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SELF-POTENTIAL VARIATIONS WITH TIME AND THEIR POSSIBLE RELATION WITH SEISMIC ACTIVITY IN WESTERN GREECE

G-Akis TSELENTIS, Apostolos IFANTIS
University of Patras, Seismological Centre
Rio 261 10, Greece

Abstract

An apparent appearance of characteristic anomalies of the earth's electrotelluric field prior to two imminent earthquakes at an observation site in Western Greece is discussed. The analysis of the data revealed the development of a characteristic periodic variation of the field which lasted for about 53 days prior to a M_s=4.7 earthquake which occurred at an epicentral distance of 90 km. A similar anomaly was also detected prior to a M=5.0 earthquake which occurred at an epicentral distance of 18 km from the observation site.

1. Introduction

Recordings of changes of the natural electric field of the earth in search of precursors of strong earthquakes have been reported by many researchers. In USSR, extensive experiments in the seismically active region of Kamchatka (Myachkin *et al.*, 1971; 1975; Sobolev, 1975; Fedotov *et al.*, 1977) revealed the existence of some characteristic bay-like anomalous changes of the earth's electric field 3–16 days prior to main shock, at epicentral distances of up to 150 km.

In China (Coe, 1971) anomalies are expressed by an abrupt drop of the electric field, a few hours prior to the earthquake which recovers after the occurrence of the shock. For example, the successfully predicted earthquake of 1975 was preceded by an abrupt drop of the electric field at a station located 25 km from the epicentre (Raleigh *et al.*, 1977).

Similar phenomena have also been reported in Japan (Koyama and Honkura, 1978), and in India (Nayak *et al.*, 1983).

In Greece, a systematic observation of the earth's electric field changes as earthquake precursors has been conducted since 1981 by a network of stations (Varotsos and Alexopoulos, 1984 a,b; Varotsos and Lazaridou, 1991), telemetrically connected to a central station in Athens (VAN network). The possible polarising effect of the above long period electric field is used to explain the nature of the SES signals (Varotsos and Alexopoulos, 1986).

Meyer and Pirjola (1986), and Meyer and Teisseyre (1988) using recordings from the VAN network revealed the development of a 24 hours periodic anomaly in the electrotelluric field prior to two earthquakes from the seismically active region of Cephallonia in western Greece. Similar observations were made during an experimental investigation by Thanassoulas and Tselentis (1986). In a recent investigation Ifantis *et al.* (1993) using all the existing recordings of the VAN network at nine sites all over Greece prior to two earthquakes revealed the existence of similar anomalies in connection with the development of bay type long period anomalies. These researchers tried also to find a possible relation between the azimuthal vector of the electric field and the epicentral region of the imminent earthquakes.

In this paper we discuss some electrotelluric records observed prior to two earthquakes in western Greece. It is characteristic to note that one of the two earthquakes cosidered occurred at the same epicentral region of the events dicussed by Mayer and Teisseyre (1988) who reported similar anomalies.

2. Field measurements

As a part of an experiment dealing with the continuous monitoring of various geophysical parameters as possible earthquake precursors, the seismological laboratory of Patras University has recently comensed the monitoring of the variations of the earth's electric field at a site in the seismically active region of western Geece (Fig. 1).

The site for the experiment was selected on the basis of results of a systematic geophysical investigation carried out around the University campus. The main geological features of the site selected consisted of gravelly sediments of an old river bank cutting throughout clayey sediments.

Due to the strong lateral variation in the electric properties of the prevailing geologic formations it was throught according to the existing experience in conducting similar

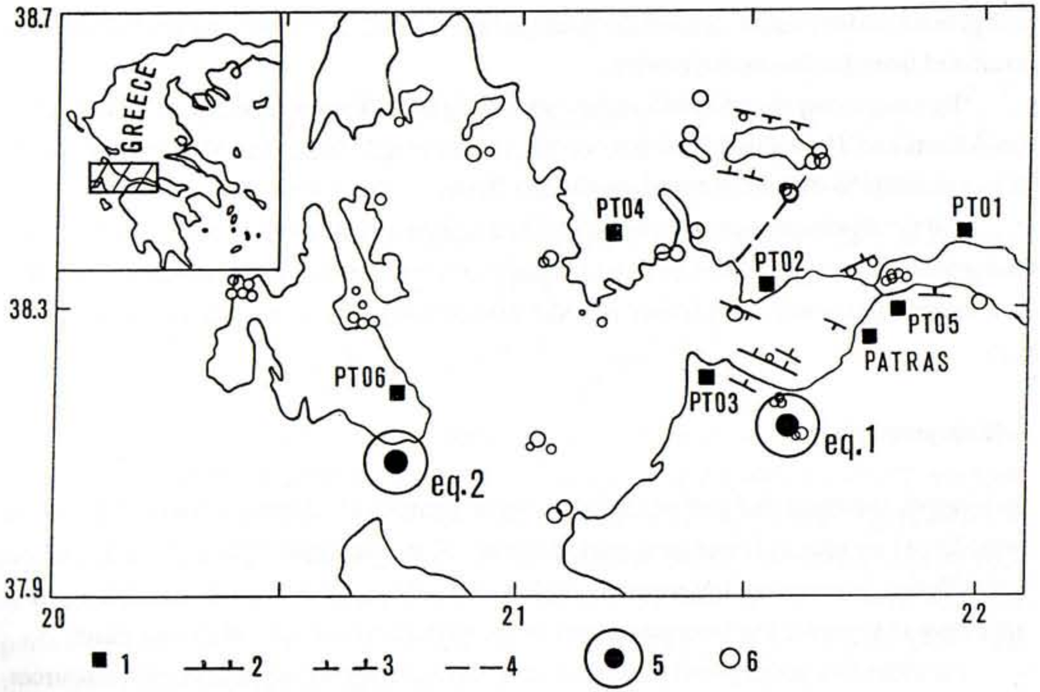

Fig.1. Map showing seismicity of the region, recorded by the seismological network of Patras University for the whole period of the experiment: 1– peripherial station, 2– normal fault, 3– probable normal fault, 4– probable strike-slip fault, 5– focal region, 6– magnitude.

experiments (Varotsos, personal comm., 1992) that the total absence of graphite and sulphides results in a more straightforward dependence of the recorded self potential on the physical properties of the rocks such as grain size and electrical resistivity. Further, it was envisaged that the geophysical parameters dependent on the mechanical characteristics of rocks would vary with time according to the electric deformation caused by stress field variations, especially for the case of near field events.

The discrimination of electrotelluric precursors from other disturbances is an important task. In order to eliminate any possible cause of error the electric field was measured in two directions, north-south (N–S) and east-west (E–W) by parallel pairs of electrodes with two different distances between the electrodes (100 and 50 m). Furthermore, a large dipole of a length of 6 km was deployed by using existing telephone lines (Fig. 1). The dipoles used consisted of pairs of polarized (Pb) and unpolarized ($Pb/PbCl_2$) electrodes buried at a depth of 5 m. The ground above the electrodes was covered by a geomembrane in order to reduce any possible effects by rainfall.

The criterion used to delineate signals from noise was as follows. If ΔV denotes the variation of the potential difference between a pair of electrodes, the anomalies which do not give a constant value to the field strength $\Delta E = \Delta V/L$ for different parallel lines are excluded from further consideration.

By comparing electric field variations recorded in dipoles installed at remote sites (in Athens and Thessaloniki), with recordings of the magnetic field at Athens observatory it was possible to delineate magnetotelluric effects.

All the dipole outputs were amplified by employing a differential amplifier and after being passed through a 16-bit analog to digital converter were stored on a microcomputer at a sampling rate of 2 samples/sec and simultaneously plotted on a chart recorder.

3. Data processing

In general, the recorded self potential curve is composed of components of different periods: a) an almost linear long period trend, b) the possible signal, c) short period noise. Before attempting any correlation of the recorded signals with seismic activity, it is necessary to separate the interesting part of the variation from the other two parts.

As with other geophysical potential fields, an unambiguous separation of the sources contributing to the measured signal is impossible. Thus, the decomposition into three components of different period content must be regarded as gross simplification. Especially the separation of the long period trend from the signal is somewhat problematic due to the broad periodic spectrum of the interesting part of the recorded curve. After testing various filtering techniques, we adopted the following approach which gave very satisfactory results.

The real valued data $t_0, t_1, \ldots, t_{N-1}$, after performing a discrete Fourier transform, produce two sets of real valued transforms

$$R_k = \frac{1}{N} \sum t_j \cos\left(\frac{2\pi jk}{N}\right), \qquad k = 0, 1, 2, \ldots, N-1, \tag{1}$$

$$I_k = \frac{1}{N} \sum t_j \sin\left(\frac{2\pi jk}{N}\right), \qquad k = 0, 1, 2, \ldots, N-1. \tag{2}$$

The high frequency removal is achieved by the operation

$$R_k = f_k \cdot R_k \qquad \text{and} \qquad I_k = f_k \cdot I_k, \tag{3}$$

where

$$f_k = 1 - \left(\frac{k}{E}\right)^2, \qquad k = 1, 2, \ldots, E-1,$$

$$f_k = 0, \qquad k = E,\ E+1,\ E+2$$

is a quadratic filter function. The parameter E, ranging in the interval $1 < E < \frac{N-1}{2}$, controls the value of the attenuation of high frequencies. For $E = \frac{N-1}{2}$ no high frequency attenuation is performed at all on the original data. Subsequently t_j filtered data are obtained by the inverse discrete Fourier transform

$$t_j = \sum \left[R_k \cos\left(\frac{2\pi k}{N}\right) - I_k \sin\left(\frac{2\pi k}{N}\right)\right]. \tag{4}$$

By selecting different values of the parameter E we were able to separate the interesting part of the signal from the other two components. Figure 2 depicts an example of the above process on the raw data for 1600 hours of recording period. Figure 2a is the orginal obtained signal. Figure 2b shows the removal of the high frequency (noise) part of the signal, while the doted line in Fig. 2a demonstrate how we can estimate the long period trend by adjusting the parameter E. Figure 2c depicts the residual signal when the long period trend has been removed.

4. Analysis of the records

Figure 1 depicts seismic activity of the region during the whole period considered in the present research (2798 hours of continuous recording). Apart from the usual background seismic activity of the region, two events occurred. The first had magnitude M_s=5.0 and occurred on 30 May 1992 at a well known fault and at an epicentral distance of 18 km (hereafter called earthquake 1). This event can be considered as near field to the observation site. The second event of magnitude 4.7 occurred on 18 August 1992 in the southern part of Cephallonia Island and at an epicentral distance of 90 km (hereafter called earthquake 2).

Figure 3 shows the obtained records of the electrotelluric field for the entire considered period at the E–W and N–S components, respectively.

4.1 Anomaly related to earthquake 1. The earthquake of 30 May 1992 occurred at an epicentral distance of only 18 km from the recording site, this is one of the few existing cases in the world where continuous measurements of the earth's electric field have been obtained prior to imminent seismic activity at such close distances.

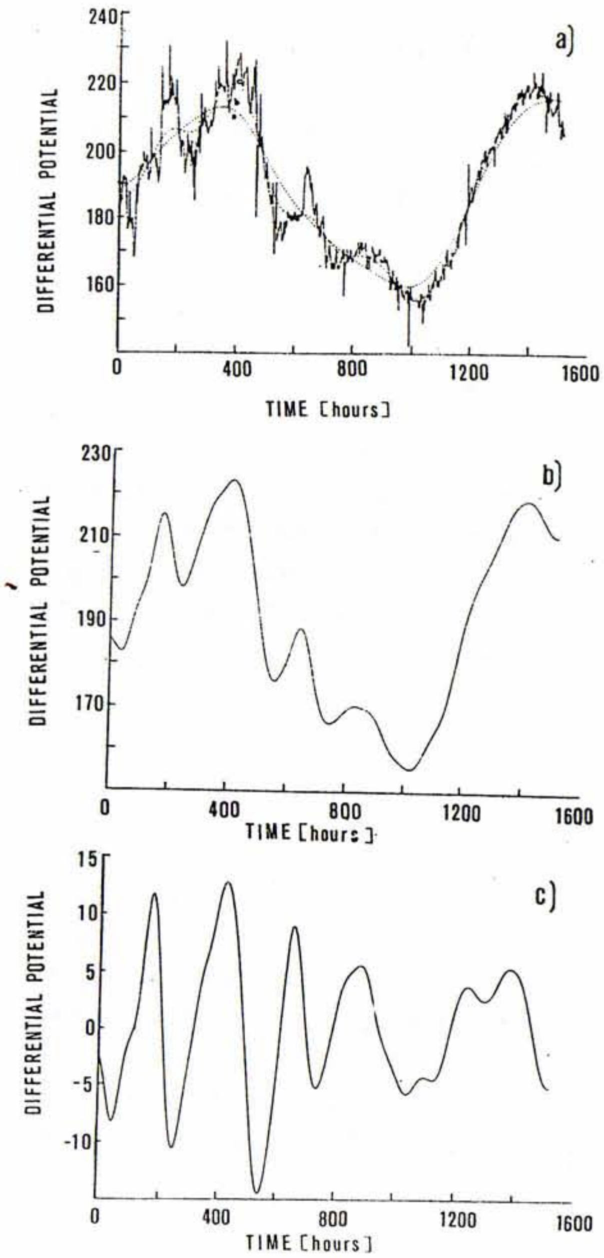

Fig. 2. Original signal for 1600 hours of recording period; dotted lines correspond to various cutoff frequencies: (a=0.04h−1, b=0.06h−1, c=0.07h−1) and various trends (a); long period trend (b); residual signal (c).

Figure 4a depicts the total electric field obtained as follows:

$$V_{\text{total}} = \left(V_{\text{NS}}^2 + V_{\text{EW}}^2\right)^{1/2}, \tag{5}$$

where V_{NS} and V_{EW} are the orginal recordings at the two dipoles.

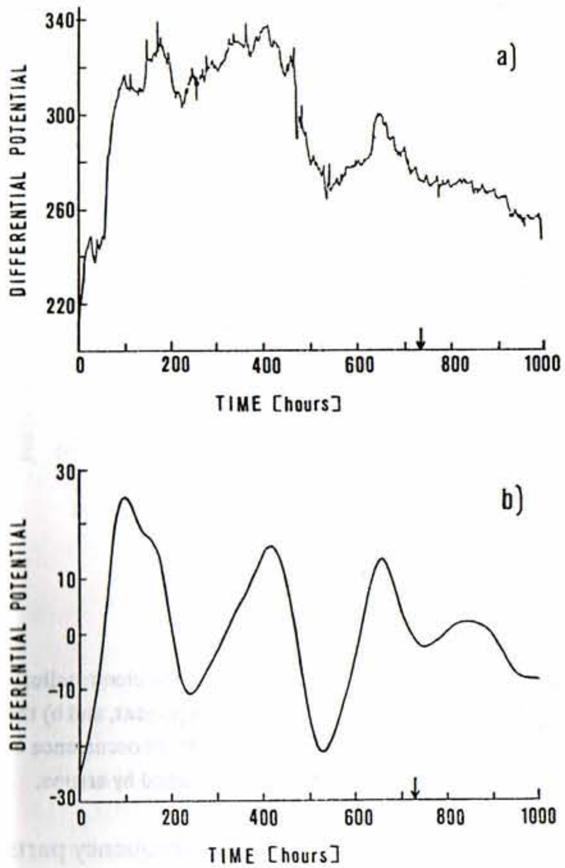

Fig. 4. Vector synthesis of the total field (a) and the corresponding residual signal (b). The time of occurrence of earthquake 1 is marked by an arrow.

warning was sent on 27 July 1992 to the National Organization for the Protection from Earthquakes in Athens.

The observed telluric field on the E−W and N−S components is depicted in Fig. 6. Judging from Fig. 6a we point to a kind of anomalous electric signal which appears as a periodic component superimposed onto the linear trend.

This phenomenon cannot be observed on the N−S component of the recordings apart from a small part of the signal (between 200 and 400 hours in Fig. 6b) which shows an oscillatory nature.

Figure 7 presents the corresponding spectra for 1290 hours part of the signal prior to the earthquake and 155 hours after the earthquake (for the E−W component). The development of a 24 hours periodic component prior to the event, which diminishes just after it, is obvious.

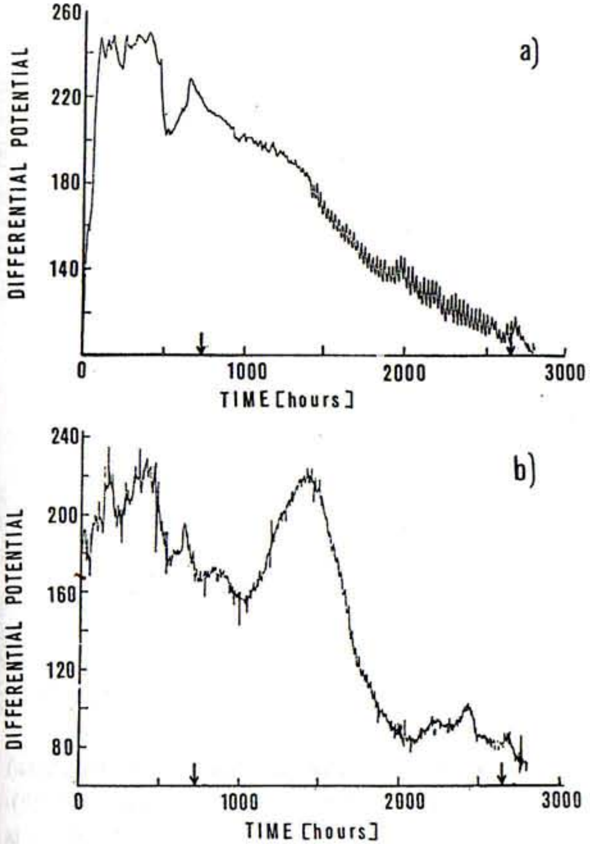

Fig. 3. Entire recording of the electrotelluric field for: a) the E–W component, and b) the N–S component. The time of occurrence of the two earthquakes is marked by arrows.

The residual signal obtained after the removal of the high and low frequency parts of the signal in Fig. 4a is depicted in Fig. 4b. The development of an oscillation prior to the earthquake is obvious.

The spectral analysis of the signal for the period of 732 hours proir to the earthquake reveals the strong periodic nature of the signal with predominant periods of 23 and 25 hours (Fig. 5a). This periodic oscillation disappears after the earthquake (Fig. 5b).

A total different picture is obtained when we evaluate the spectra for the 268 hours interval after the event. In this case, the corresponding spectra seem to be displaced to the left with a predominant period of 12 hours.

Another characteristic variation of the electrotelluric field, which can be attributed to the earthquake, is the bay-type anomaly observed just prior to the origin time at the E–W component (Fig. 3a).

4.2 Anomaly related to earthquake 2. The second event considered in the present investigation was predicted by the authors 53 days prior to its occurrence and an official

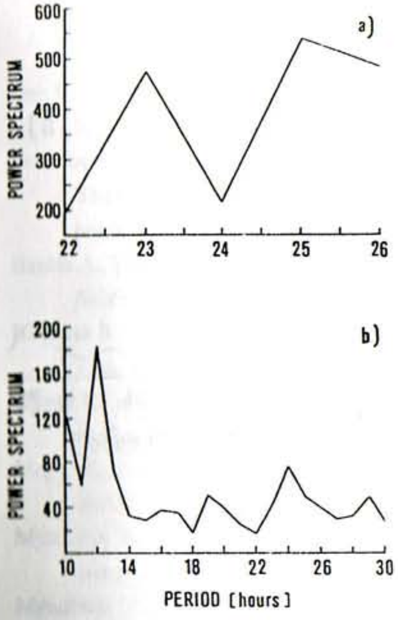

Fig. 5. Fourier amplitude spectra before (a) and after (b) earthquake 1.

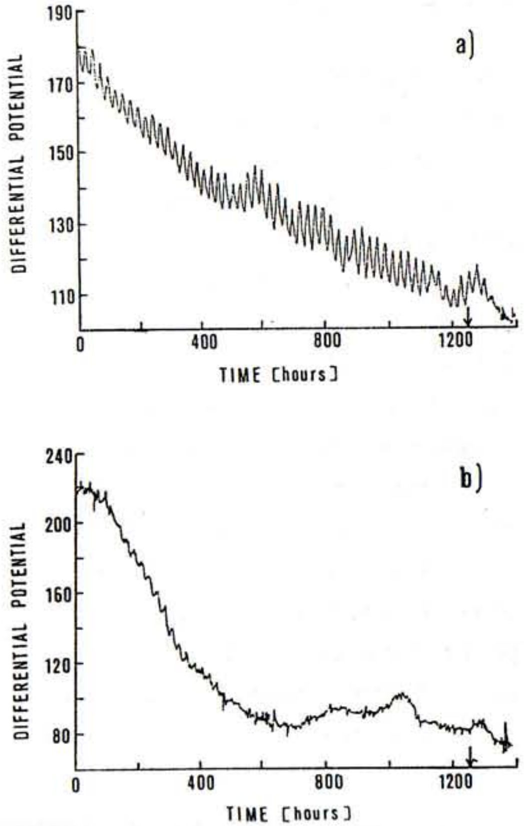

Fig. 6. Recorded telluric field at the E–W (a) and the N–S (b) components related to earthquake 2. The time of occurrence is marked by an arrow.

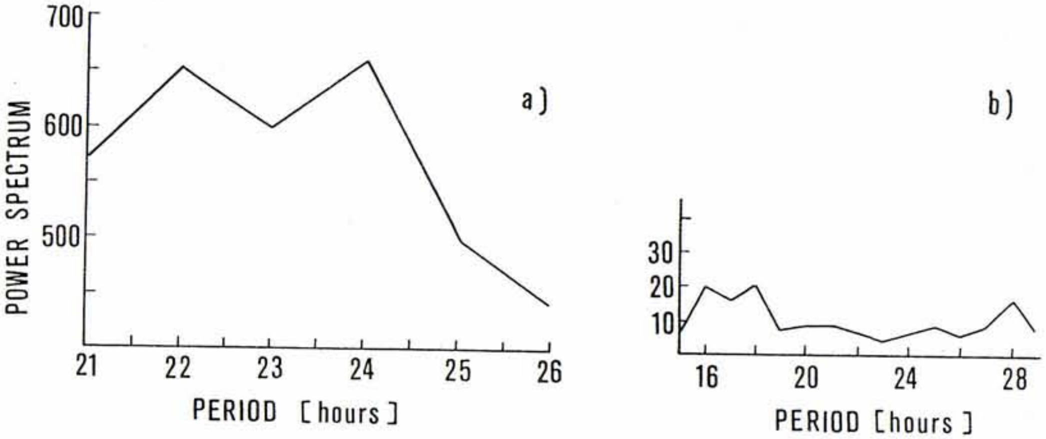

Fig. 7. Fourier amplitude spectra (E–W component) before (a) and after (b) earthquake 2.

5. Discussion and conclusions

The observed telluric anomalies prior to the discussed earthquakes may be explained by different phenomena. One can attribute these telluric variations to: a) temperature dependent electro-chemical effect at the electrodes, which is observed when rain water reaches the electrodes; b) induced by similar variations of the earth's geomagnetic field. As far as the first case is concerned, no rainfall at all the recording period occurred at the experimental site. As far as the second possible cause, we can demonstrate by following the procedure of Meyer and Pirjola (1986) that the induced electric field derived from the variations of the geomagnetic field are smaller by more than an order of magnitude than the observed electric field, excluding the possibility that the observed periodic anomalies are due to geomagnetic induced effects.

Hence, we are inclined to consider these anomalies as being connected with geophysical processes in the earthquake preparation zone.

Thanassoulas and Tselentis (1986) attributed a piezoelectric origin to the phenomenon and attempted to explain it as the result of the superposition of stress accumulating prior to earthquakes and tidal stresses. The observed different behaviour of the E–W and N–S telluric components prior to the considered earthquakes also suggests a piezoelectric (or electrostictive) effect. The quantitative evaluation of the recorded anomalies and an attempt to describe their origin will be the subject of another publication.

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