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ΣΥΝΕΔΡΙΑ ΤΗΣ 3ΗΣ ΙΟΥΝΙΟΥ 1982

ΠΡΟΕΔΡΙΑ ΠΕΡΙΚΛΗ ΘΕΟΧΑΡΗ

ΦΥΣΙΚΗ.—**Electrotelluric precursors to earthquakes,** *by P. Varotsos - K. Alexopoulos - K. Nomicos**. 'Ανεκοινώθη ὑπὸ τοῦ 'Ακαδημαϊκοῦ κ. Καίσαρος 'Αλεξοπούλου.

ABSTRACT

Transient changes of the telluric field of the order of 0.5 — 30 mV on a line of 50 m occur about seven hours before each earthquake. A time chart is given of all the signals (around 32) collected and all the earthquakes mentioned in the official bulletin [1] of Athens for a period of 15 days. Their correlation was computed and a pronounced maximum found for a lead time between 5 ½ and 11 hours. A plot of the logarithm of the intensity of the signal (after reduction for the epicentral distance) versus the magnitude is approximatively linear.

Changes of the electrotelluric field prior to earthquakes have been reported in a number of cases [**1**-**4**]. It seems however that they do not ocour regularly enough in order to predict the time of an earthquake (EQ). After the outbreak of high seismicity in Greece in February 1981 the telluric current has been monitored nearly continuously. Beyond the usual disturbances due to meteorological and magnetic storms two types of sudden changes were observed. The first is a pulse of a few volts

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(measured on a line of 50 m) with the duration of a few milliseconds; it occurs between 1 and 4 minutes before an earthquake [**5**]. It was easily detected by comparing the time of the pulse to the time of an EQ observed on a seismograph at the same site. The second type is a transient change of the telluric field of much smaller intensity (0.5 to 30 mV on a 50 m line) and a duration of the order of 30 min; it is also a precursor with a lead time around 7 hours [**6**]. Photographs of the signals on the recording charts have published in Ref 7. They can be clearly seen during time-periods of low noise. The signals registered on our recorder do not seem to have a similar form to those described in Refs 1 - 4.

The electric signals (ES) were observed in the chart recordings since the first experiments but they could not be associated to earthquakes during the initial period of high seismicity because a large number of EQ occured each hour. Later, when the seismicity subsided, a pattern emerged which showed that each ES was a precursor to an EQ in a one to one correlation. Signals smaller than 0.5 mV were sometimes hidden in disturbances of the telluric current, however by observing simultaneous signals at stations far apart, disturtbances of uncertain origin could be decided upon.

The present paper describes the recent experiments on electric signals collected at various sites.

EXPERIMENTAL PART

Two brass cylinders of 6 cm in diameter were inserted into the ground (depth 40 to 200 cm) at a distance of 50 m and connected to a differential amplifier with unity amplification. After passing through a low-pass filter with a cut-off frequency of 0.3 Hz and an offset the potential difference V was displayed on a chart recorder with a speed of 20, 30 or 60 cm/hour. A second pair ofelectrodes was installed, perpendicular to the first. The value of V was betwen 10 and 100 mV; it depended on the site where the electrodes were implanted and changed when it rained [**2, 3**]. By suitably choosing the offset the changes ΔV of the potential could be displayed with a sensitivity usually around 1 mV/cm. The resistance R of the earth measured between two electrodes was usually between 0.5 and 10 KΩ. Often the noise on lines perpendicular to each other are not equally strong.

CORRELATION OF ELECTRIC SIGNALS TO EARTHQUAKES

As mentioned the ES occur a number of hours before the EQ; this has been ascertained for many hundred of events since March 1981. In Fig. 1 we give a time chart of the ES collected at Glyfada (near Athens) during the period between the 3^{rd} and the 18^{th} of November in continuation to the data of Ref. 7. On the same chart we have marked the times of all the EQ recorded at the preliminary readings of the Observatory of Athens ($M > 2.8$). As will be described later, the intensity of an ES decreases with the epicentral distance. The same holds for EQ so that one should demand a detectable correlation only of the stronger EQ, both observed at the same site. In order to make the practically constant lead time better visible in the figure, 7 hours have been subtracted of the time of the EQ. We notice a one to one correspondance for 32 earthquakes with the exception of two EQ 4.3 and 5.3 (marked with a) which were mentioned to have occured at distances of 450 and 890 km far from the station. The earthquakes marked with b were mentioned as distant.

Due to the lead time not being exactly equal to 7 h but lying between $5\,^1/_2$ and $9\,^1/_2$ hours the markings to the right and the left of the time-axis are randomly shifted in regard to each other by about one hour. In some cases an overlap of the signals for two EQ or inversely a double-earthquake might have occured. The correlation becomes very clear during periods of time where no EQ occured because also no ES was registered. In Fig. 2 we give the curve which shows the degree of correlation between the ES and EQ in function of the time difference $\Delta t \equiv t_{EQ} - t_{ES}$ between the two kinds of events for values from -24 to $+24$ h. The ordinate gives the percentange of correlated events within a time span of ± 1 hour. The maximum is one order of magnitude larger than the statistical fluctuations of the background. The fact that it occurs at a positive value of Δt shows that the ES definitely precede the earthquakes. Assuming a one to one correspondance we give

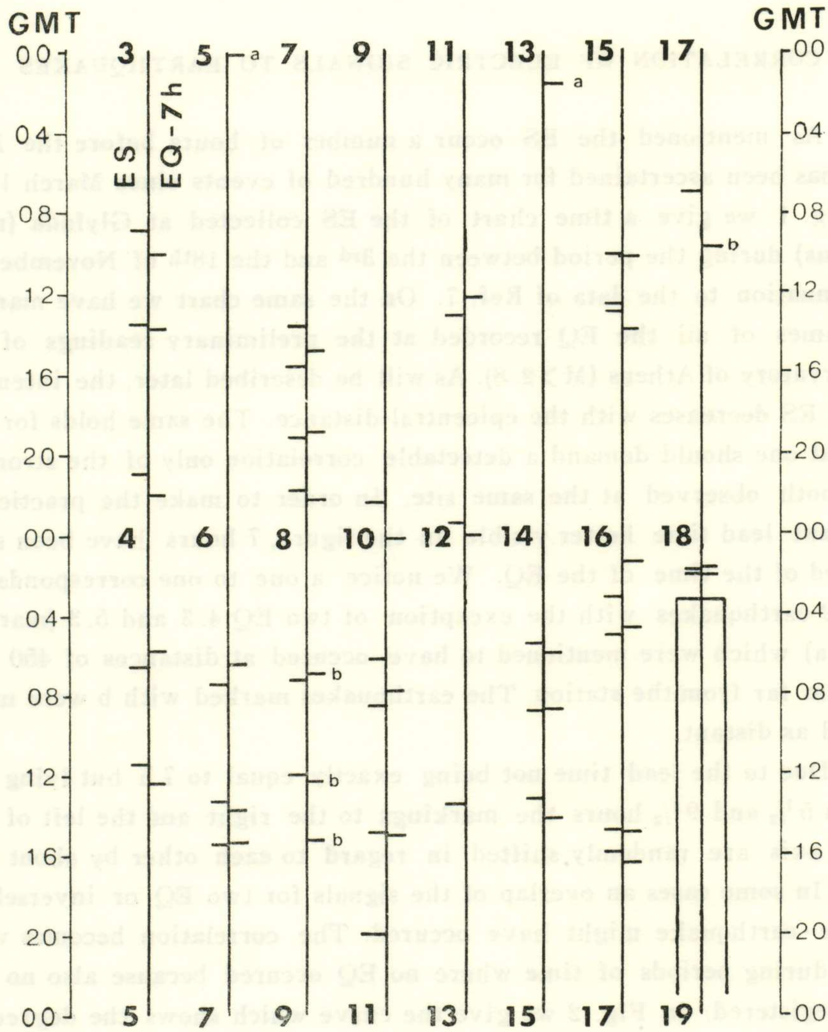

Fig. 1. Time chart of signals and earthquakes from Nov. 3rd to Nov. 18th. Note the time — shift of the EQ by 7 hours.

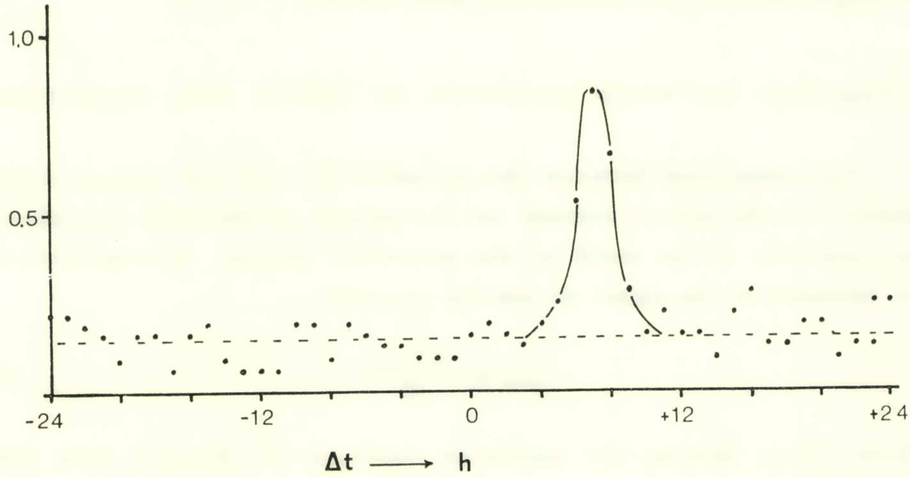

Fig. 2. Degree of correlation between electric signals and earthquakes.

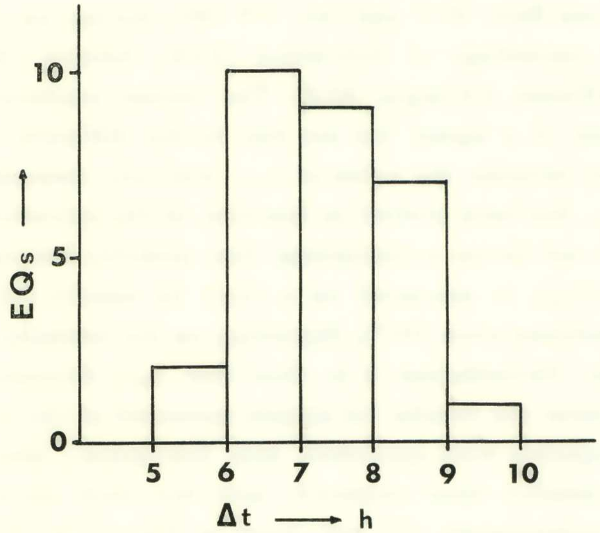

Fig. 3. Histogramm of lead times.

in Fig. 3 a histogramm of the lead-times. Note that the same study made for larger periods gave exactly the same feature.

CONNECTION BETWEEN STRENGTH OF SIGNAL AND MAGNITUDE

The connection between the measured ΔV with the change of the density I of the telluric current on the surface of the earth depends on the resistivity of the earth at the measuring station. As a measure of the intensity of the signal we use the quantity

$$I_{max} \equiv \frac{\Delta V_{max}}{R} \tag{1}$$

where ΔV_{max} denotes the maximum value of ΔV. Because each line (NS, EW) registers one component of the current the value of I_{max} is:

$$I_{max} = \left\{ \left(\frac{\Delta V_{max}}{R} \right)^2_{EW} + \left(\frac{\Delta V_{max}}{R} \right)^2_{NS} \right\}^{1/2} \tag{2}$$

In Table 1 we present the measurements for a number of EQ that occured between Sept. 27^{th} and Oct. 3^{rd} 1981, during an experiment of simultaneous recordings at Zakynthos (ZAK, Astacos (AST), Nemea (NEM) and Alfiousa (Olympia, ALF). The vacant positions do not indicate an absense of a signal but are due to the difficulty of extracting from the chart recorder the value of I_{max} with any reasonable accuracy. In Fig. 4 I_{max} has been plotted in function of the epicentral distance r. The points do not lie on a continuous line probably because the errors with which ΔV_{max} is measured on a chart lie usually between 30 and 50 % and sometimes even 100 % depending on the intensity of the signal and the noise. Nevertheless it is clear that I_{max} decreases with r. In Fig. 5 we present the results for signals measured at the Zakynthos station for earthquakes with epicenters near Zakynthos ; they have annintensity much smaller than expected ; note that such anomalies for the Zakynthos measurements did not occur in Figs. 4 and 5 in which the epicenters were remote. A large fault that passes within 30 km of the station may have influenced the ES - amplitude.

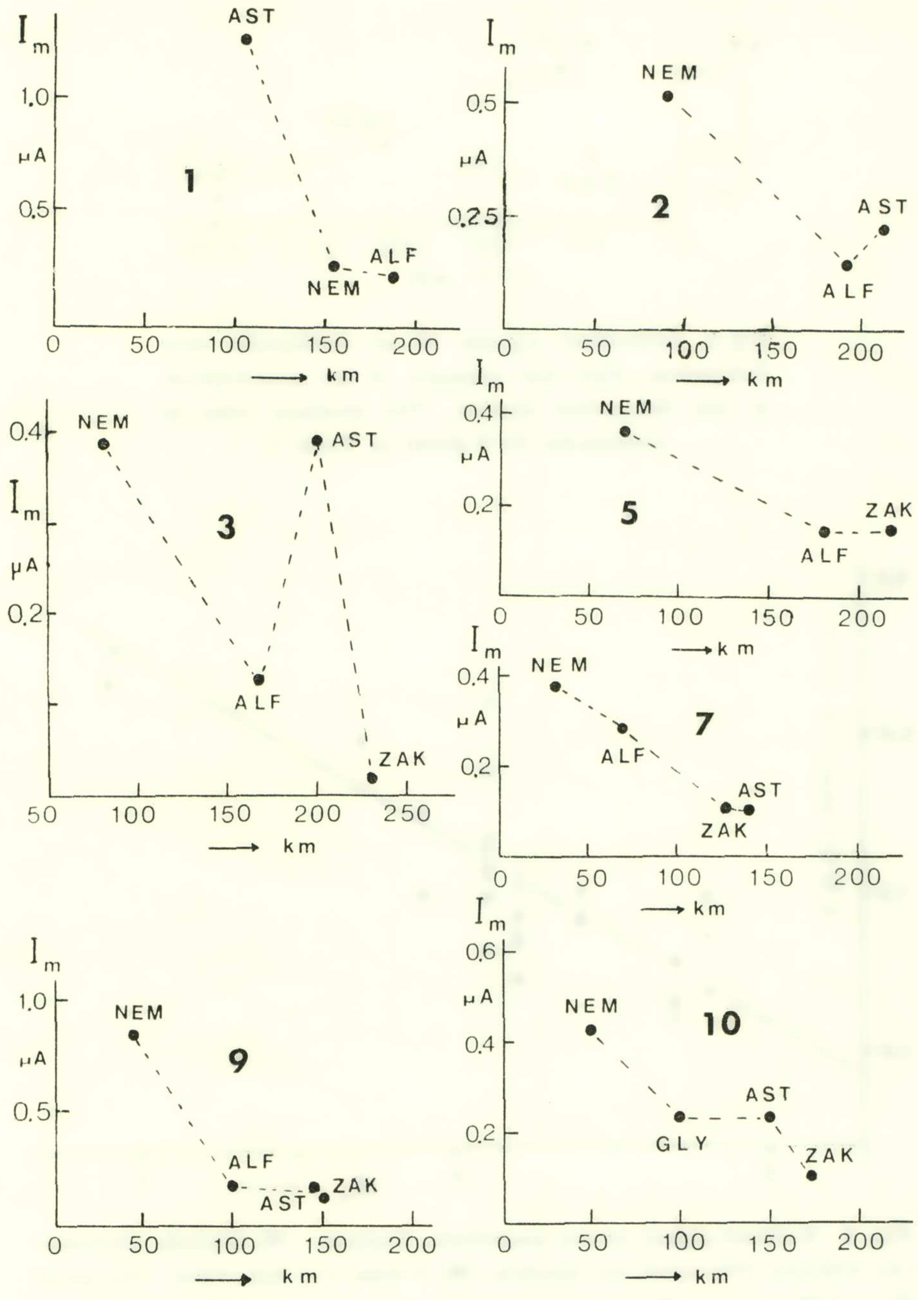

Fig 4. Coincident values of I_{max} in function of the epicentral distance. The numbers refer to earthquakes 1 to 10 given in Table I. In the plot of Nr 10 the value 0.23 μA obtained at Glyfada (r = 105 km) has been added.

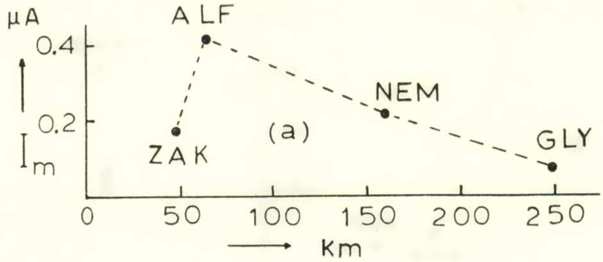

Fig 5. Coincident signals of an earthquake near Zakynthos. Note the anomaly of the measurement at the Zakynthos station. The numbers refer to earthquake No 8 given in Table I.

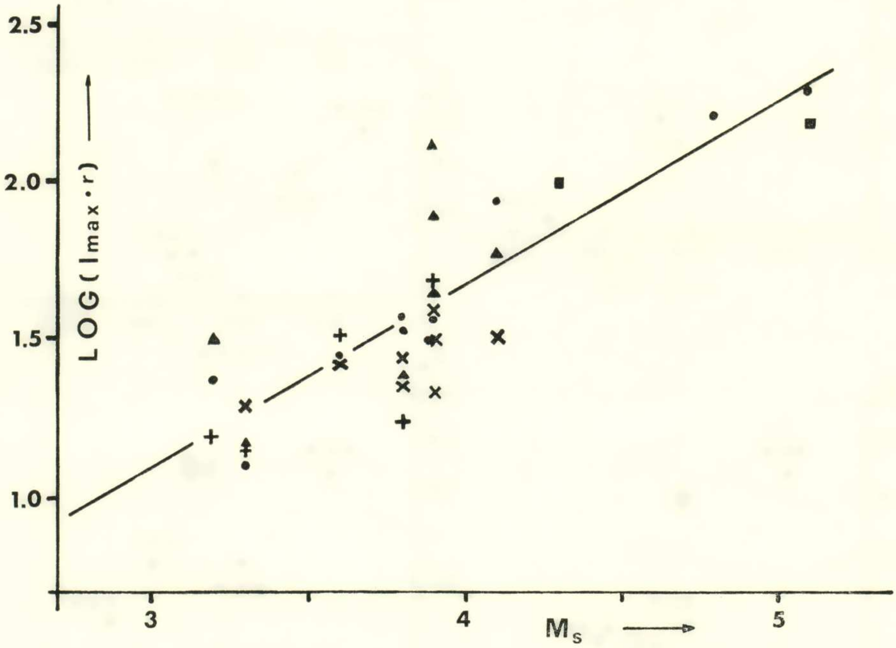

Fig. 6. Reduced gignal versus magnitude. Stations : (■) Glyfada (Athens), (×) Alfiousa (Olympia), (Δ) Astakos, (●) Nemea, (+) Zakynthos. The point (5.1 : 2.18) corresponds to an EQ on Oct. 14th, 10 : 59 GMT at a distance 295 km from Glyfada.

Assuming as a first approximation that I_{max} decreases with the epicentral distance according to a law :

$$I_{max} \sim \frac{1}{r}$$

we establish a relation between I_{max} and the magnitude M_s for each station. In Fig. 6 we have plotted $\log_{10}(I_{max}\ r)$ in function of the magnitude M_S; the values of I_{max} and r are taken in μA and km. The relevant data are given in Table I. We have added to the plot point (5. 1 ; 2. 18) measured at Glyfada (r = 295 km) corresponding to the EQ of Oct. 14th 10 : 59 GMT. On the other hand we have not inserted in the plot the two measurements at Zakynthos that carry questions marks in Table I because they fall completely out of the expected region. We notice that the values of the log $(I_{max}\ r)$ for a given EQ (they lie on the same vertical) measured at different stations differ by 40%. This can be attributed both to the inaccuracy of the assumed 1/r — relation and the errors in the individual values of ΔV_{max}. Further the values of M are given with a certain margin. A fitting to a straight line gives a slope of 0.586 with a correlation factor of 0.82 and an intercept of —0.67. Two points have been left out of this fitting procedure. Point (5. 1, 2. 18) was measured while only a single electrode — pair was operating so that its true value, according to Eq (2), must have been larger. The other point (4.1, 1.5) is uncertain because it was measured immediately after a rainfall which might have temporarily decreased the resistance ; unfortunately the latter was not measured at the time.

DISCRIMINATION BETWEEN PRECURSOR ES AND DISTURBANCES INDUCED BY MAGNETIC EFFECTS

The identification of a transient changes of the telluric field as an ES demands that the later is **NOT** accompanied by any significant change of the magnetic field during the effect. Two characteristic examples are given below.

Figure 7 is the ES at 07 : 48 GMT Dec. 19th, 1981 on a 20 m line at Glyfada ; it was followed seven hours later (14 : 41 GMT) by a 7 R seismic event close to Agios Efstratios at a distance of 160 km. Its iden-

TABLE I.

Some earthquakes and signals from Sept. 27th to Oct. 3rd 1981.

EARTHQUAKE					SIGNAL																
							ASTAKOS			ALFIOUSA			NEMEA			ZAKYNTHOS					
No	DATE	TIME	M_s	Seismic region	DATE	TIME	I_{max} (μA)	r (km)	log (I_{max} r)	I_{max} (μA)	r (km)	log (I_{max} r)	I_{max} (μA)	r (km)	log (I_{max} r)	I_{max} (μA)	r (km)	log (I_{max} r)			
1	27	19:58	3.9	Karditsa	27	12:51	1.25 or 0.9	105	2.12 1.96	0.22	180	1.60	0.24	157	1.58	—					
2	27	21:45	3.9	Thiva	27	13:22	0.22	207	1.66	0.17	188	1.50	0.52	95	1.69	—					
3	29	20:11	3.9	Thiva	29	12:47	0.39	202	1.9	0.13	168	1.34	0.39	83	1.51	0.02	233	0.67?			
4	30	07:37	5.1	Crete	30		—			—			0.33	570	2.28	—					
5	30	08:22	3.6	Thiva	30	01:16	—			0.15	178	1.43	0.37	75	1.44	0.15	223	1.52			
6	30	14:00	4.8	Ioannina	30		—			—			0.56	287	2.2	—					
7	30	20:52	3.3	Tripolis	30	13:38	0.11	141	1.17	0.29	68	1.29	0 37	34	1.1	0.11	133	1.16			
8	1	11:23	3.8	Zakynthos	1		—			0.42	65	1.44	0.21	162	1.53	0.17	47	0.9?			
9	1	21:43	3.8	Distomo	1	14:40	0.17	145	1.39	0.18	126	1.36	0.83	45	1.57	0 11	159	1.24			
10	2	01:52	3.2	Antikyra	1	19:15	0.24	136	1.5	—			0.42	56	1.37	0.09	172	1.19			

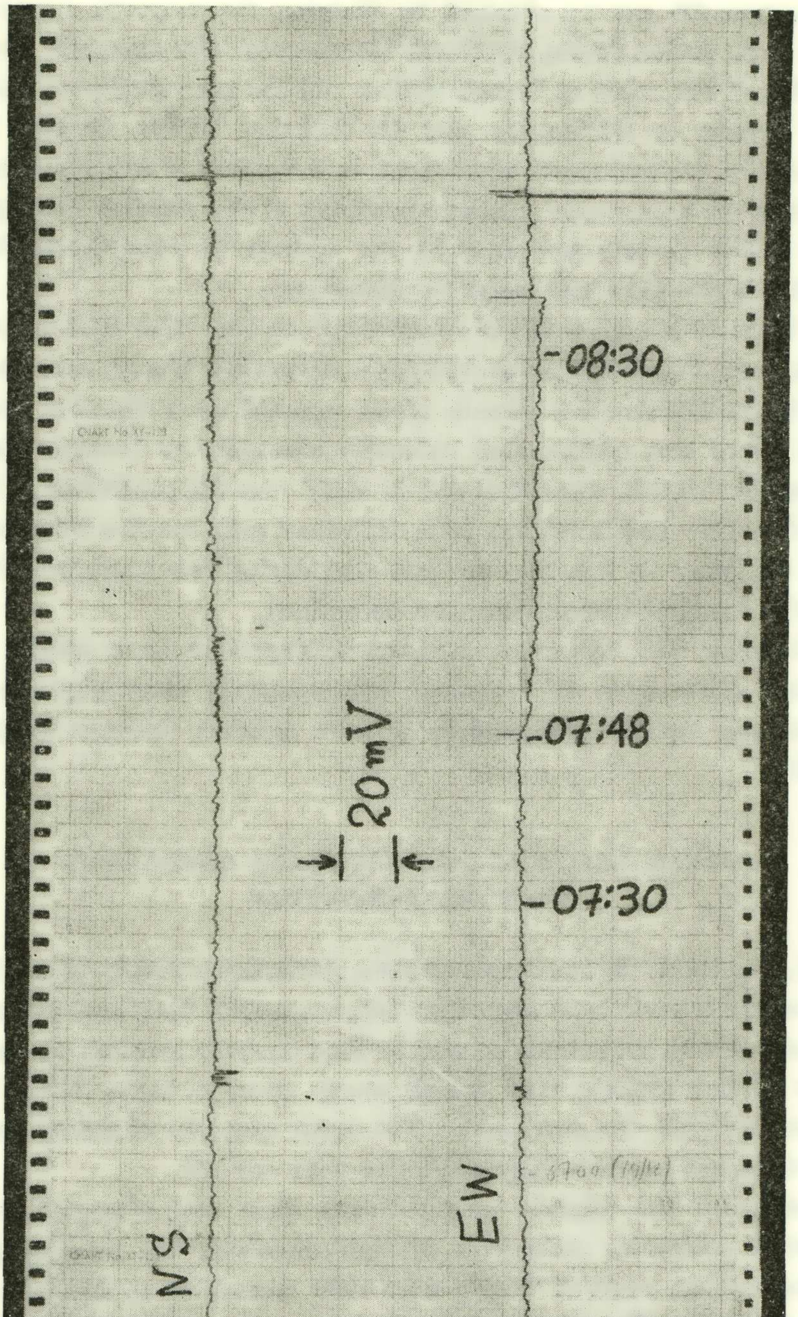

Fig. 7. Precursor ES of the 7 R earthquake of Dec. 19th 1981 collected at GLY station.

tity as a true ES can be checked by studying the magnetic recordings for the same period during which the ES occured. The magnetic recording of Fig. 8 was made at Penteli station and has been kindly forwarded to the authors by Dr Stavrou and Mr Caskabas (ΙΓΜΕ, Greece). The sensitivity of the horizontal component is 3.6 γ/mm. Further, magnetic recordings of appreciably higher sensitivity of the Swedish Geological Survey (SGS) — kindly forwarded to the authors by Prof. L. Erickson (Fig. 9) — do not show any magnetic disturbance.

Figure 10 is a clear ES of 13:06 GMT on Jan. 18th 1981 recorded on both lines (length 100 m) of Iraklion - station [**8**]. Almost seven hours later (19:56 GMT) a 7 R seismic event occured at a distance around 500 km from this station (the epicenter was close to Lemnos island). Simultaneous signals were observed in GLY — on the conditions of high noise (Fig. 11) — and in Megara (Fig. 12) where only one line was operating at the time. In Fig. 13 one sees that during the same period NO noticeable magnetic disturbance can be noticed.

Magnetic SSC - disturbances of the telluric field have usually features that differ from ES - signals: a) a relatively short duration and b) an abrupt increase followed by a more gradual decrease (Figs 14 and 15).

FORMER ELECTRIC MEASUREMENTS ASSOCIATED WITH EQ - PREDICTION

R. Coe (1971) [**9**] has reported some preliminary results from China that concern telluric field anomalies (approximately 2mV/km) preceding earthquakes with magnitude around 3. This anomaly consists of a small change in the electric field which starts about 5 hours before and recovers AFTER the earthquake. The latter property of this precursor effect definitely precludes any similarity with our ES.

In Japan the electric measurements have also attracted strong interest. A resistivity variometer of high sensitivity has been in operation about 60 km south of Tokyo since 1968. According to Rikitake and Yamazaki (1978) [**10**] a 67 Hz alternating current of 100 mA is sent into the ground — through two outer electrodes — and the potential difference

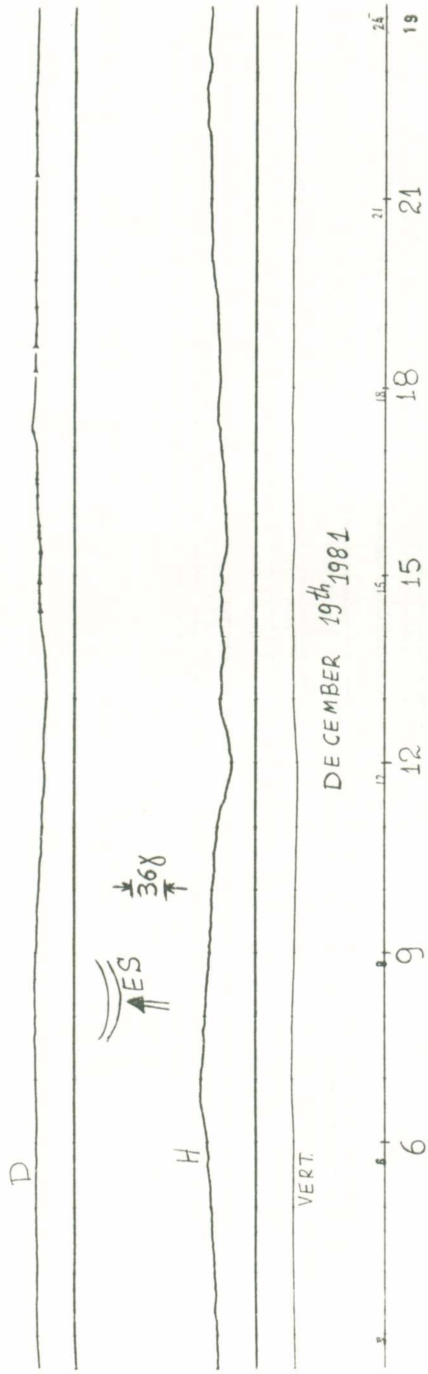

Fig. 8. Magnetic recordings on Dec. 19th 1981.

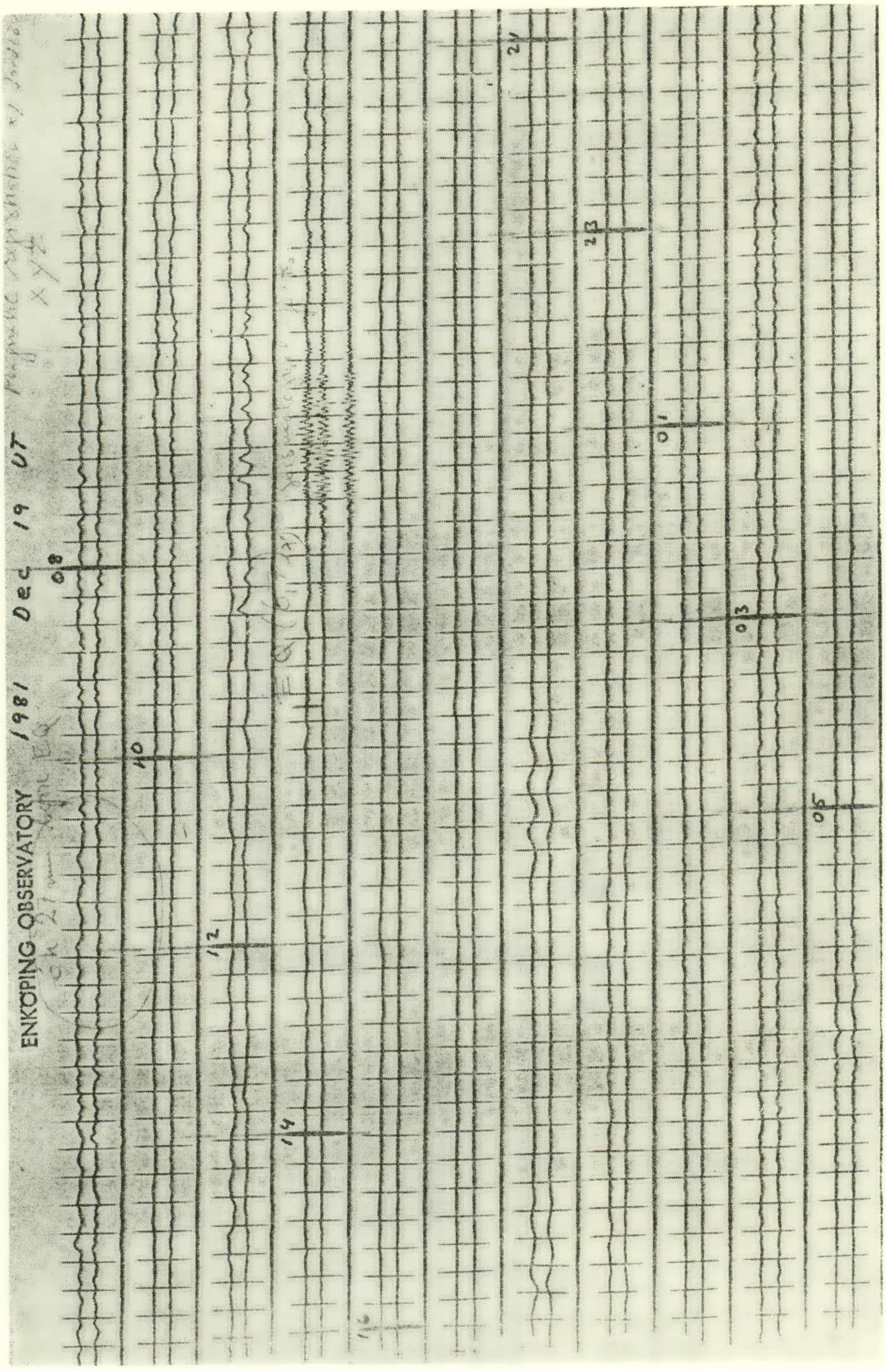

Fig. 9. Magnetic recordings on Dec. 19th 1981 at Uppsala.

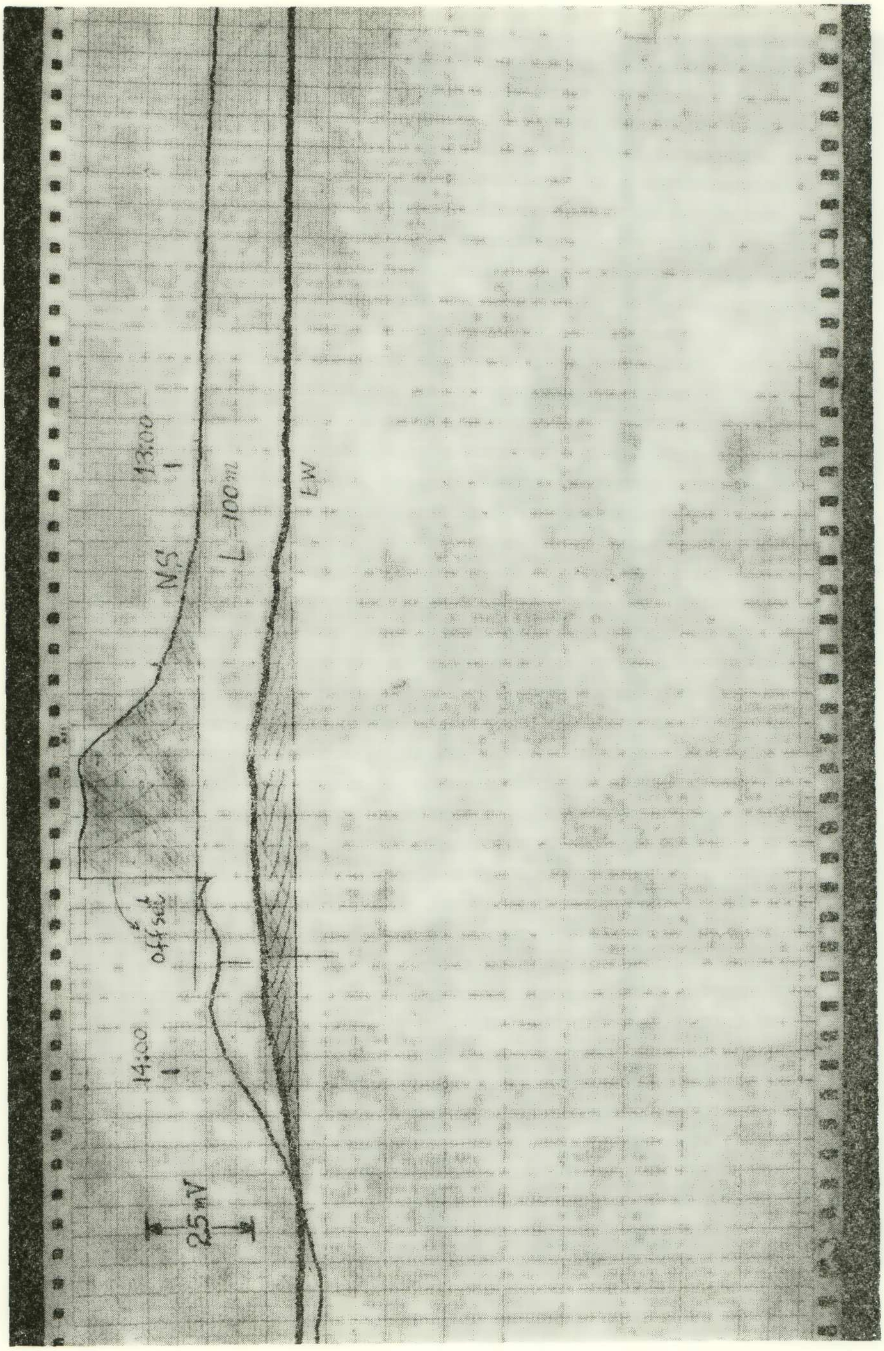

Fig. 10. Precursor ES of the 7 R earthquake on Jan. 18th 1982. (Iraklion station).

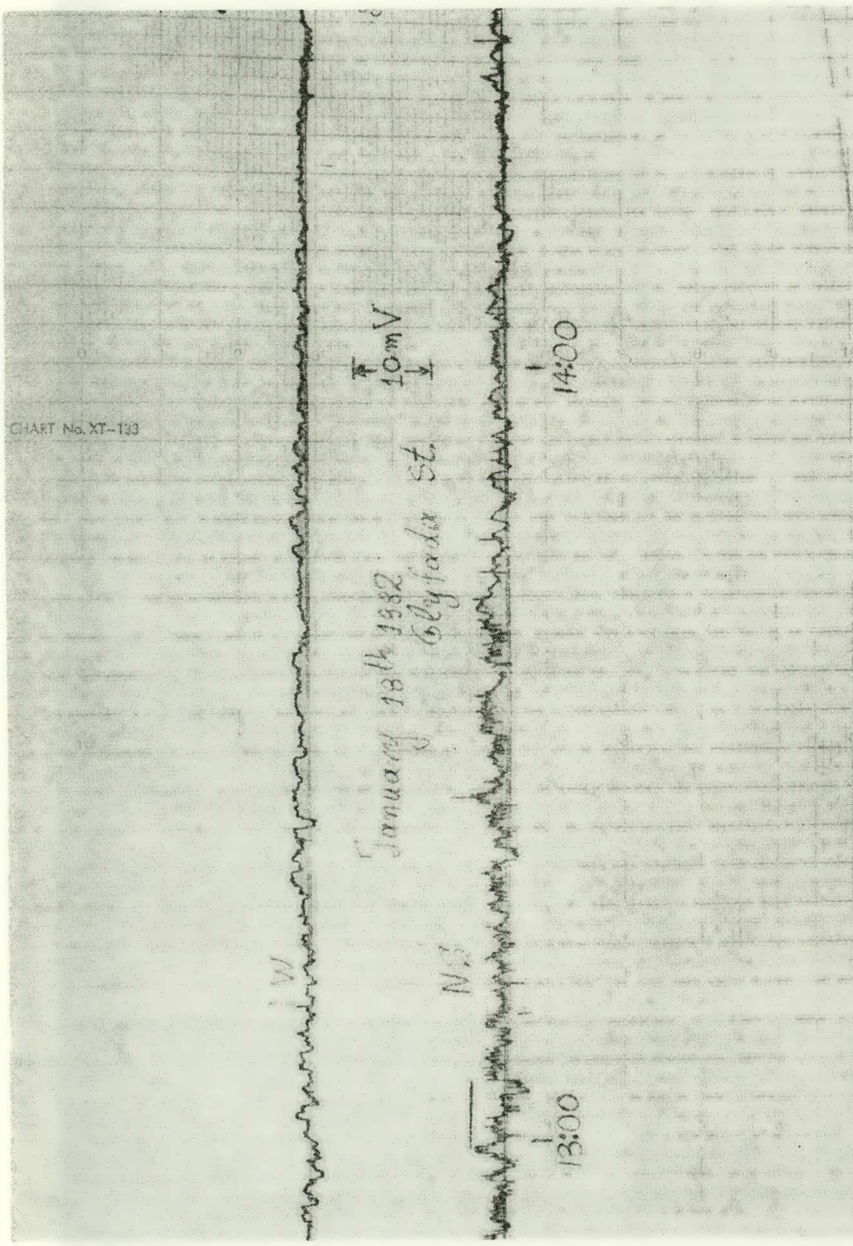

Fig. 11. Simultaneous ES with Fig. 10 collected at GLY - station.

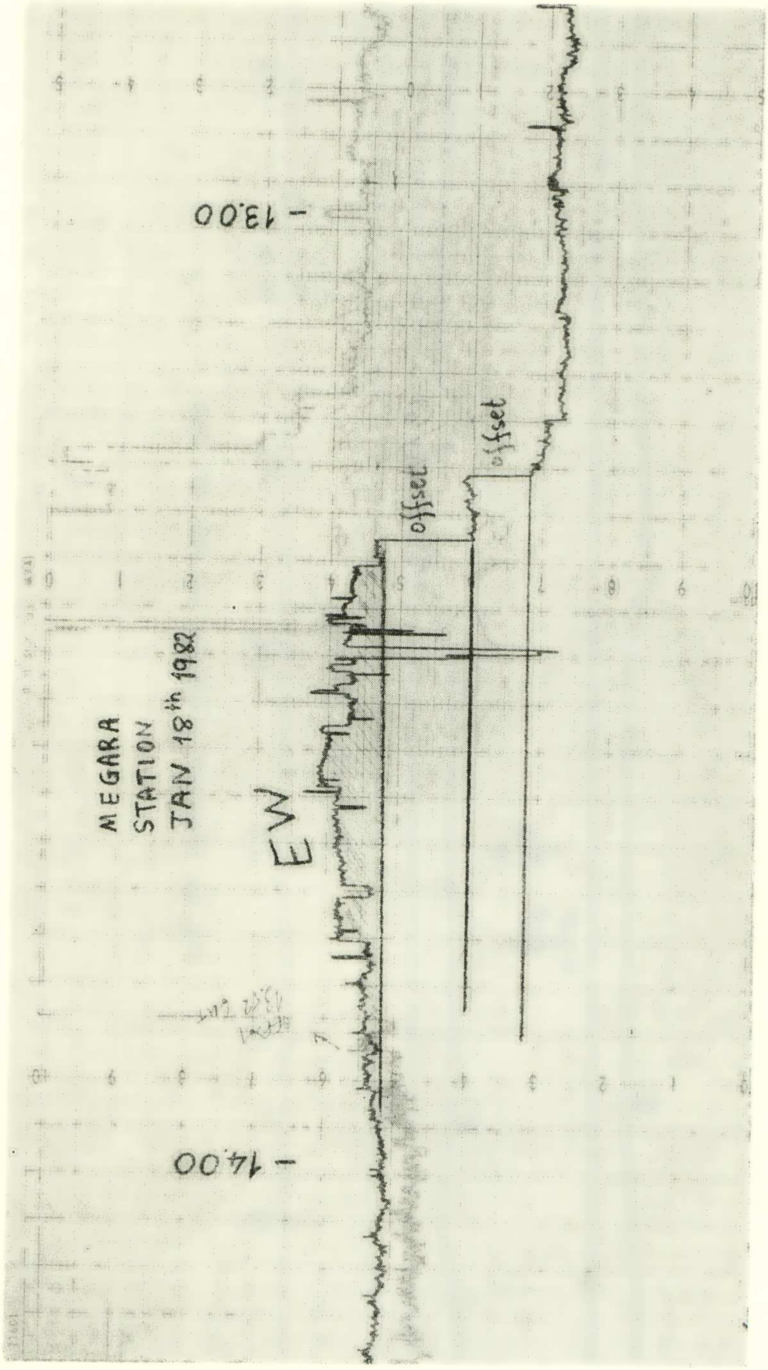

Fig. 12. Simultaneous ES with Fig. 10 collected at MEG - station.

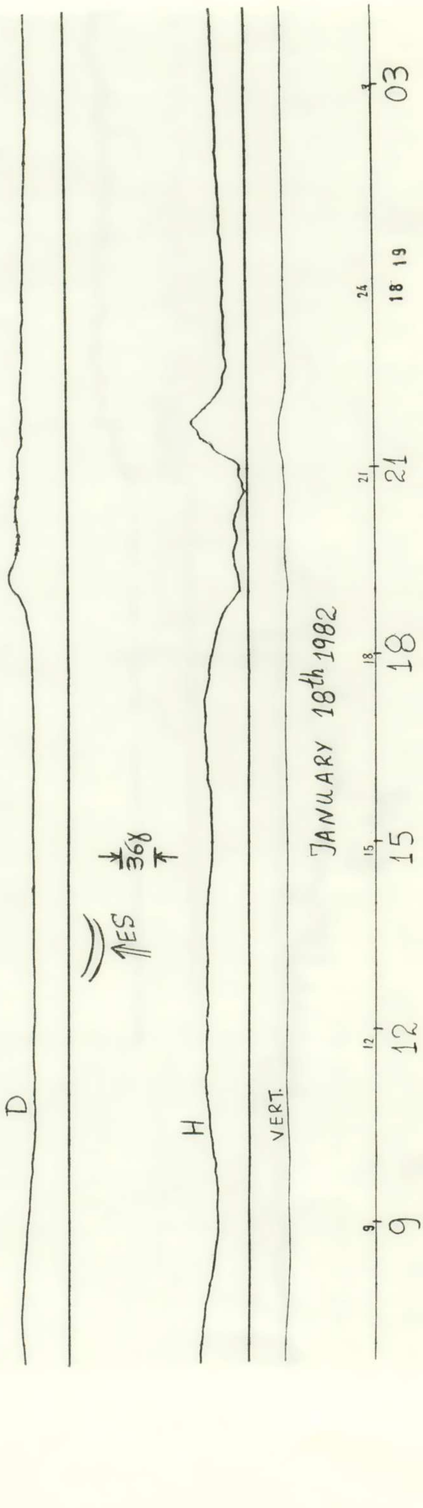

Fig. 13. Magnetic recordings on Jan. 18th 1982.

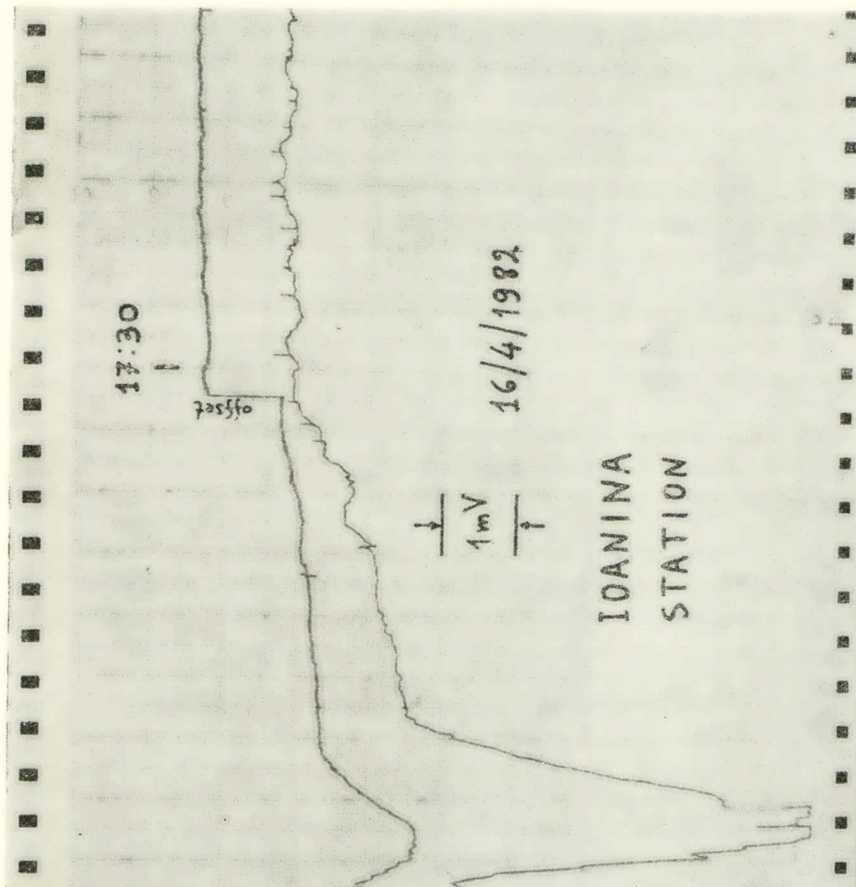

Fig. 14. Disturbance of the telluric field collected at IOA - station due to an SSC occured on April 16th 1982.

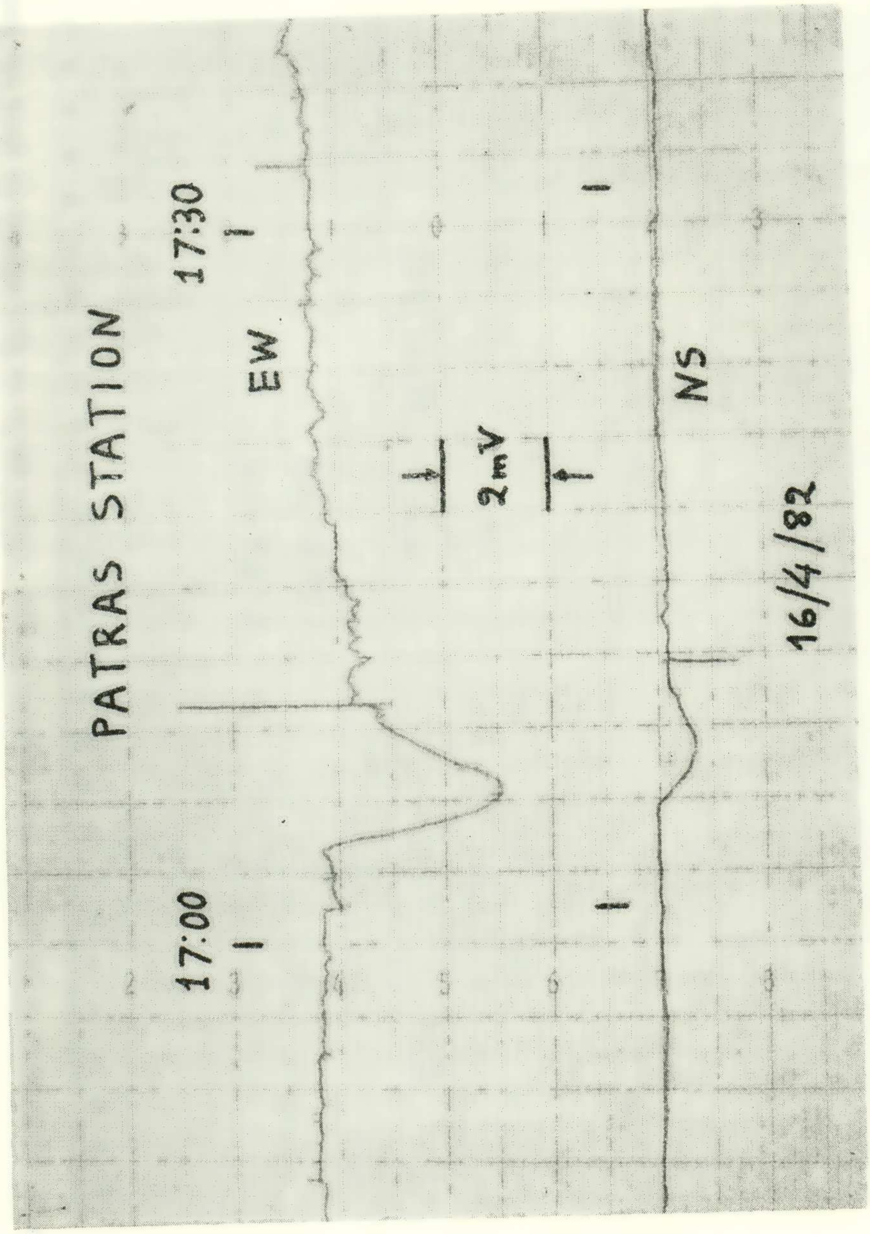

Fig. 15. The same as in Fig. 14 but collected at PAT station.

between two inner electrodes; this is a measure for the resistivity of the ground. In some earthquakes a co-seismic resistivity step

$$\left(\frac{\Delta\varrho}{\varrho} \approx 10^{-4}\right)$$

has been observed; further in 21 cases among the 30 examples — for which a coseismic step was recorded — a premonitory gradual decrease of the resistivity takes place a few hours before the main shock. Attention is drawn to the point that the Japanese's experimental technique [**10**] although allowing an accurate determination of a transient variation of the resistivity however cannot detect precursor ES of the type described here; this is due to the fact that our ES are transient changes of electric current during the emission of which the resistivity of the station does not have to change.

We turn now to the pioneering electric field measurements made in Kamchatka since 1966. In a serie of papers Sobolev and coworkers [**11**] have reported a number of electric precursors associated with strong earthquakes. However — it will become clear below — there are fundamental differences between the present procedure and that followed by the Russian group. These basic differences refer not only to the whole experimental set-up and the form of the obserwed signals but also to the way of analysing the experimental data and their interpretation. Our experience definitely shows that the Russian procedure cannot lead to the earthquake prediction as for as the time, the epicenter and the magnitude of an impending earthquake is concerned.

The electrical precursors mentioned by Sobolev (1975) consist of a change of the telluric field which starts several days before the EQ and recovers its value after (or at the time) of the shock; as Sobolev stated the absence of precursors of shorter duration can be accounted for because the frequency of observations was one hour. It is therefore obvious that the type of the ES described in this paper — having a typical duration of $^1/_2$ hour — would not have been observed by Sobolev [**11**]. It should be also stressed that our measurements did not show any evidence for the existence of Sobolev's several-days-precursor anomally even in the case of the strong events that occured in Greece on Dec. 19th 1981 and Jan. 18th 1982. In other words if the Sobolev's experimental procedure had been applied to Greece it is certainely sure that the ES depicted in Figs 7 and 10 would had not been observed. No attempt for the determination of the epicenter (x_0, y_0) and the magnitude M has been made by the Russian group.

In our procedure the determination of the parameters (x_0, y_0) and M is absolutely based on the quantity $\Delta V/R$ (l=constant) which is a measure of the current density in the direction of the electrodes of each line. The choice of this quantity is not fortuitous but is a result of theoretical aspects [**12**]. The quantity R is a result of a classical four pole measurement but usually it is not representative of the effective resistivity of the earth surrounding a station because of inhomogennities. We ascribe the errors in the determination of the epicenters to such an effect but this difficulty has been surpassed. By considering a large number of magnetotelluric observations — simultaneously recorded at our stations — we find for each line (of every station) its effective relative resistance in respect to the corresponding line of an isotropic station.

Acknowledgment: In the experiments with 5 stations Dr. G. Papaioannou, Mrs. E. Dologlou and Mrs. M. Varotsou participated both in the measurements and their evaluation.

ΠΕΡΙΛΗΨΙΣ

Πρόσκαιροι μεταβολαὶ τοῦ γηίνου ἠλεκτρικοῦ πεδίου τῆς τάξεως τῶν 0,5 ἕως 30 mV μετρούμεναι εἰς γραμμὰς μήκους 50 m ἐμφανίζονται περίπου 7 ὥρας πρὸ ἑκάστου σεισμοῦ. Δίδεται χρονοδιάγραμμα 32 ἠλεκτρικῶν σημάτων καὶ σεισμῶν παρατηρηθέντων κατὰ τὸ διάστημα 15 ἡμερῶν. Ἡ συνάρτησις συσχετίσεως παρουσιάζει μέγιστον διὰ διαφορᾶς χρόνον μεταξὺ $5^1/_2$ καὶ 11 ὡρῶν. Ἡ τεταγμένη τοῦ μεγίστου εἶναι 10 φορὰς μεγαλυτέρα τῶν στατιστικῶν διακυμάνσεων τοῦ ὑποστρώματος.

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