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Electric pulses some minutes before earthquake occurrences

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Electric and magnetic pulses are measured shortly (some minutes) before earthquakes. These pulses differ greatly from the seismic electric signals, which have appreciably longer lead times (days to months). In the case of 1995 Grevena-Kozani earthquake with a magnitude of 6.8, the time difference of ≈ 1 s was observed between the recordings of the electric and magnetic components at Ioannina station, providing further support that the pulses were not from local man-made source but most probably from the epicentral area about 100 km away. A tentative explanation of the phenomenon is proposed considering what happens in the very last stage before the earthquake occurrence. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2450779]

Early observations[1,2] of the electric field E of the earth revealed that, at epicentral distances r around a few tens of kilometers, electric pulses were detected $\frac{1}{2}$–4 min before magnitude M5 class earthquakes (EQs). These pulses, lasting for a few millisecond (see p. 404 of Ref. 2), were stored at a transient memory recorder (sampling frequency appreciably larger than 1 kHz) by measuring the potential difference between electrodes located at distances of ~ 50 m using a Keithley 610 or a Cary 401 vibrating reed electrometer.[1] Low pass 10 Hz filters were later added in order to reduce the electric noise, thus allowing the detection of an additional precursor termed seismic electric signals (SESs). The latter are low frequency (≈ 1 Hz or smaller) transient variations of the electric field of the earth that have amplitude markedly smaller than that of the aforementioned electric pulses but are particularly useful since they are detected at longer lead times, i.e., several hours to a few months before an EQ.[3–7] In the following, we report our later observations of the electric pulses, which differ from the earlier ones in several respects. Since the principal aim of this experimentation was the SES detection, our measurements were made with sampling rate of 1 sample/s at several permanent sites (10–18), which were carefully selected to be sensitive[3,5,7] to SES collection. Furthermore, at five of these sites, simultaneous measurements of the magnetic field B were also carried out.[7,8] In the electric field measurements, the use of the 10 Hz low pass filters was retained (in view of the purpose for the SES detection) although it hampered the recording of the actual amplitude of the electric pulses. (More details on the instrumentation can be found in Ref. 9.) In spite of this fact, however, clear electric pulses were observed before all five[9] EQs with $M \geqslant 6.5$ (according to the United States Geological Survey, USGS) that occurred during the period 1995–2005 with epicenters within $N_{35}^{41}E_{19}^{27}$.

The major new features of the electric pulses presented in this letter are the following: (1) At the epicentral distances $r \approx 100$ km, a time difference of around 1 s has been observed between the arrival times of the electric and the magnetic variations for each pulse. As will be explained later, this time difference excludes the possibility that these pulses can be attributed to nearby man-made sources. (2) We will try to provide an explanation for the value of the lead time in the light of the recent understanding of what happens in the very last stage before earthquake occurrence. We take into account the views that tectonic earthquakes usually take place by sudden slippage along preexisting faults or plate interfaces[10] and that the sudden slippage is related to the onset of frictional motion (slip) as the result of transition from static to dynamic friction.[11]

Figure 1(a) shows the electric and magnetic pulses that have been observed at Ioannina (IOA) station shortly before the $M = 6.8$ Grevena-Kozani EQ which occurred at 08:47:13 universal time on May 13, 1995 with an epicenter at 40.15° N 21.69° E, about 100 km away from Ioannina in northern Greece (a location map of its epicenter and IOA is given in Fig. 1 of Ref. 9). Figure 3 of Ref. 9 shows the map of measuring dipoles (pairs of electrodes) at IOA with lengths a few to several tens of meters (short dipoles) or a couple of kilometers (long dipoles). Here, we present the E-field recordings of two horizontal short dipoles of length 50 m [installed at site "c," depicted in Fig. 3(a) of Ref. 9] oriented along EW and NS. These electric field variations were recorded by 20 ms integration to avoid 50 Hz noise, with a sampling rate of 1 sample/s by using low pass 10 Hz filters. The magnetic variations were measured by two horizontal coil magnetometers, also oriented along EW and NS, which act as dB/dt detectors for periods larger than around half a second. A signal recorded by these magnetometers should correspond[8,9] to a magnetic variation that has "arrived" at the sensor less than 200 ms before the recording.

The bottom panel of Fig. 1(a) reveals that five magnetic pulses (marked "a"–"e") are detected before the EQ occurrence. They started at 16 min before the EQ and the last one was at 3 min before. They were identified also in the electric records, with varying definitude. (b and d are nonvisible on the NS dipole, thus emphasizing the importance of measuring in different directions in order to detect these pulses, see also Ref. 9.) Simultaneously with the arrival of the seismic waves, some seconds after the origin time (OT), disturbances, reminiscent of seismograms, were recorded by both E and B sensors. No true coseismic, i.e., cofracture signal, was observed at OT. Observation of coseismic wave signals

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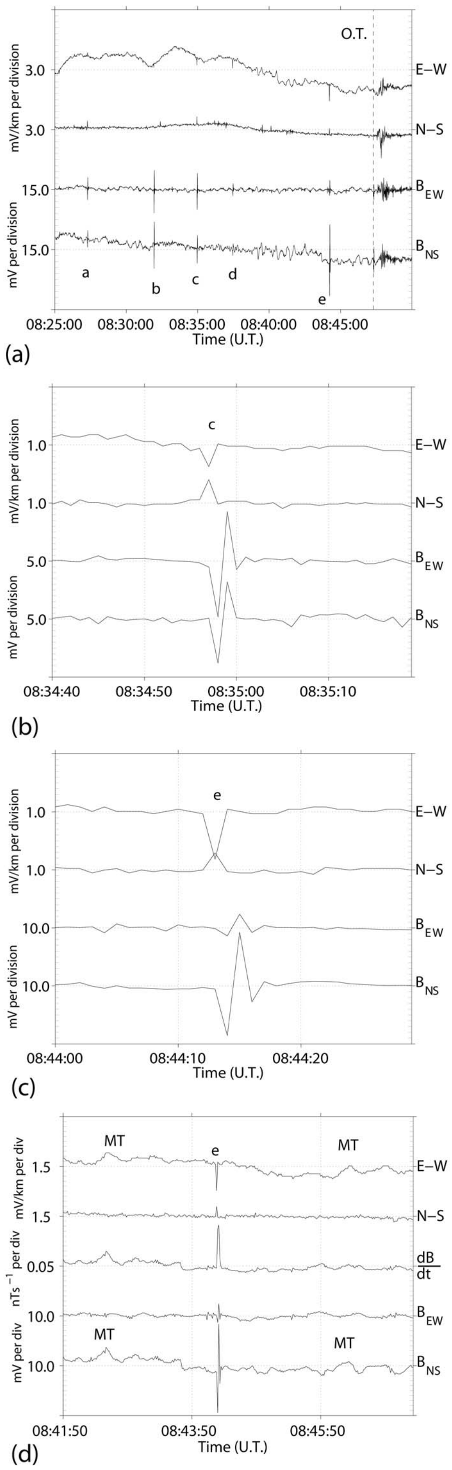

FIG. 1. Variations of the electric field (the upper two channels) and the magnetic field (the lowest two channels) recorded at IOA station. (a) For the time period: from 22 min before, until ~3 min after the occurrence of the $Ms=6.8$ mainshock on May 13, 1995. The symbols a–e mark the five pulses observed before this occurrence, while the vertical broken line shows the origin time (OT). [(b) and (c)]: The pulses "c" and "e," respectively, in an expanded time scale. (d) Excerpt from (a) to show magnetotelluric disturbances in an expanded time scale. For the scale in the vertical axis for the magnetometers: 20 mV correspond to a constantly increasing magnetic field of 0.1 nT s^{-1}. In the middle channel of (d) the amplitude of dB/dt (in nT s^{-1}) is also plotted.

but no cofracture signal was reported earlier for other cases.[7,12,13]

Let us now focus on these precursory pulses. First, example pulses "c" and "e" of Fig. 1(a) are shown in Figs. 1(b) and 1(c) in a more expanded time scale. It can be noted that the magnetic field disturbance was recorded around 1 s after the *E*-field variation. This time difference can only be understood if it is realized that the electromagnetic fields emitted from a source are transmitted through the conductive earth's crust obeying the diffusion-type equations[7,14] (see also below).

This time difference is of profound importance, because it demonstrates that the pulses were emitted from source lying at a distance of the order of 100 km and *cannot* be attributed to neither noise from nearby source nor magnetotelluric origin for the following reasons: (i) The time difference between arrivals of *E*- and *B*-field variations should not be in the observable range in the case of emission from nearby sources[7,8] and (ii) the magnetic variations (dB/dt) are recorded before[7,8] (not after) the *E*-field variations in the case of magnetotelluric (MT) disturbances [see the examples marked MT in Fig. 1(d)].

Second, the ratios of either the *E*-field or the *B*-field components were noticeably different for different pulses as seen in Figs. 1(a)–1(c). We should remark that these observations were made only for Grevena-Kozani EQ. If this is further confirmed to hold general, it may indicate that some change of the angle between the principal stress axis (which may govern the orientation of the emitting dipole, hence the direction of the measured electromagnetic fields) and the neighboring fault (which may constitute a conductive path[7,15]) might have occurred at the very last stage before the main shock. Furthermore, we note that the diffusion-type equations mentioned above reveal (see p. 192 of Ref. 7) that for a dipole source lying along the main axis z of a conductive path (in a cylindrical system of coordinates ρ,φ,z), the electric field component E_ρ perpendicular to the path reaches detectable values *earlier* than the component E_z. The latter accompanies the high current density flowing inside the path and hence is simultaneous with the magnetic fields B_φ (thus reflecting a time difference between E_ρ and B_φ).

In what remains, we discuss whether the observed lead times of the electric pulses can be explained. We recall that the early field observations[1,2] related to $M\approx 5$ EQ showed lead times in the range of $\frac{1}{2}$–4 min, while the earliest pulse a in Fig. 1(a) was detected almost 16 min before the $M=6.8$ EQ occurrence. We first note that tectonic earthquakes usually take place by sudden slippage along preexisting faults or plate interfaces and the sudden slippage is the result of transition from static to dynamic friction (e.g., see Ref. 10). According to the recent laboratory studies[11,16–19] on sliding of interface between blocks, the dynamics of local small slips, before overall sliding, proceeds via the interplay between three different types of coherent cracklike fronts, called "detachment fronts." While two of these fronts propagate at subsonic (sub-Rayleigh) and intersonic velocities,[16–19] the third type of front was found[11] to propagate an order of magnitude more *slowly* with velocities v ranging from around 30 to 80 ms^{-1} [see Fig. 4(c) of Ref. 11]. It has been noted that the third slow front plays most important roles in the transition from static to dynamic friction, ensuring overall motion (sliding), i.e., no sliding occurs until either of the slower two fronts has traversed the entire interface. Although these laboratory observations made on the interface between two blocks are obviously not directly applicable to earthquake faults with vastly different scales and complexities, a tentative order of magnitude estimation leads to the following. Here we further assume that transient electric pulse is emitted upon the coherent establishment of the slow detachment front [cf. since an abrupt variation of the polarization is then expected to occur arising from the (re)orientation of the electric dipoles formed due to crystal defects[7]] and hence upon its start of movement. (Cf. some changes of the conductivity[20] and the diffusion coefficient[21] may also occur, but are disregarded, for the sake of simplicity.) The rupture length (L) for $M \approx 5$ and $M \approx 6.5$ earthquakes may roughly be $L \approx 5$ km and $L \approx 30$ km. If the velocity v of the slow detachment front is around 50 ms^{-1}, i.e., comparable to that of measured in the laboratory experiment, this front would need times roughly $t(=L/v)$ around 10^2 s and 6×10^2 s to sweep through the distances of rupture lengths L of the earthquakes with $M \approx 5$ and $M \approx 6.5$, respectively. These values more or less agree with the field observations.

Finally, the following possibility may be pointed. Since the lead time of the pulses is in the range of tens to a few minutes, it was considered too short for EQ prediction in the early stage of Varotsos-Alexopoulos-Nomikos method development. But nowadays even a few minutes at most of the "real time seismological alert," using the arrival time difference of P and S waves of already occurred EQ, may be useful, under certain circumstances such as during heavy surgery operation, in reducing disasters. If so, an order of magnitude longer lead time of the pulses may provide an even more useful warning system for the imminent EQ occurrence when monitored at a number of remote ($\sim$100 km) observation sites.[9] Moreover, the lead time and the E and B time difference provide complementary information on r and M of the impending EQ, additional to information from SES. Ideally, comprehensive EQ prediction may work as follows: SES will first give estimates of epicentral area and M with lead time of ten days to months.[4,7] Then, the natural time analysis[22] of the seismic activity after SES appearance will narrow the time window to a few days[7,23] and the pulses will specify the occurrence time in some minutes. Real time seismology may give further emergency alert.

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