Experimental Studies of Electrical Fields on a Breaking Rock Sample

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Abstract

When a rock sample is pressed by a force, the pressure on the crystal lattice generates an electrical field around the quart grains due to the piezoelectric effect. If a rock is saturated by conductive fluid, the relative motion between the pore fluid and the matrix solid generates an electromagnetic field due to seismoelectric conversion, and the permeating of fluid into new microcracks made by the pressure changes the fluid distribution and the natural potential level.

In this paper, we measure the electrical fields on dry and water-saturated Westerly granite cylinder samples during their breaking. Experimental results show that there are two kinds of mechanisms that generate two kinds of electrical fields during rock breaking: (1) Pressure, or rock breaking, generates an electrical potential on the dry rock surface due to piezoelectric effect; and (2) the potential on a dry sample due to a piezoelectric effect is small, and its polarization depends on the characteristic and orientation of quartz grains around the measurement point. Experiments with water-saturated granite samples record two electrical fields: An electromagnetic wave due to seismoelectric conversion, and the dc or low-frequency electrical potential due to the piezoelectric effect, which is an important indicator of rock breaking.

1 Introduction

We can observe variations of a natural electrical potential in the ground and electromagnetic waves in the air during an earthquake initiated by rock breaking, which also excites acoustic waves. Fraser-Smith et al. (1990) recorded the magnetic field before and after the Ms 7.1 Loma Prieta, California, earthquake of October 17, 1989. The geomagnetic field at low-frequency range (0.01-10 Hz) before the earthquake, and the electromagnetic field at high-frequency (10 Hz-32 kHz) during the earthquake, were recorded at locations about 7 km and 54 km from the epicenter, respectively. Park et al. (1993) reviewed electromagnetic precursors before earthquakes and discussed the possible mechanisms. They concluded that the pressure in formation and rock breaking always generate electric, magnetic or electromagnetic fields.

If a quartz crystal is pressed by a force in a certain direction, an electrical field will be generated on the quartz surface due to the piezoelectric effect. When an acoustic wave propagates through a rock, the acoustic pressure generates a piezoelectric field around quartz grains. Thus a piezoelectric field is an electric potential field on the grain surface.

When a porous rock is saturated by an electrolyte, double electric layers form at the interface between the fluid and solid (grains). The fluid-flow driven by an acoustic wave, or breaking, can induce an electromagnetic wave in fluid-saturated porous rock due to seismoelectric conversion. The natural electrical field is related to the adsorption, permeability, and some chemical process in fluid-saturated rock. Zhu et al. (1999, 2000) investigated the seismoelectric fields generated by acoustic waves in fluid-saturated porous media and borehole models. Because the pressure on a rock makes microcracks within the rock, the fluid motion inside the cracks changes the distribution of fluid and the natural potential.

In order to study electrical fields in a breaking rock, we perform laboratory experiments with Westerly granite to measure the electrical signals generated in dry or wet granite samples at different pressure rates during rock breaking.

2 Measurement System

Figure 1 shows the measurement system used in our experiments. A rock cylinder is placed between two plates of a press. Plastic films isolate the rock sample electrically from the ground of the press. An acoustic P-wave transducer is mounted on the base of the press. We then make three ring electrodes on the rock sample with conducting glue and wires.

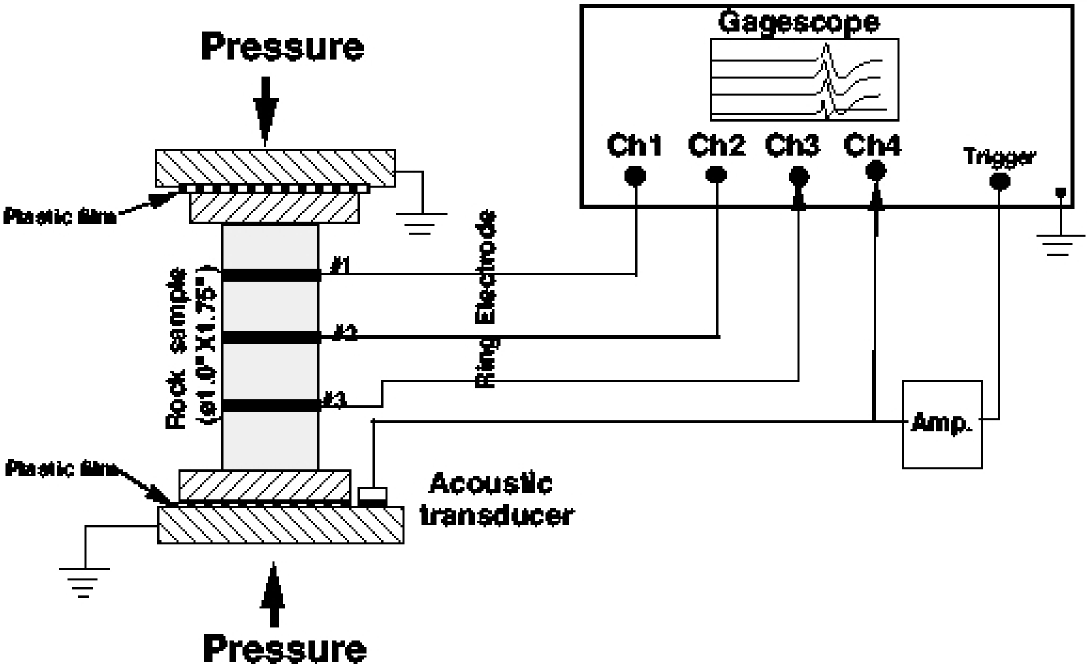

Figure 1: Diagram of setup to measure electric signals on a rock sample when it is pressed and broken. A P-wave transducer is mounted on the base of the press. The acoustic wave received by the transducer is recorded and applied as a trigger for the Gagescope recording system.

The core samples used in this study are Westerly granite, which comes from Westerly, Rhode Island. All samples were cored from the same granite block using a core drill machine. The core samples were polished on the ends with a diamond drill while squeezing on the sides of the sample with a conical base to ensure that the ends were also parallel. The sizes of the samples are 2.54 cm in diameter and 10 cm in length. It is composed of 27.5% quartz, 35.4% microcline, 31.4% plagioclase (with 17% anorthite), and 4.9% biotite. Total porosity is 0.9% and density is 2.646 g/cm^3 (Brace and Orange, 1968). Wong et al. (1989) found that Westerly granite has crack apertures that vary from 0.7 to 0.002 micrometers in width and the crack surface area per volume (Sv) was measured to be approximately 7.89 mm^2/mm^3. The dry samples have been heated in a vacuumized oven at 120^oC for eight hours. The wet samples are saturated with tap water in a vacuumized system. The conductivity of the tap water is about $0.57mS$.

The multichannel recording system, Gagescope, records the four electrical signals coming from the three electrodes and the transducer. The electric pulse received by the transducer is also used as the trigger signal. The recording system records the signals before and after the trigger. When an acoustic pulse through the amplifier is higher than the threshold of the preset trigger level of the recording system, the system is triggered and records four traces of the signals. Sometimes more than one set of the signals can be recorded when more than one sound is excited before the rock is broken completely. We can select the displacement rate of the press before measurement. Because the acoustic signals recorded by the system are converted from acoustic waves with the transducer mounted on the press base, the arrival time of acoustic signals and electrical signals coming from the electrodes should be a little different, even though the same source generates these signals. In our measurements the sampling rate of the recording system is 0.2 ms. Each trace records 1024 points. Half of them are recorded before the trigger.

3 Dry Granite Sample

We performed the measurement with a dry sample at the displacement rate of $10^{-2} mm/sec.$ Figure 2 shows the three electrical signals received by the electrodes on the rock sample and the acoustic waveform (Figure 2d) received by the transducer (Figure 1). In order to analyze more details of these signals, we change the horizontal (time) scale and vertical (amplitude) scale, and plot them again in Figures 3 and 4, respectively.

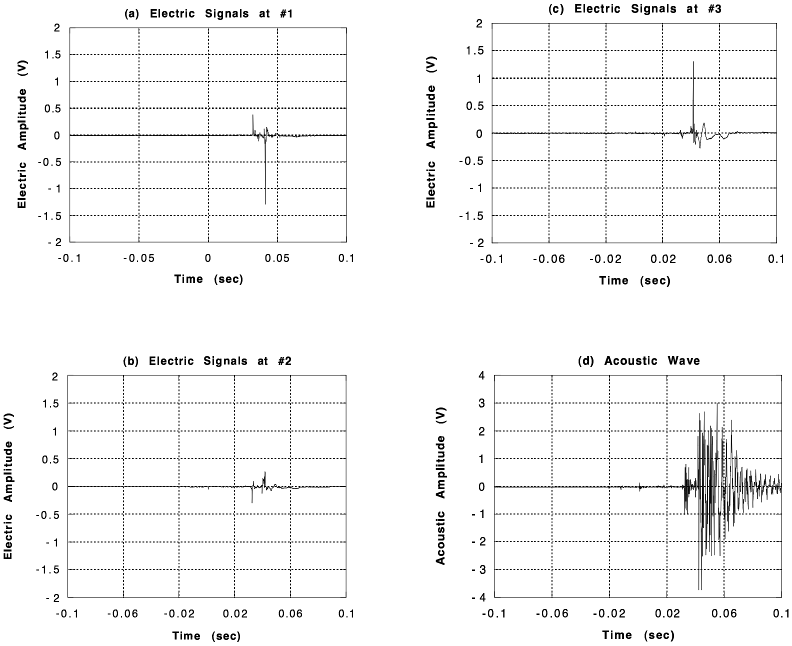

Figure 2: The electrical signals (a, b, and c) and the acoustic wave (d) recorded with a dry granite sample during its breaking. The displacement rate of the press is $10^{-2} mm/sec.$

We recorded a very strong acoustic wave and electrical signals at different locations on the rock surface when the rock was breaking. Changing the horizontal (time) scale (Figure 3), we may study the amplitude and polarization of these electrical pulses, which are different from each other at different measurement points. The largest amplitude at location #1 (Figure 3a) is negative, but that recorded at the same time is positive at location #3 (Figure 3c). The amplitude of the electrical signal at location #2 (Figure 3b) is smaller than the other two signals in Figures 3a and 3c.

Changing the vertical (amplitude) scale (Figure 4), we can see more details of the potential before the sample is broken. We see that the smaller sounds also generate electrical pulses, but do not cause a big change in the basic potential levels with the smaller amplitude (about -0.005 V). Some low-frequency variation of the potentials is also recorded.

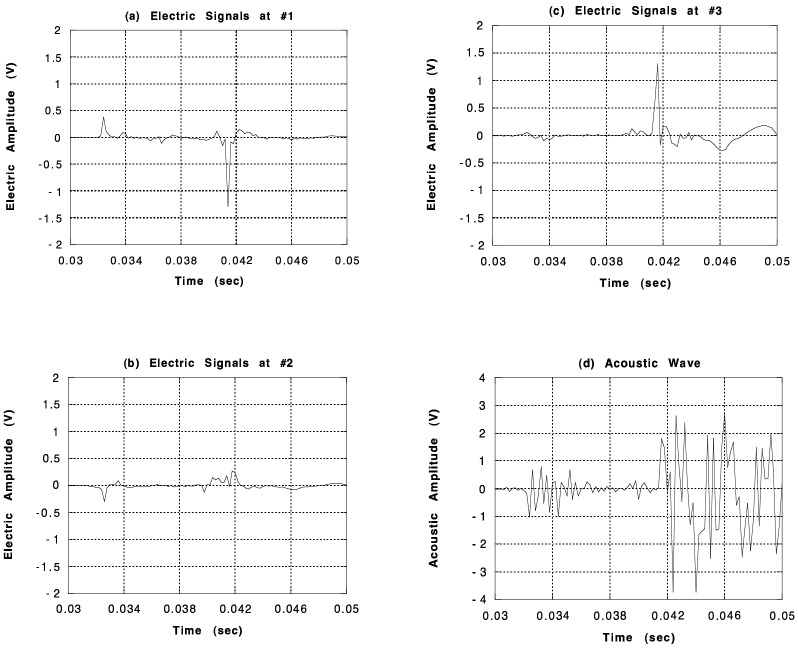

Figure 3: The same signals as in Figure 2 but with different time scale (horizontal axis).

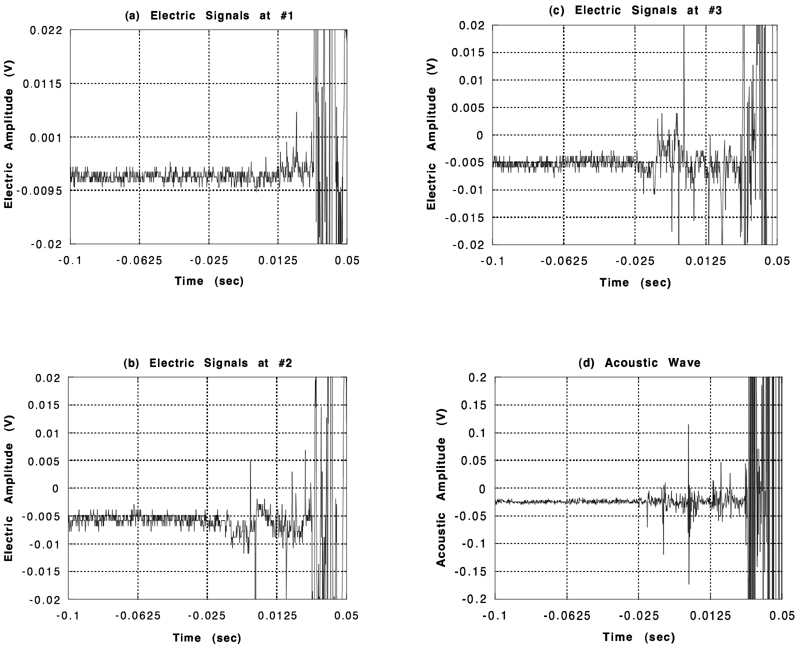

Figure 4: The same signals as in Figure 2 but with different time scale (horizontal axis) and amplitude scale (vertical axis).

Because granite contains 27.5% quarts, at each measurement point the group of quartz grains show a piezoelectric characteristic on the average. The pressure applied on the rock sample generates a piezoelectric field, whose amplitude and polarization depend on the piezoelectric characteristic of the local quartz group and its orientation related to the direction of the pressure. This field is a local electrical potential, which does not propagate in the rock. The sum of the electrical potential is very small due to the random distribution of the quartz in a rock. The piezoelectric effect is the main mechanism that generates electrical signals when a dry rock sample is broken.

4 Wet Granite Sample

The wet granite sample is saturated with tap water of 0.57 mS in conductivity in a vacuumized system. Figure 5 shows the electrical signals received on the water-saturated granite sample, and the acoustic waveform received by the acoustic transducer (Figure 1). More details of the signals and acoustic waveform are studied by changing the horizontal or vertical scales in Figures 6 and 7.

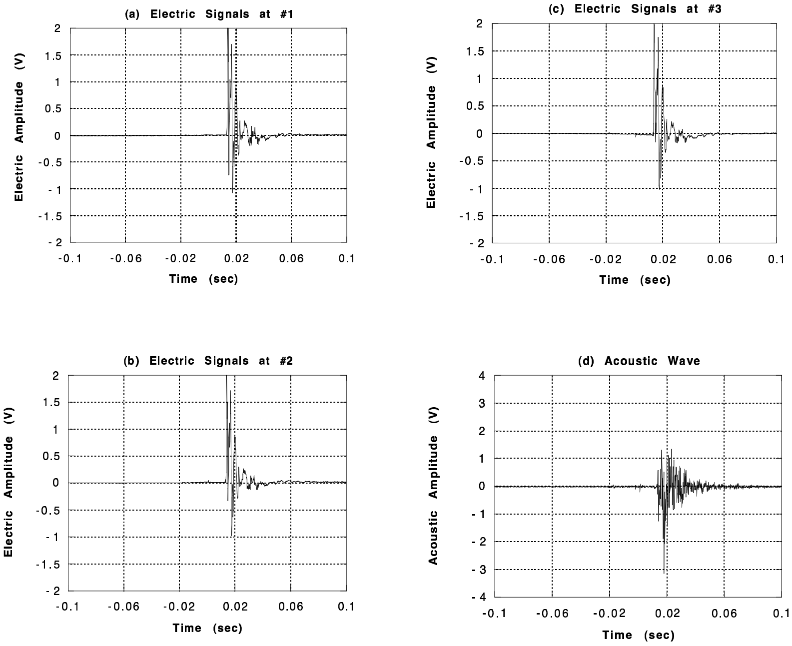

Figure 5: The electric signals (a, b, and c) and the acoustic wave (d) recorded with a water-saturated granite sample during its breaking. The displacement rate of the press is $10^{-2} mm/sec$.

In this case, we record stronger electrical signals, which have almost the same amplitude, shape, and phase at the three measurement points. This means that all of the electrical signals are induced by the same source or rock breaking and received by electrodes at different locations. Compared with the dry sample, we know that the mechanism of energy conversion in the water-saturated sample is different from the piezoelectric effect in a dry sample. This conversion in a wet rock sample is the electrokinetic effect in nature. The breaking generates an electromagnetic wave due to relative fluid flow in the wet rock. The electrical signal generated by the breaking is a radiating electromagnetic wave, which can be received simultaneously at different places.

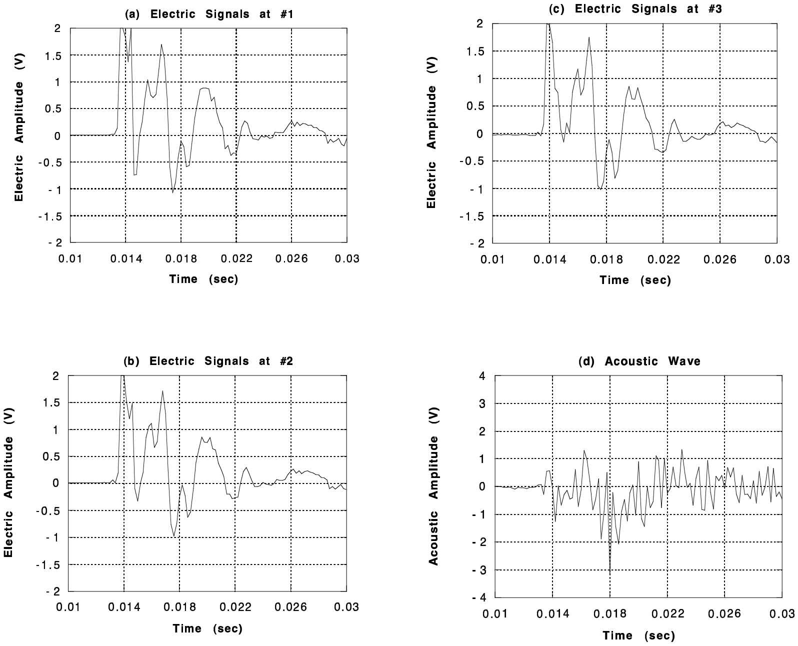

Figure 6: The same signals as in Figure 5 but with different time scale (horizontal axis).

Changing the amplitude scale, we can see more details of the potential variation before rock breaking occurs. Before the rock sample is broken completely, we record some sounds with small or smaller amplitudes between -0.04 second and 0.01 second (Figure 7d). The larger ones generate electrical pulses (Figures 7a, 7b, and 7c). Since recording the small sounds around -0.04 second, the basic electrical level (the dc potential) rose (Figures 7a and 7b) or dropped (Figure 7c). The amplitudes and polarizations of the potentials are different from each other. This means that the potentials due to the piezoelectric effect depend not only on the pressure, but also on the piezoelectric characteristic and orientation of the quartz group around the measurement points. They are local electrical potentials, and the potential and its variation can be observed before the rock breaking. Because the stress concentrates around the breaking area, we can record the local potentials around the area. When a fluid-saturated rock sample is breaking, the moving charges in the fluid induce electromagnetic waves, which propagate independently and can be received near or far from the breaking area. Their frequencies are usually much higher than the natural potential and close to those of acoustic waves. This phenomenon is very similar to that observed in the Loma Prieta earthquake of 17 October 1989 (Fraser-Smith et al., 1990).

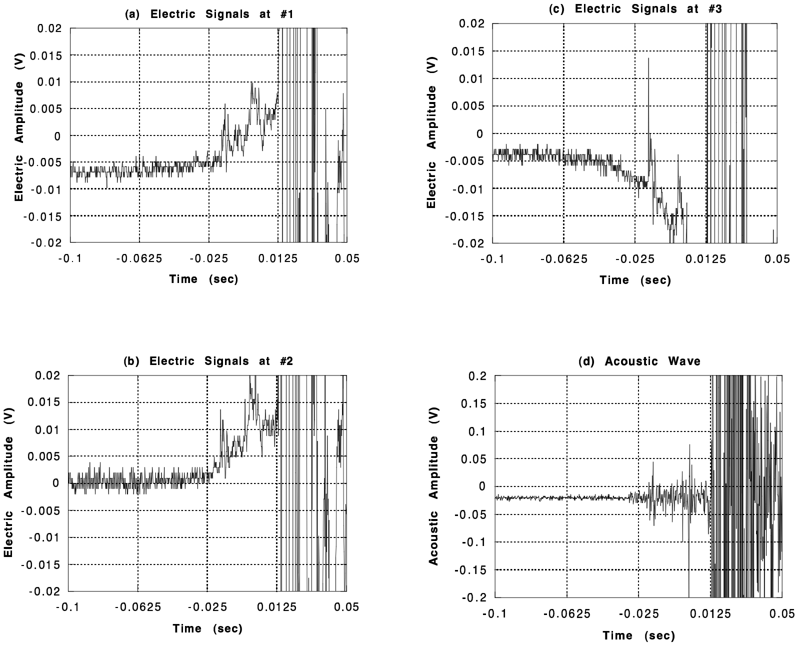

Figure 7: The same signals as in Figure 5 but with different time scale (horizontal axis) and amplitude scale (vertical axis).

To investigate the seismoelectric field generated by rock breaking, we change the rate (displacement speed) of the press. In the previous experiments with dry and wet samples, the displacement speed is $10^{-2} mm/sec$. Figure 8 shows the electrical and acoustic signals with a water-saturated Westerly granite sample at the displacement speed of $10^{-4} mm/sec$ before the rock breaking. In this case, we have only observed the potential variation in DC or low-frequency ranges, we did not record any strong acoustic waves or electric signals. There was no loud sound during rock breaking (Figure 8d), and only few electric pulses were recorded in Figures 8a, 8b, and 8c, but we observed the continuous variation of the natural potential. The amplitude and polarization of the variation are different at the three measurement points. The potentials go up in Figure 8a and 8b, but go down in Figure 8c. In this case the pressure makes more microcracks within the rock. Then the pore fluid flows into the cracks and changes the natural potential, which is related to the adsorption potential between the fluid and solid of grains.

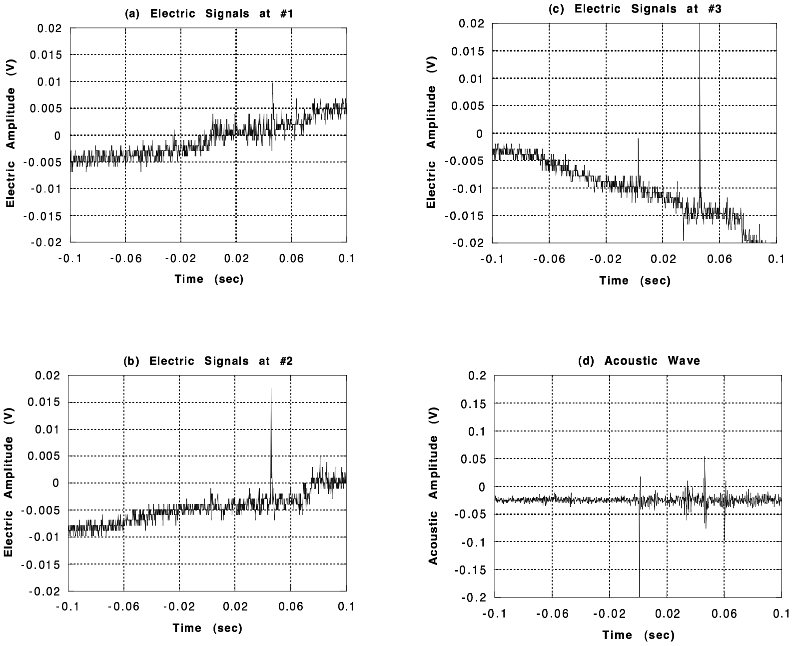

Figure 8: The electric signals (a, b, and c) and the acoustic wave (d) recorded with a water-saturated granite sample during its breaking. The displacement rate is $10^{-4} mm/sec$, which is lower than the previous rate of $10^{-2} mm/sec$.

5 Conclusions

In this paper, we performed experiments with dry and water-saturated granite samples to measure electric and acoustic signals when the samples were pressured and broken. The experimental results show that the electrical signals recorded during rock breaking are generated by two different mechanisms of the piezoelectric effect and seismoelectric conversion. The results help us to understand the whole electric and acoustic procedures due to the piezoelectric effect and seismoelectric conversion during rock breaking.

The experiment with a dry rock sample shows that the amplitude and the polarization of the electrical potentials due to the piezoelectric effect depend not only on pressure, but also on the piezoelectric characteristic and the orientation of the grains around the measurement points.

Rock breaking generates a relative motion between the fluid and the solid matrix in a fluid-saturated rock. Moving charges in the fluid induce electromagnetic waves in the rock. If the breaking is big enough, it generates a seismoelectric pulse, which is a radiating electromagnetic wave and can be simultaneously received at different places. Some pore fluid flows into the new microcracks made with smaller breaking and establishes new balance, which also changes the natural potential in the rock.

6 Acknowledgements

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