

Seismoelectric measurements on artificial porous media and Berea sandstone

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Abstract

Seismic to electromagnetic wave conversion has been proposed as a possible exploration method. We present laboratory measurements of the conversion of an acoustic wave into electric potential, which occurs at a fluid/porous-medium interface. The conversion is measured for artificial porous media and Berea sandstone. Recorded electric potentials are smaller for large-grain samples. We also show variability of the conversion over a time span of 120 hours.

1 Introduction

Near the grain surfaces of fluid-saturated porous materials (e.g. natural sandstones) a charge separation is created. Immobile charge along the grain surface is balanced by ions in the fluid

which are free to move. The two layers thus formed are commonly referred to as the “electric double layer”. When a compressional wave propagates in the porous medium, a coseismic electric field is created due to the mobile excess charge of the double layer. This field in homogeneous media is confined to the seismic pulse and cannot propagate by itself (Pride and Haartsen, 1996). A different effect occurs when a seismic wave encounters a contrast in electrical or mechanical contrast. When this occurs, an independently travelling electromagnetic (EM) wave is produced (Haartsen and Pride, 1997). Both the conversion of a seismic wave into a coseismic electric field and the conversion into a radiating EM-wave are called “seismoelectric conversion”.

Several studies have measured seismoelectric conversions in the field (e.g., Thompson and Gist, 1993; Mikhailov et al., 1997; Garambois and Dietrich, 2001; Haines et al., 2007) and in the laboratory (e.g., Zhu et al., 2000; Block and Harris, 2006; Zhu et al., 2008). We present seismoelectric conversion measurements in a setup similar to Zhu et al. (2008) due to an interface between water and a water-saturated porous-medium. Four porous media are compared: packed 3 mm and 1 mm glass-beads, a sintered-glass filter, and Berea sandstone. Large-grain samples show smaller seismoelectric responses. We also measure the amplitude of the seismoelectric conversion over time in a fixed geometry and find that the amplitude increases in the first 30 hours, after which it is approximately constant.

2 Seismoelectric experimental setup

A source hydrophone (Celesco LC-34) and a fully water saturated porous sample are suspended in a $36 \text{ cm} \times 27 \text{ cm} \times 38 \text{ cm}$ tank filled with deionized water (Figure 1). A function generator (HP 3314A) emits a pulse which is amplified by a factor of 15 (AE Techron 3620 Linear Amplifier). The resulting electric pulse excites the piezoelectric source hydrophone for each measurement. Two $1 \text{ cm} \times 1 \text{ cm}$ copper mesh electrodes are placed in front of and behind the sample at a distance of 2 mm. Received electric potentials are recorded due to an acoustic wave emitted from the source. Source-sample distance is approximately 20 cm. Prior to the seismoelectric measurements, pressure recordings as a function of frequency are measured with a receiver hydrophone (Brüel and Kjær 8103).

3 Acoustic measurements

Figure 2 shows pressure recordings of a receiver hydrophone as a function of the frequency fed into the source hydrophone. Source-receiver distance is approximately 20 cm. The measured one-way travel time of the acoustic pulse is about $135 \mu\text{s}$, which agrees well with the predicted value of $136 \mu\text{s}$ (using a measured wave speed of 1474 m/s). From $210 \mu\text{s}$ onwards, a more complex pattern is observed, which is attributed to reflections from the walls of the water tank.

4 Seismoelectric measurements

Figure 3 shows electric potential recordings of the electrode in front of (V1) and behind (V2) Berea sandstone as a function of the frequency fed into the source hydrophone. Properties of Berea sandstone are given in Table 1. Strong electric cross-talk starting around zero-time is observed. According to numerical simulation (e.g., Haartsen and Pride, 1997), an acoustic wave impinging upon the porous sample creates a current imbalance across the interface which acts, to first order, as a (time-varying) vertical dipole antenna. The resulting radiation propagates with EM-wave speed and the electric potential changes sign across the interface. Comparing measurements V1 and V2, we see that the first part of the pulse starting at about $140 \mu\text{s}$ shows opposite phase and simultaneous arrival, indicating that these recordings are produced by conversion of an incident acoustic wave into independently propagating EM-waves. When the (fast) P-wave arrives at the back of the sample, another seismoelectric conversion is expected. The measured travel time through the sample is about $10 \mu\text{s}$, and the duration of the incident acoustic pulse is $15\text{-}30 \mu\text{s}$. The simultaneous and opposite-phase electric recordings in the time-interval $145\text{-}190 \mu\text{s}$ can therefore be explained by superimposed seismoelectric conversions into EM-waves, caused by scattering of the (fast) P-wave within the Berea sandstone.

Electric potential recordings of V1 and V2 are shown for a sintered-glass filter (P3C) in Figure 4 and packed 1 mm glass-beads in Figure 5. Recorded waveforms show similar features as those of the Berea sandstone. However, the amplitudes differ, which is attributable to differing porous medium properties (Table 1). Increased porosities favor seismoelectric conversion because it increases the amount of surface charge. Seismoelectric

conversion is also sensitive to permeability changes (Garambois and Dietrich, 2002).

Electric potential recordings of V1 and V2 are shown for packed 3 mm glass-beads in Figure 6. Recorded waveforms do not show opposite phases. Electrode V1 does, however, measure a clear arrival around $135 \mu\text{s}$, associated with the one-way acoustic travel time. From the measured fast P-wave velocity, the wavelength at 100 kHz is 1.5 cm and for the 1 mm glass-beads sample we obtain 1.9 cm. The different features of recorded waveforms for the 3 mm glass-beads sample could therefore be explained by effects arising from the individual grains becoming too large with respect to the wavelength.

The glass-beads diameters are much larger than the grain dimensions of the glass filter, which are on the order of 0.1 mm, and of the Berea sandstone, which are on the order 0.01-0.1 mm (Plouraboué et al., 1996). From the amplitude scales in Figures 3, 4, 5 and 6 we observe that typical measured amplitudes of the larger grain glass-beads samples are one order of magnitude smaller than those of Berea sandstone and glass filter P3C.

For an accurate comparison of measured seismoelectric amplitudes of different porous media, the time-variability of such recordings must be taken into account. Figure 7 shows the amplitude of seismoelectric conversions due to incident acoustic waves upon a sintered, crushed-glass porous sample (N5b). Properties of sample N5b are given in Table 1. In a fixed geometry, with electrode V1 5 mm in front of the sample, the seismoelectric (interface) response was picked for each measurement. The measured potential increases from 0.02 mV to about 0.10 mV in the first 30 hours. Thereafter it is approximately constant.

5 Acknowledgements

Delft University supplied the glass filter and crushed-glass porous sample while Berea Sandstone was provided by Schlumberger-Doll Research. Properties of the glass filter were measured by Jeroen Jocker and Karel Heller. The authors thank an anonymous reviewer for valuable comments. This work was performed under the financial support of Shell-FOM within the research program “The physics of fluids and sound propagation”.

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	Berea*	P3C	N5b**
Bulk mod. frame (Pa)	...	6.6×10^9	9.3×10^8
Shear mod. (Pa)	...	5.5×10^9	8.8×10^8
Grain dens. (kg/m^3)	2.66×10^3	2.221×10^3	2.57×10^3
Tortuosity (-)	2.70	...	1.7
Porosity (-)	2.29×10^{-1}	3.55×10^{-1}	5.2×10^{-1}
Permeability (m^2)	5.71×10^{-13}	2×10^{-12}	3.4×10^{-12}
Thickness sample (cm)	2.6	2.2	3.1

* From measurements on similar material (Pengra et al., 1999)

** Wisse (1999)

Table 1: Porous medium parameters of Berea sandstone (Berea), a sintered-glass filter (P3C) and a sintered, crushed-glass sample (N5b).

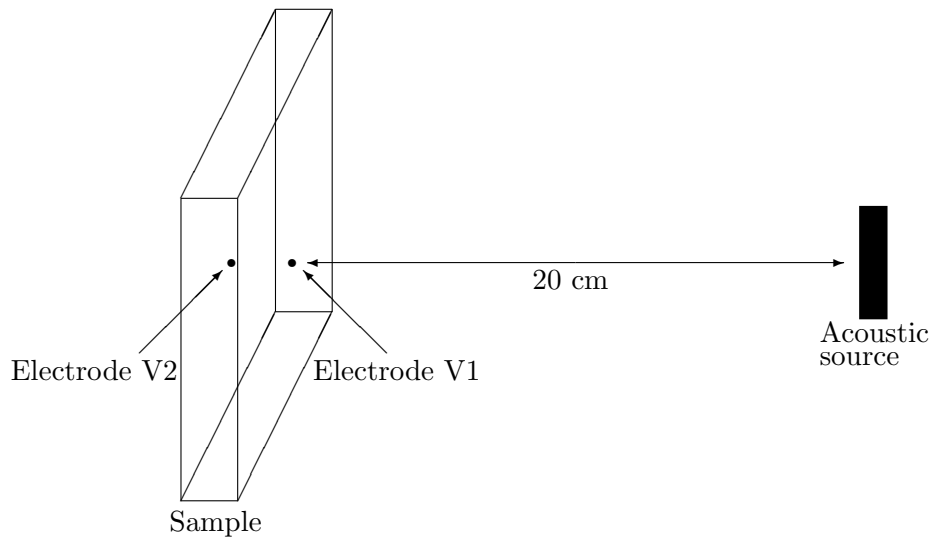


Figure 1: Geometry of the seismoelectric experiment.

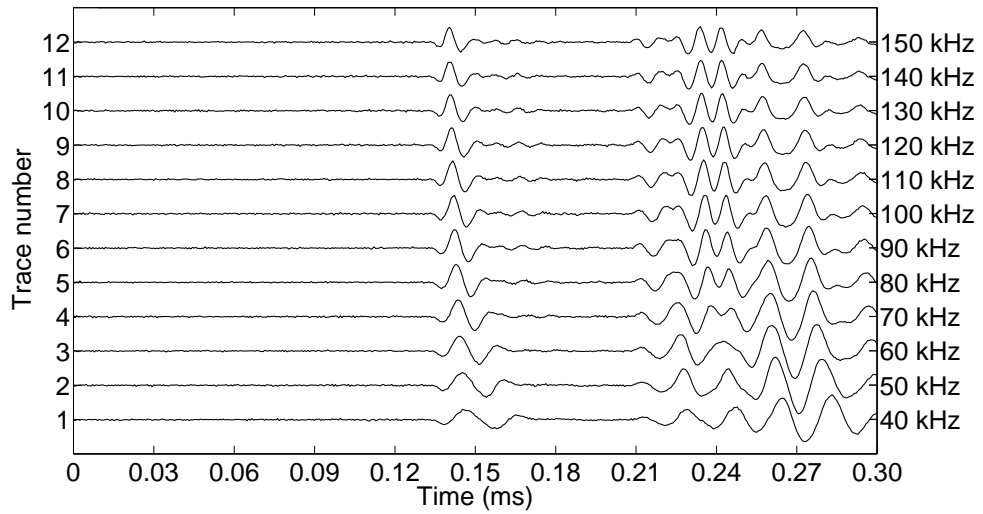


Figure 2: Receiver hydrophone pressure recordings due to an acoustic source at 20 cm excited by an electric pulse with indicated frequencies. One trace spacing represents an amplitude of 1 kPa.

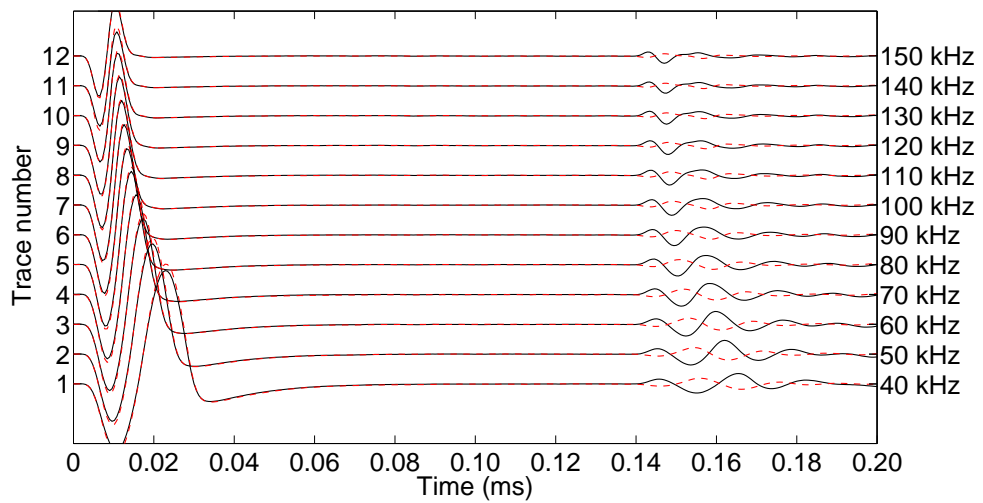


Figure 3: Electric potential recordings of electrodes V1 (solid) and V2 (dashed) in front of and behind the Berea sample, respectively. The acoustic source is excited by an electric pulse with indicated frequencies. One trace spacing represents 0.10 mV.

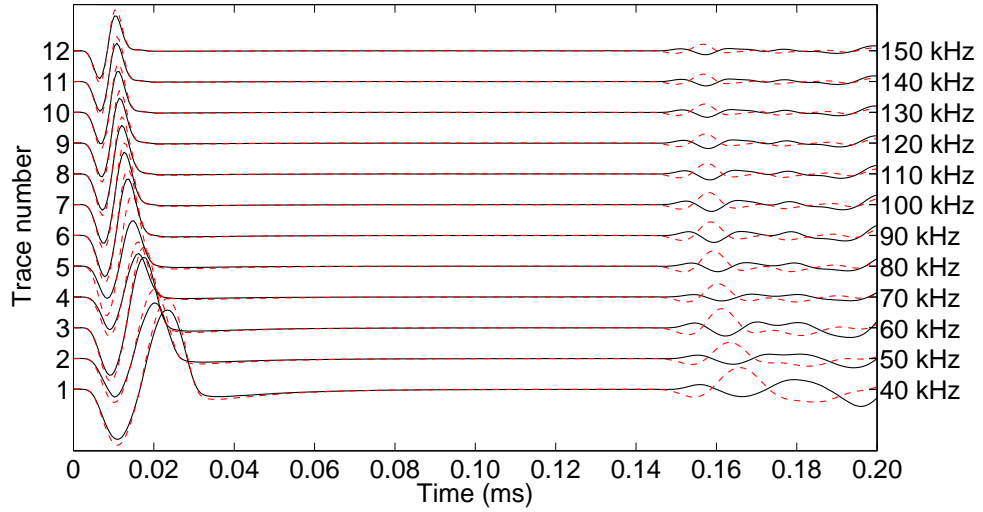


Figure 4: Electric potential recordings of electrodes V1 (solid) and V2 (dashed) in front of and behind sample P3C, respectively. The acoustic source is excited by an electric pulse with indicated frequencies. One trace spacing represents 0.20 mV.

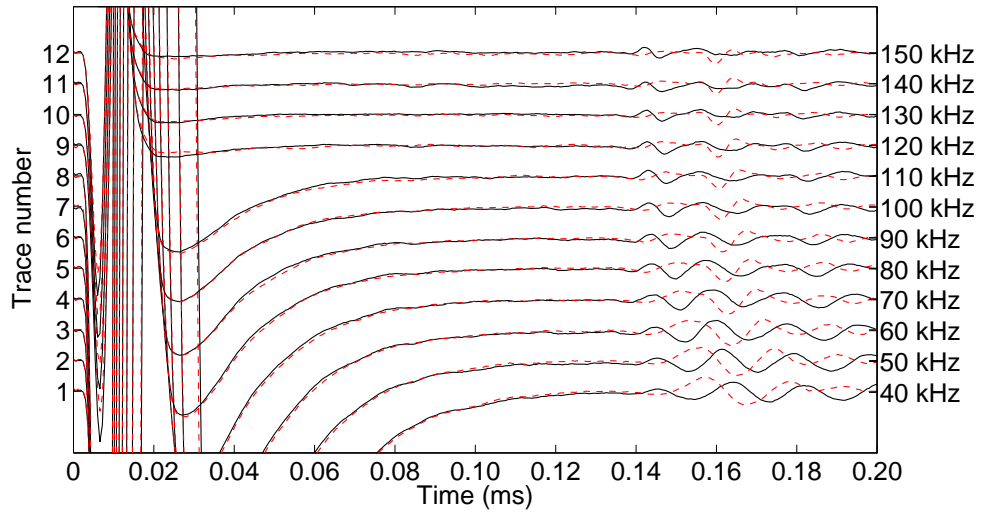


Figure 5: Electric potential recordings of electrodes V1 (solid) and V2 (dashed) in front of and behind a packed 1 mm glass-beads sample, respectively. The acoustic source is excited by an electric pulse with indicated frequencies. One trace spacing represents 10 μ V.

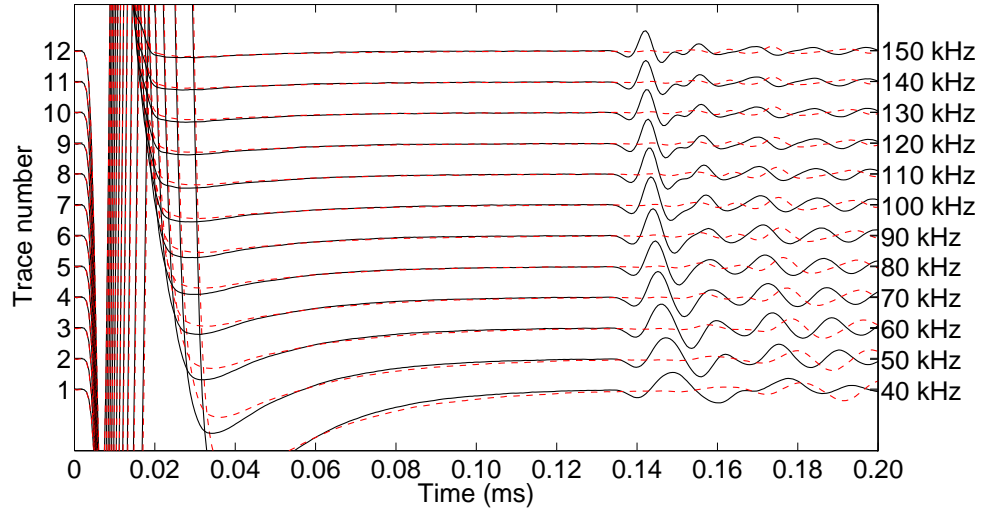


Figure 6: Electric potential recordings of electrodes V1 (solid) and V2 (dashed) in front of and behind a packed 3 mm glass-beads sample, respectively. The acoustic source is excited by an electric pulse with indicated frequencies. One trace spacing represents $30 \mu\text{V}$.

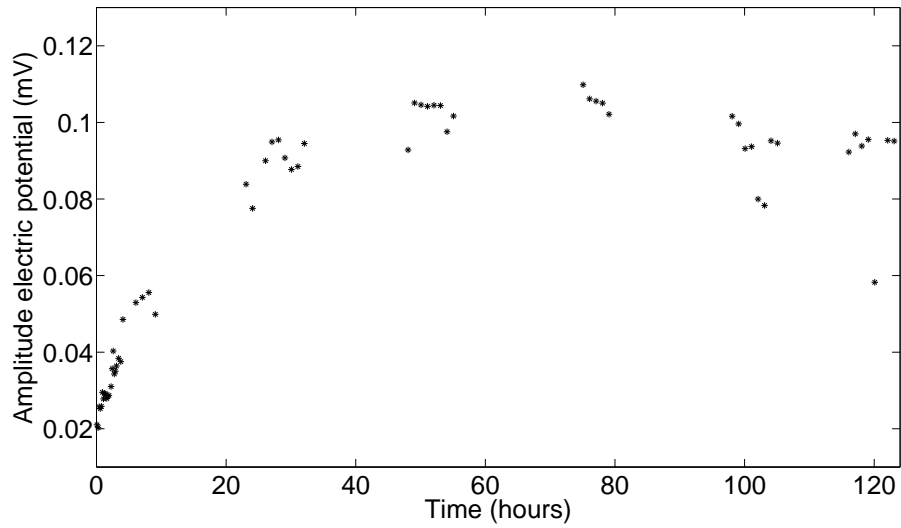


Figure 7: Amplitude of seismoelectric response due to an incident acoustic wave upon a sintered, crushed-glass porous sample as a function of time.