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Small pressure drop triggered near a fault by small teleseismic waves

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Abstract

We describe a pressure transient triggered near an active fault by seismic waves generated more than 10 000 km away during the 2003 $M_w = 7.8$ Rat Island earthquake. In contrast with previous similar observations, the pressure drop occurs simultaneously with the arrival of S waves, and not during the passage of the Rayleigh waves that have larger amplitudes and smaller frequencies. This small 60 Pa drop is compatible with a small slip on the fault, which induced either dilatant damage or a transient disruption in the impermeable barrier the fault constitutes.

Keywords: dynamic triggering; pore pressure monitoring; active fault long-term monitoring; borehole instrumentation

Water-level changes induced by remote earthquakes have been documented since the Alaskan Earthquake of 1964 [1]. Montgomery and Manga [2] review dozens of such events and compare their distance to the epicenter to the magnitude of the corresponding earthquake. All their data lie above a line that corresponds to a volumetric strain equal to 10^{-8}, and they attribute this limit to instrumentation resolution. Such small a threshold suggests that some of these disturbances are dynamically triggered.

High frequency data shows that these disturbances can be concurrent with the passage of the Rayleigh waves [3]. These pressure changes are often interpreted as changes in permeability, which has also been shown to be altered by seismic waves [4]. Interestingly, triggered seismicity can also start from Rayleigh waves arrival [5]. The relationship between the two triggering phenomena is still not clear.

The Corinth Rift Laboratory is devoted to the joint observation of deformation and fluid pressure in a seismically active area. In addition to pressure data, seismometers and strainmeters monitor the Rift deformation. After a presentation of the borehole intersecting the Aigio fault, we describe the pressure drop induced by the 2003 Rat Island earthquake together with data from a seismometer and a dilatometer located 10 km away from the well. We check the absence of artifact due to the instrumentation or to a change in oceanic loading.

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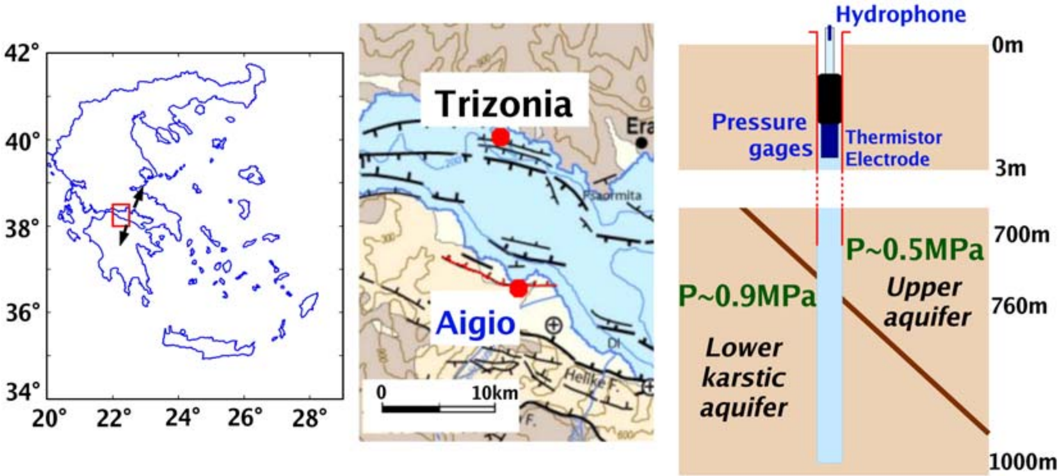

Fig. 1. (Left) The Corinth Rift, Greece, opens at a rate of 1.5 cm/yr. (Middle) In its western part, this activity is accompanied by intense faulting on its southern shore. We will focus on the Aigio fault, in the city of Aigio. (Right) The Aigio fault is intersected at 760 m by the deep Aigio borehole. The fault is surrounded by two aquifers decoupled from the surface by more than 300 m of clay and radiolarite: the upper fractured limestone aquifer with an overpressure of 0.5 MPa and the karstic lower aquifer, with an overpressure of 0.9 MPa. The difference in pressure implies that the fault is a hydraulic barrier. A pressure transducer has been installed at his wellhead. In addition to the pressure records, we consider the data from a hydrophone set up within the wellhead and from a set of seismometer and dilatometer located on Trizonia Island, some 10 km north to the borehole.

Finally, we propose several interpretations for the pressure drop.

1. The Corinth Rift and the Deep Geophysical LABoratory

The Corinth Rift is one of the most active extensional regions in Europe. This 130 km long, 20 km wide gulf separates continental Greece from Peloponnesus (Fig. 1). Its extension rate reaches locally 1.5 cm/yr, accompanied by large earthquakes like the $M_s=6.2$, June 15th, 1995 Aigio earthquake [6]. This earthquake caused up to 3 cm of surface displacement along the Aigio fault on the south-western shore of the Gulf [7], although the main rupture zone was slightly north to the Gulf, on a shallowly dipping fault.

This suggests that the fault may be creeping. GPS data over 11 years ([8], Fig. 4) show that a horizontal movement of 4 mm/yr has been monitored across the Aigio fault. This is similar to the slip rate along the fault obtained by paleoseimologic studies [9]. This motivated the choice of the Aigio fault as the site of the Deep Geophysical LABoratory project (DGLab).

The 1000 m deep AIG10 borehole intersects the active Aigio fault at 760 m (Fig. 1). The well is cased down to 700 m. Cores and logging images provide a precise description of the formations below the casing. The Aigio fault is smeared by a 1 m thick layer of clayish material that acts as a hydraulic barrier separating two different limestone aquifers [10]. The upper one has an overpressure equal to 0.5 MPa. Its hydraulic conductivity has been estimated to be 8×10^{-8} m/s through production test [11]. The lower aquifer is an artesian karst, with an overpressure of 0.87 MPa. Its high hydraulic conductivity ($1.3\pm0.2\times10^{-5}$ m/s) is caused by the cavities of metric size intersected by the borehole.

Its instrumentation was installed in September 2003 (Fig. 1). This includes a high-precision absolute pressure transducer, which operates at a sampling rate of 1/8 Hz with a resolution of 10 Pa. Another major sensor is a hydrophone, sampled at 2.5 kHz, that monitors the local high frequency microseismic activity. The installation was operating from fall 2003 to the end of 2004.

Three months after the installation, the wellhead pressure stabilized to about 0.85 MPa, a value very close to the original lower karstic aquifer overpressure (Fig. S2). As expected from the high permeability and storativity of the karst, the recorded pressure variations reflect the changes in the karstic aquifer.

2. Hydraulic transients triggered by teleseisms

2.1. Recordings of the 2003 Rat Island earthquake

On November 17, 2003, a $M_w=7.8$ earthquake occurred below Rat Island in the Aleutian archipelago, some 10 000 km away from the AIG10 borehole. The piezometer gave excellent recordings of the seismic waves (Figs. 2 and 4), superimposed with a 60 Pa drop.