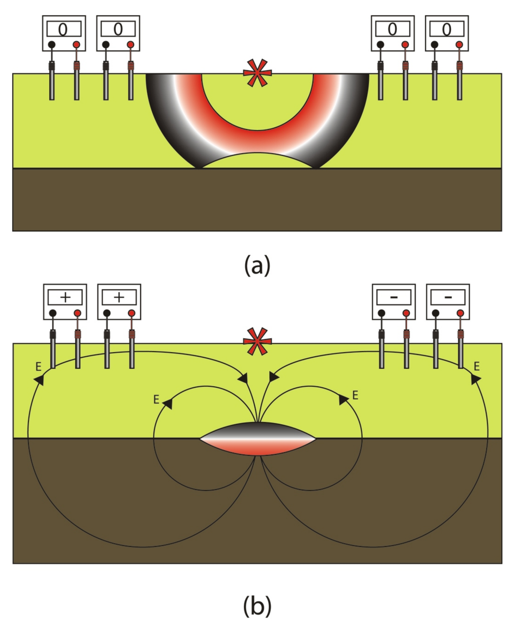


Figure 3
(a) Coseismic. seismoelectric signal
(b) Interfacial seismoelectric signal

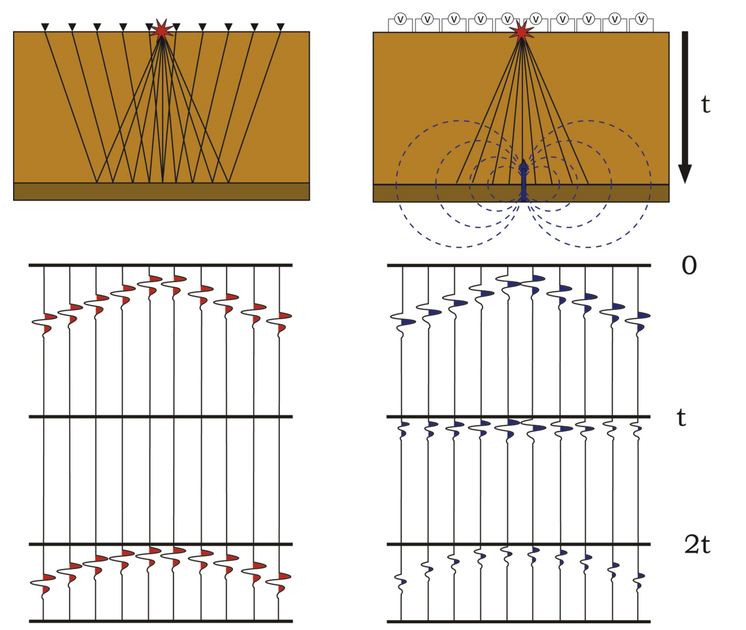
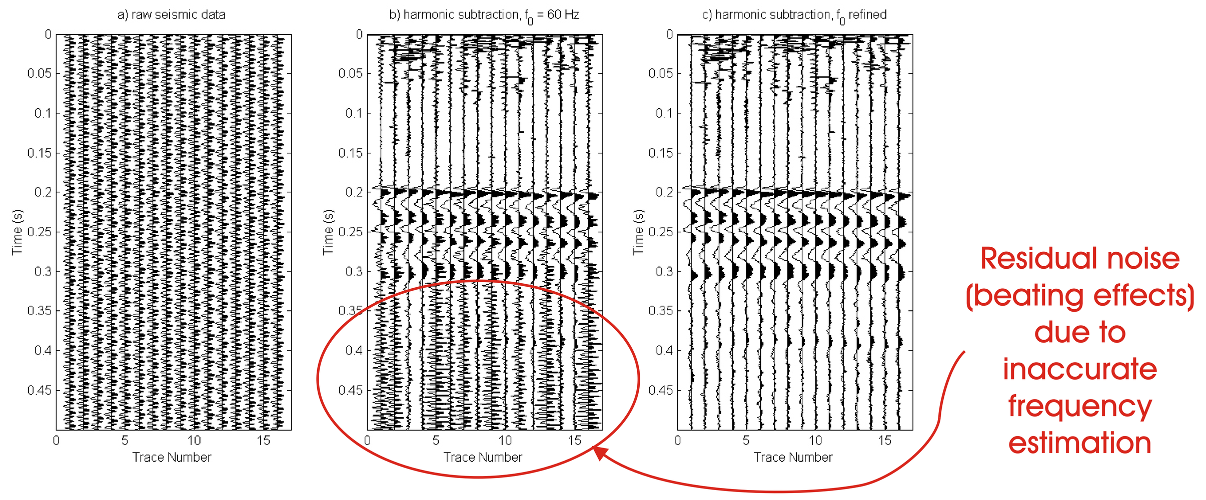


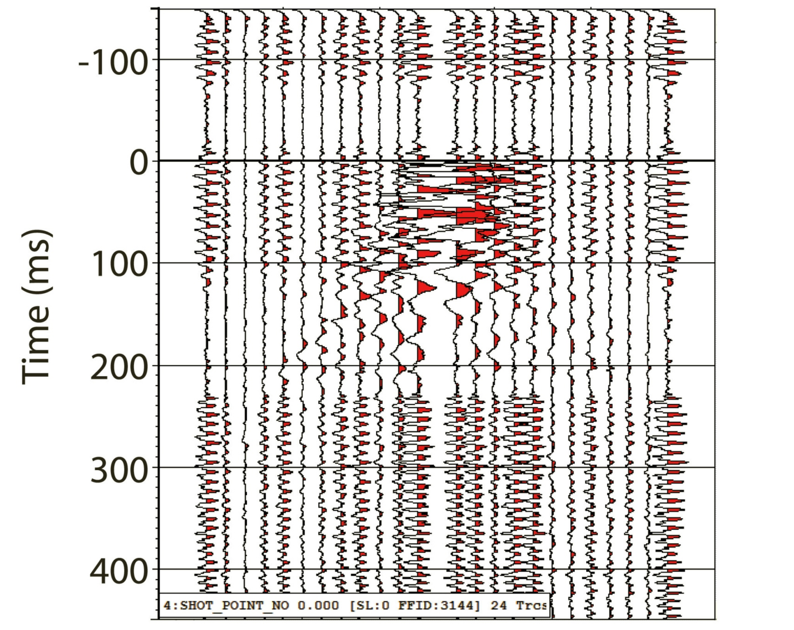
Figure 4
Conceptual seismic and seismoelectric records

Powerline Noise Removal by Sinusoid Subtraction



Downhole seismic data example illustrating the importance of refining the fundamental frequency f_0 prior to harmonic subtraction. (a) Raw seismic records from sixteen sequential shots contaminated with harmonics of 60 Hz. (b) Result of applying sinusoid subtraction assuming f_0 = 60 Hz for all traces. (c) Improved result obtained after estimating f_0 for each trace individually. It is commonly possible to reduce powerline harmonic noise by a factor of 100 (40 dB) through sinusoid subtraction. Selective stacking/rejection of shot records may also be required in areas where the harmonic noise is unstable due to power system load variations. (Butler & Russell, 2003)

Inadvertent Demodulation of AM Radio Broadcasts (RFI)

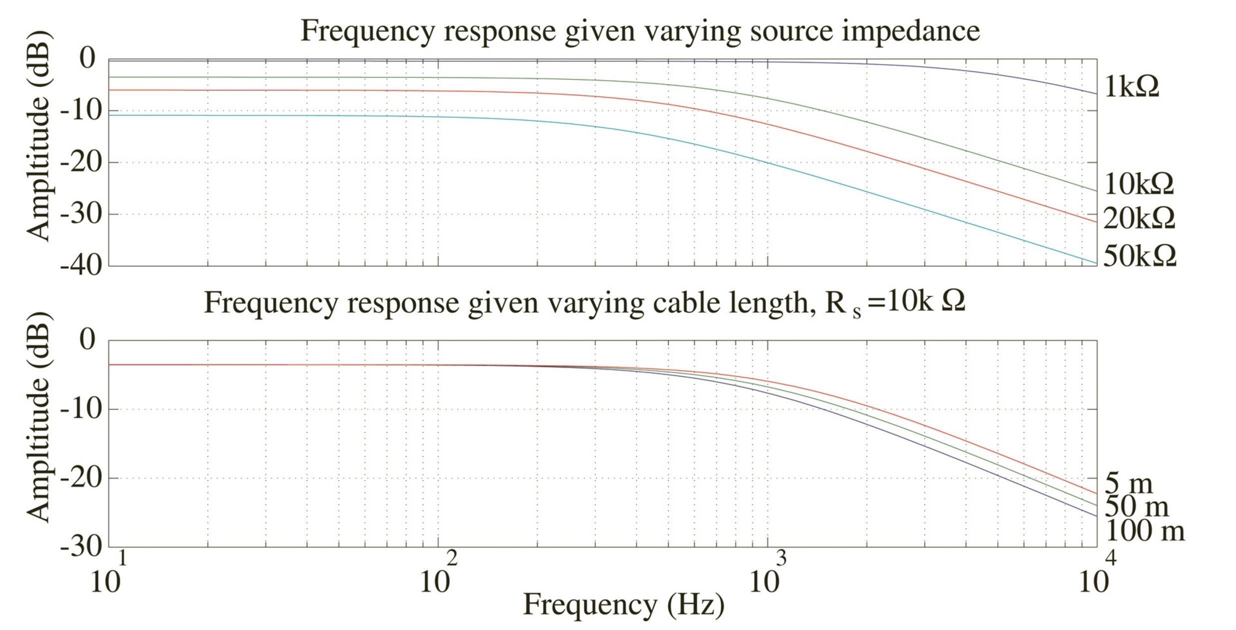


Example of AM signal demodulated over the signal of interest

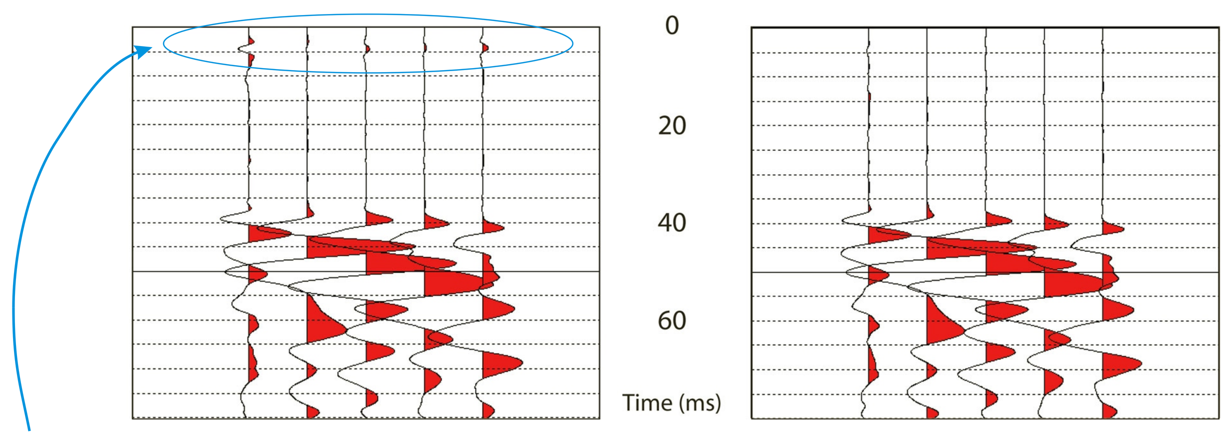
Common Sources of Noise in Seismoelectric Measurements

Noise Sources	Origin of the noise	Method to minimize its impact
Ambient sources	Powerline harmonics (60, 50 and/or 25 Hz and their harmonics)	Harmonic subtraction (Butler & Russell, 2003), Remote reference subtraction Exploit difference between signal and ambient noise polarity when stacking
	Telluric noise (earth currents) associated with atmospheric electricity (sferics)	Acquire shot records individually and stack multiple shot records if spherics are low. Kill shot records where sferics dominate (Dupuis & Butler, 2006)
Acquisition-related Artifacts	Errors in gain, and bandwidth limitations associated with inadequate signal buffering/preamplification	Buffer signal with preamplifiers that have large input impedance and sufficient bandwidth
	Impact related noise transients (especially from metal to metal contact)	Use a non-metalic impact block or place non-conductive material on top
	Triggering noise	Use a balanced accelerometer triggering circuit, buffered with a transformer attached to a high quality microphone cable
	Noise from electrical blasting caps	Use non-electrical blasting caps and fiber optic trigger (Kepic & Russell 1996)
	Inadvertent demodulation of AM radio broadcast	Use shielded cable, and reduce the contact impedance of your electrodes
Source-generated	"Co-seismic" electrical signals that accompany the arrival or P-waves (and other wave types) at the receiving dipole antennas (analogous to surface wave interference in seismic reflection surveying)	Dense wavefield sampling (composite shot gathers) (Kepic & Rosid, 2004)
		Deploy recording array below the interface (VSP-like) (Dupuis et. al, 2007a)

Gain and bandwidth effects caused by improper signal buffering



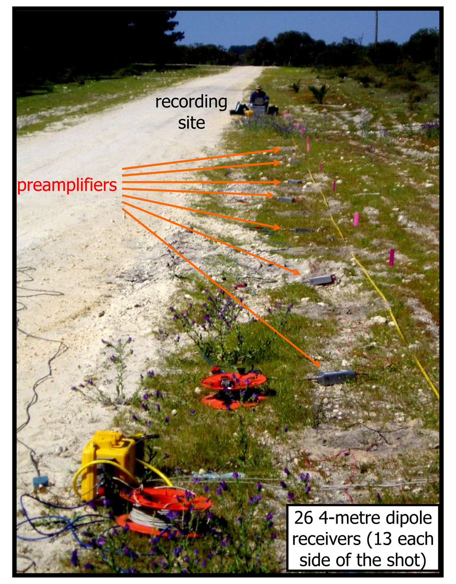
Trigger or Shot-generated noise at time zero



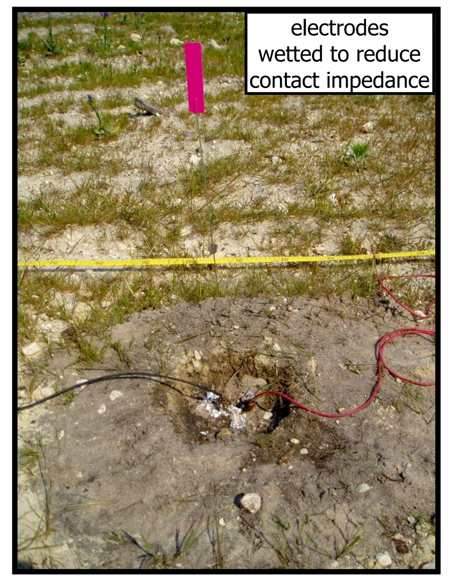
Noise transients appearing at 'time zero' can be caused by electrical blasting caps, the impact of a steel hammer on a steel plate, and trigger cross-talk. In this example (left), the culprit was associated with strain on the trigger cable attached to the sledge-hammer source. High quality microphone cable reduces the problem. In this case, moving the trigger to the impact plate reduced the cable strain and time zero noise (right).

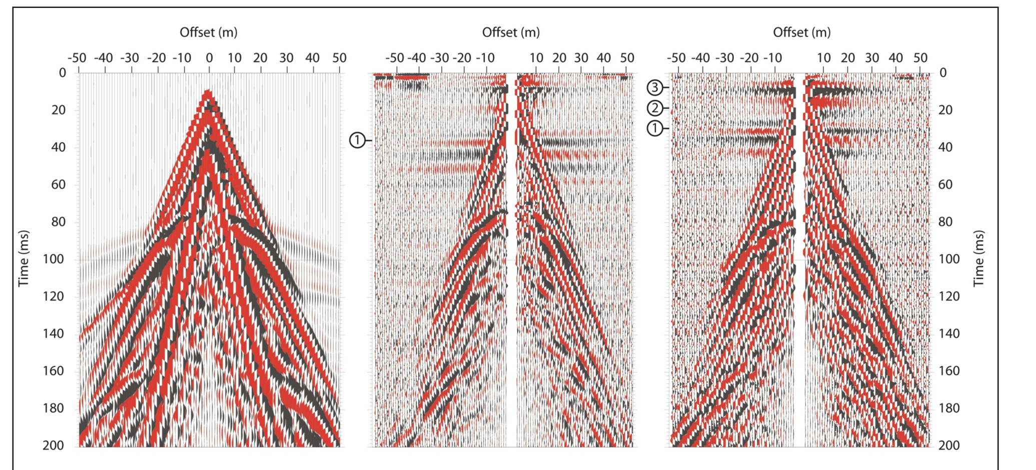
Recent Field Experiments on the Gnangara Mound, Perth, Australia

Borehole and surface experiments were carried out over an unconfined sand aquifer near Perth in spring, 2006 (Dupuis et al., 2007a, b). The results provide unprecedented evidence in support of models for interfacial seismoelectric effects and demonstrate that the method may be used to image heterogeneity within the unsaturated vadose zone as well as the water table at 14m depth. Multi-channel wavefield separation filtering may help to uncover deeper interfacial signals beneath the co-seismic interference.



45 kg acclerated weight drop seismic source

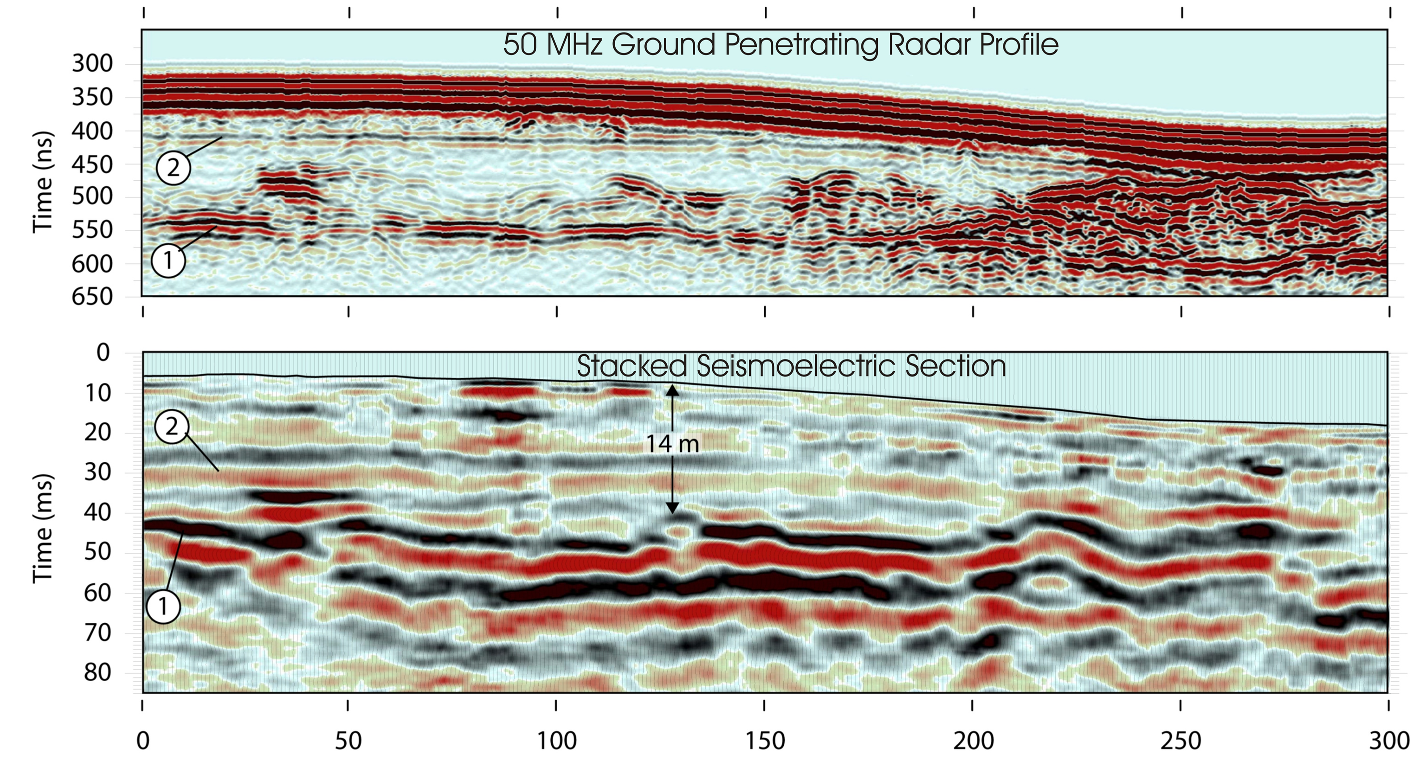




Seismic and Seismoelectric Supergathers (composite shot gathers)
Seismic (@ 128m) Seismoelectric (@ 128m) Seismoelectric (@ 36 m)

Signals (1) and (2) in the seismoelectric supergathers above exhibit polarity reversal and amplitude vs offset variation similar to that of a vertical dipole in agreement with the predictions of theoretical models for interfacial seismoelectric effects of electrokinetic origin. Peak amplitudes are up to 1 V/m compared with noise levels of 100 to 400 V/m in the raw records. Events (1) and (2) correspond respectively to the water table and a shallower water retentive layer. The lack of polarity reversal on event (3) suggests that it may be a very shallow resistivity modulation effect.

Interfacial events (1) and (2) can also be traced coherently along road as demonstrated in the 300 m long sesmoelectric section shown below along with a parallel 50 Mhz radar profile. The depth estimate to the water table of 14 m is consistent with the signal's arrival time on the GPR profile if we assume a radar wave velocity of 0.14 m/ns - a reasonable value for partially saturated sands. Depth estimates from the seismoelectric and GPR profiles place the water retentive layer between 6 and 7 meters.



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