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Electric currents streaming out of stressed igneous rocks – A step towards understanding pre-earthquake low frequency EM emissions

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Abstract

Transient electric currents that flow in the Earth's crust are necessary to account for many non-seismic pre-earthquake signals, in particular for low frequency electromagnetic (EM) emissions. We show that, when we apply stresses to one end of a block of igneous rocks, two currents flow out of the stressed rock volume. One current is carried by electrons and it flows out through a Cu electrode directly attached to the stressed rock volume. The other current is carried by p-holes, i.e., defect electrons on the oxygen anion sublattice, and it flows out through at least 1 m of unstressed rock to meet the electrons that arrive through the outer electric circuit. The two outflow currents are part of a battery current. They are coupled via their respective electric fields and fluctuate. Applying the insight gained from these laboratory experiments to the field, where large volume of rocks must be subjected to ever increasing stress, leads us to suggest transient, fluctuating currents of considerable magnitude that would build up in the Earth's crust prior to major earthquakes.

Keywords: Seismo-electromagnetic phenomena; Uniaxial loading; Igneous rock; Positive hole (p-hole); p-type semiconductor; Battery current

1. Introduction

A recent letter in Nature (Gerstenberger et al., 2005) begins with the words: "Despite a lack of reliable deterministic earthquake precursors, seismologists have significant predictive information about earthquake activity from an increasingly accurate understanding of the clustering properties of earthquakes." This statement alludes to the fact that, when earthquakes happen, they are chaotic events. Their chaotic character is exacerbated by the heterogeneity of the Earth's crust, particularly along seismically active plate margins, which are crisscrossed by faults and pot-marked by deeply buried asperities. When and where a given fault segment will fail depends on processes that take place under kilometers of rock. Unless there is a history of prior seismic activity that leaves a trail of signals, it is unknowable where faults go at depth and when asperities might fail. Therefore, the tools of seismology can cast time and approximate location of the next earthquakes only in terms of rather coarse statistical probability.

However, there is a non-seismological approach, which can add to our knowledge base. In this approach, we attempt to understand the electromagnetic signals, if any, that the earth reportedly sends out before major earthquakes.

The literature is replete with reports of pre-earthquake phenomena. Some of these phenomena can be explained mechanistically by assuming that, when large volumes of rock are squeezed deep underground, they deform

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plastically and develop microfracture leading to the well-publicized dilatancy theory (Brace, 1975; Brace et al., 1966; Hazzard et al., 2000) that can account for the bulging of the earth's surface, for changes in well-water levels (Chadha et al., 2003; Igarashi et al., 1993; Igarashi and Wakita, 1991), in the outpour of hot springs (Biagi et al., 2001; Goebel et al., 1984), and in the composition of the gases dissolved in spring waters (Hauksson, 1981; Igarashi et al., 1993; Plastino et al., 2002; Rao et al., 1994; Sano et al., 1998).

Other pre-earthquake phenomena cannot be explained mechanistically such as low-frequency electromagnetic (EM) emissions (Fujinawa et al., 2001; Fujinawa and Takahashi, 1990; Gershenzon and Bambakidis, 2001; Gokhberg et al., 1982; Molchanov and Hayakawa, 1998; Nitsan, 1977; Vershinin et al., 1999; Yoshida et al., 1994; Yoshino and Tomizawa, 1989), local magnetic field anomalies (Fujinawa and Takahashi, 1990; Gershenzon and Bambakidis, 2001; Ivanov et al., 1976; Kopytenko et al., 1993; Ma et al., 2003; Yen et al., 2004; Zlotnicki and Cornet, 1986), increases in radio-frequency noise (Bianchi et al., 1984; Hayakawa, 1989; Martelli and Smith, 1989; Pulinets et al., 1994), and earthquake lights (Derr, 1973; King, 1983; St-Laurent, 2000; Tsukuda, 1997; Yasui, 1973). This group of pre-earthquake signals requires electric currents in the ground. Sometimes the strength of the recorded signals, in particular low frequency EM emissions, require strong currents. All past attempts to identify a physical process that could generate strong currents deep in the ground have not produced convincing results.

Here we describe a simple experiment that subjects igneous rocks (granite, anorthosite, gabbro) to stress. By judiciously connecting electrodes to the rocks we show that the stressed rock volume turns into a battery: it generates, which flow out without externally applied voltage. These self-generated currents may hold the key to understand how powerful electric currents can be generated deep in the Earth prior to major earthquakes and what kind of signals they send out.

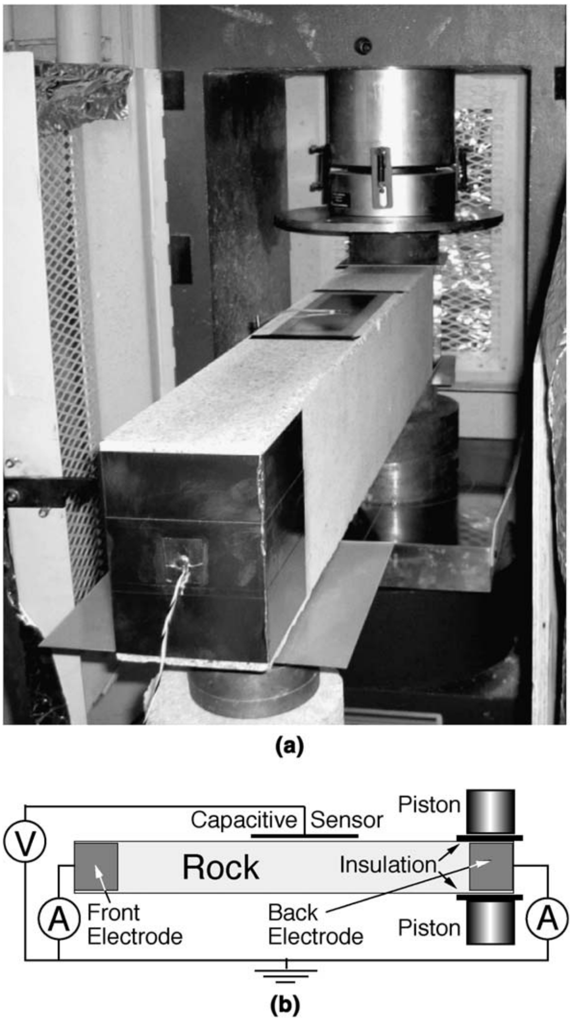

Fig. 1. (a) Granite slab placed in the press, ready for the uniaxial compression tests. The granite slab (1.2 m long, 10×15 cm^2 cross section) is fitted with two Cu electrodes (each 30×15 cm^2), one at the back end and one at the front end, plus a non-contact capacitative sensor for measuring the surface potential. The rock is insulated from the pistons and the press by 0.8 mm thick polyethylene sheets ($>10^{14}$ Ω cm). (b) Block diagram of the electric circuit for allowing the self-generated currents to flow out of the stressed rock volume.

2. Experimental

Fig. 1a shows a long granite slab, 1.2 m long with a rectangular 10×15 cm^2 cross section, in situ in a press, electrically insulated from the two pistons by means of two 0.8 mm thick hard polyethylene sheets with a resistance of $>10^{14}$ Ω. The load was applied uniaxially to one end of the slab between two pistons, 11.25 cm diameter, stressing a volume of ~1500 cm^3. The rock was fitted with two Cu tape electrodes with graphite-based, conductive adhesive, each connected to an ampere meter. One electrode surrounded the back end of the rock so that the volume to be stressed was in electrical conduct with the Cu electrode and, hence, with ground. The other electrode of the same size, wrapped around the front end of the rock, was also connected to ground. In addition we had placed a non-contact capacitive sensor on the top of the rock, made with the same Cu tape and 0.8 mm thick polyethylene insulator. Fig. 1b shows the corresponding electric circuit that is designed to allow stress-activated currents to flow out of the stress rock volume.

The back end of the slab was loaded uniaxially at a constant rate of 6 MPa/min to a maximum stress level of 67 MPa, equal to about 1/3 the failure strength of the granite. The load was applied repeatedly, a total of six times, with 30 min between loading/unloading cycles.

To measure the outflow currents we used two Keithley ampere meters, model 486 and 487. To measure the surface potential we used a Keithley electrometer, model 617. The data were acquired with National Instrument LabVIEW 7.0.

The experiment was carried out with dry, light-gray, medium-grained "Sierra White" granite from Raymond,