ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

ΣΥΝΕΔΡΙΑ ΤΗΣ 26ΗΣ ΝΟΕΜΒΡΙΟΥ 1981

ΠΡΟΕΔΡΙΑ ΙΩΑΝΝΟΥ Ν. ΚΑΡΜΙΡΗ

ΦΥΣΙΚΗ.—**Seven-hour precursors to earthquakes determined from telluric currents,** *by P. Varotsos - K. Alexopoulos - K. Nomicos**.
Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Καίσαρος Ἀλεξοπούλου.

ABSTRACT

In a former paper (Practika of Academy of Athens **56**, 277, 1981) precursor changes of the telluric currents were described; they occured a few minutes before each earthquake. Subsequently electric signals of another type have also been found; they occur about seven hours before the impending earthquake. Examples of their form and histogramms of the lead-time are given. A plot of the logarithm of the intensity of the signal (after reduction for the epicentral distance) and the magnitude is approximatively linear.

The prediction of earthquakes has been attempted by a large number of geophysical methods [**1** - **3**], none however has been able to forecast in an accurate way the time and other parameters (e.g. magnitude and epicenter) of the impending earthquake (EQ).

In a paper [**4**] published a few months ago sudden changes of the telluric current were described that preceded each earthquake by a few minutes. Since then, precursors of another type have been detected; [**5**] they appear around 7 hours before the EQ. For electrodes at a distance

* Π. ΒΑΡΩΤΣΟΥ - Κ. ΑΛΕΞΟΠΟΥΛΟΥ - Κ. ΝΟΜΙΚΟΥ, **Ἑπτάωρος προαναγγελία σεισμοῦ ἐκ μεταβολῆς τοῦ γεωρεύματος.**

of L = 50 m the change ΔV of the potential difference reached up to 50 mV depending on the epicentral distance, the resistance between the electrodes and the magnitude of the impending EQ. In the great majority of cases the change ΔV was always found to be a decrease of the potential difference. The duration d of these electric signals (ES) is usually between 2 and 50 minutes. As usual in telluric measurements two lines perpendicular to each other operated at each station. The resistance R between the electrodes was periodicaly measured. The present paper gives some of the more recent experimental results.

Signals, as they register on the recorder charts, have been photographed. Figures 1, 2 and 3 are examples of strong signals. As will be shown later in each case an EQ occured after 7 hours at epicenters lying very near the measuring station. Figures 4 and 5 correspond to EQ with larger epicentral distances. Disturbances of the telluric field of uncertain origin as in Figs. 6 and 7 can be recognised as ES only by investigating if simultaneous signals were observed at other stations. In Fig. 7 the noise changes during the signal. This has been noticed in many other cases. Figure 8 is a case recorded on both lines one of which had much less noise than the other. Many signals have abrupt edges (Fig. 9).

As mentioned the ES appear a number of hours before the occurence of an EQ. This han been ascertained in hundres of cases. As an example we plotted in Fig. 10 a time-chart of the signals detected at Glyfada (near Athens) during the period between Sept. 26^{th} and Oct. 4^{th}. On the same chart all EQ mentioned in the bulletin of Seismological Institute of Athens (usually larger than 2.9) have been marked. Further ten EQ recorded at Riolo near Patra, and Valsamata at Kefalonia (a) have been added as well as one recorded at Athens (b) and one at Alphiousa near Olympia (c). In order to make the correspondence of an ES to an EQ better visible, the time-scale of the latter has been shifted by 7 hours 20 minutes. A one to one correspondence of the events can be noticed. Due to the lead time not being exactly equal to 7 h 20 min the markings on the right and the left of the time-axis are randomly shifted in relation to each other. In two cases (Sept. 27^{th}, around 2100 and 2200 GMT) signals were not registered although EQ occured later. This is possibly explained from the fact that during this period of time the one pair of

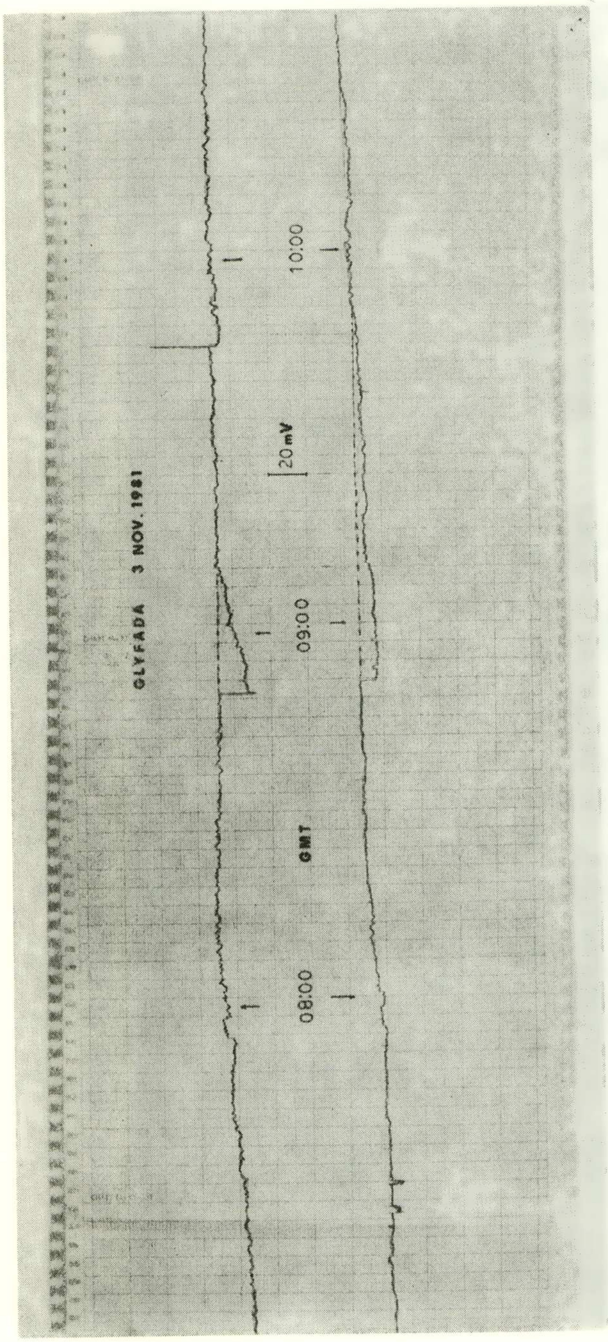

Fig. 1. Strong signal of Glyfada (near Athens) visible on two lines. An earthquake (3.1 R) occured on Nov. 7th 17:08 GMT at an epicentral distance of about 20 km.

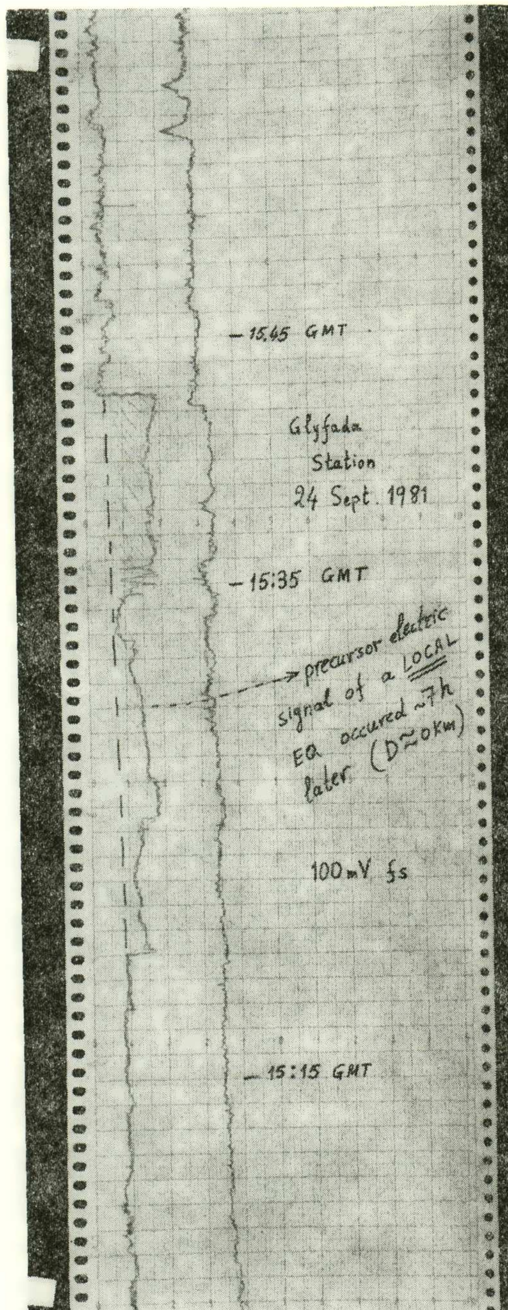

Fig. 2. Strong signal at Glyfada during relatively high noise. An earthquake (2 2 R) occured almost sevenhours later practically under the station.

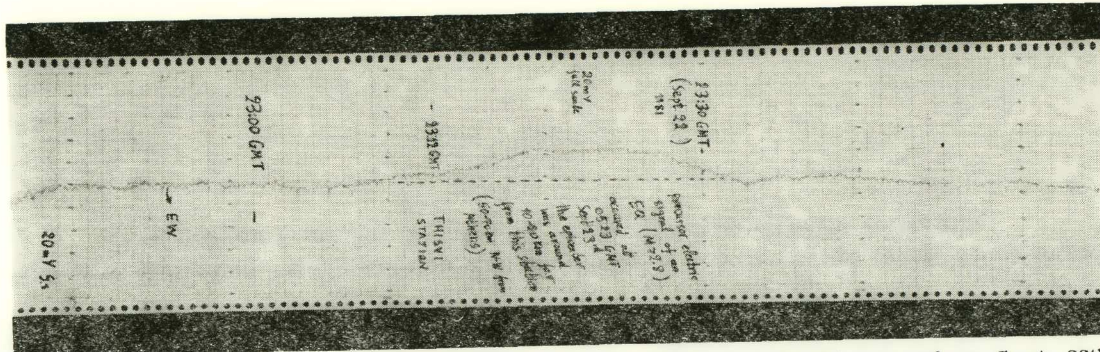

Fig. 3. Strong signal at Thisvi (near Thiva). An earthquake (2.8 R) occured on Sept. 23th 05 : 23 GMT practically under the station.

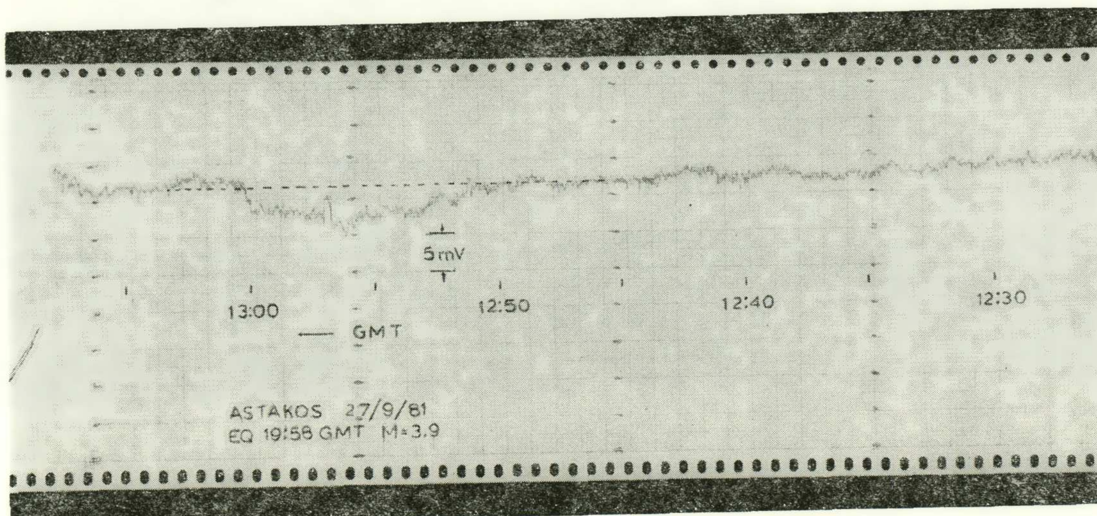

Fig. 4. Signal at Astakos. An earthquake (3.9 R) occured on Sept. 27th 19 : 58 GMT at an epicentral distance of 105 km.

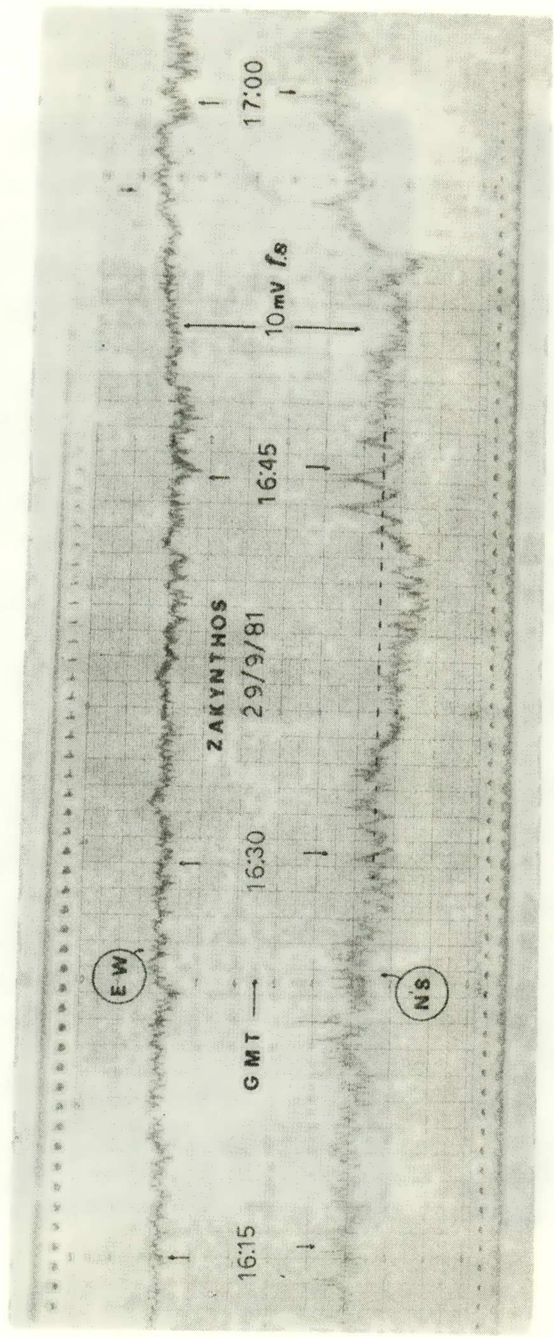

Fig. 5. Signal at Zakynthos visible only on one line during a period of high noise. An earthquake (3.3 R) occured on Sept. 30th 00:32 GMT at an epicentral distance at 222 km.

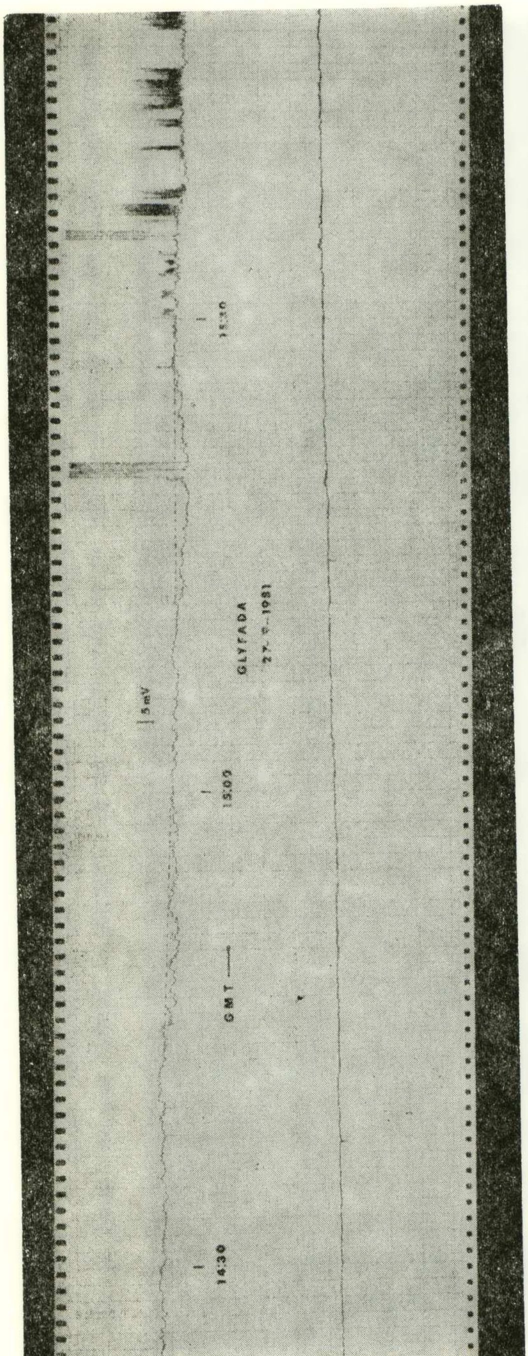

Fig. 6. Two consecutive signals at Glyfada during an atmospheric or magnetic storm. Earthquakes occured on Sept 27th 21 : 45 GMT (3.9 R) and 22 : 04 GMT (3.2 R) at epicentral distances of 45 and 55km.

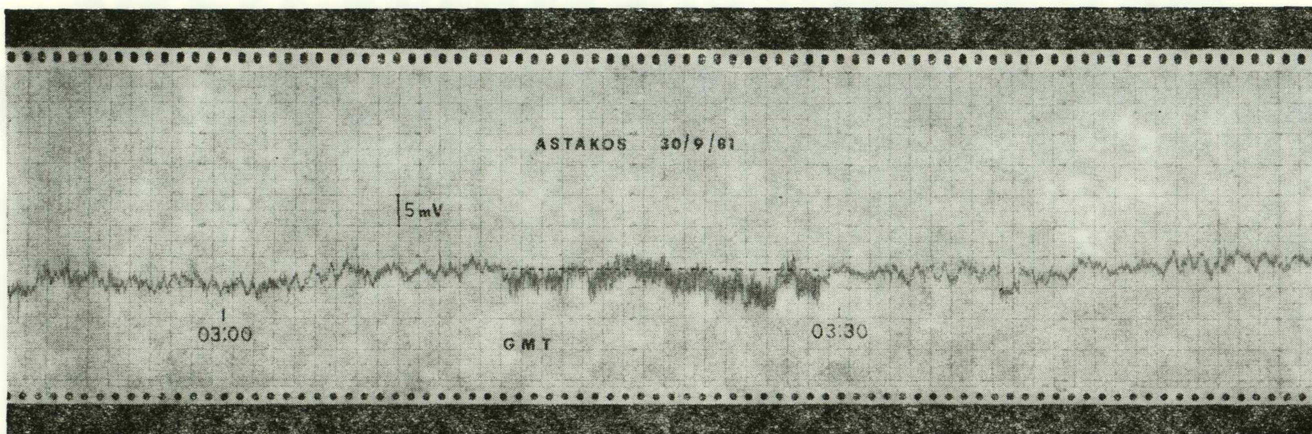

Fig. 7. Barely visible signal at Astakos. It was simultaneous to signals at other stations. Note the change of the noise during the signal. An earthquake occured on Sept. 30th 11 : 38 GMT.

electrodes (almost EW) was not working due to an instrumental problem; its should be stressed however that for these two EQ precursor electric signals were clearly recorder at other stations (e.g. at Nemea) which were simultaneously operated at the time. In some cases there must have

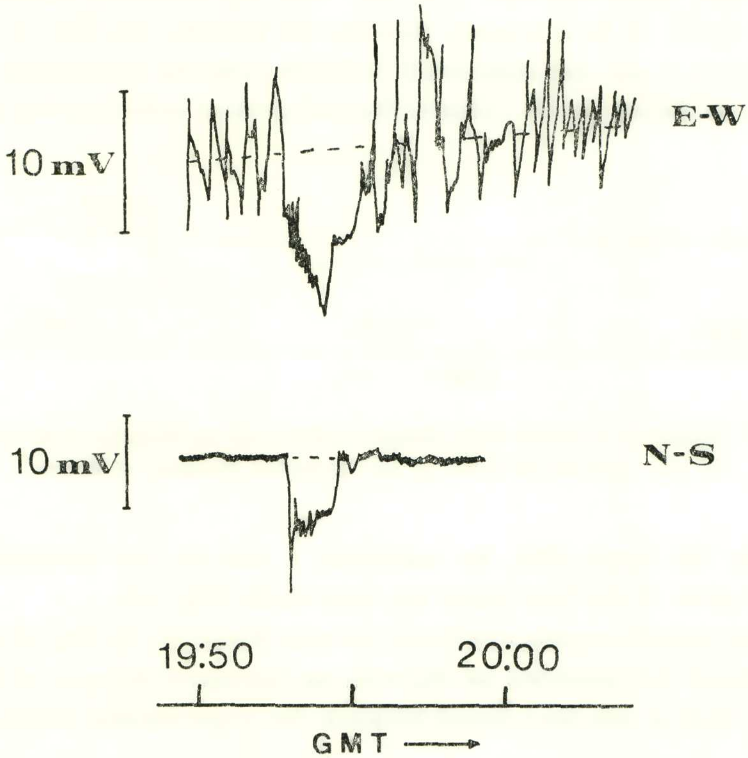

Fig. 8. Signals obtained at Vari (near Athens) on June 27th. Due to the vicinity of a high-tension line the noise on one of the two perpendicular lines is intense. An earthquake occured on June 28th 02:42 GMT with an epicentral distance of 50 km.

been an overlap of two ES or a double EQ. Extremely convincing is a 20 hours lack of signals on Sept. 29th during which no EQ occured. For a quantitative demonstration of the correlation between ES and EQ we have fed into a computer the trwe times of the signals and earthquakes displayed in Fig. 10 and computed the percentange of simultaneous events that occured within ± 1 hour for various time-differences $\Delta t = t_{EQ} - t_{ES}$ from -24 to $+24$ hours. In Fig. 11 we plot the degree of correlation. We notice a maximum which exceeds 100% because the density of the events is around 3 h/event and thus a seven hour occurence will include many overlaps. The fact that the maximum appears at a positive value of Δt is a proof that the ES precede the EQ. If the EQ marked a, b, c are not considered (without reducing the number of ES) the ratio of the maximum value to the background noise remains approx-

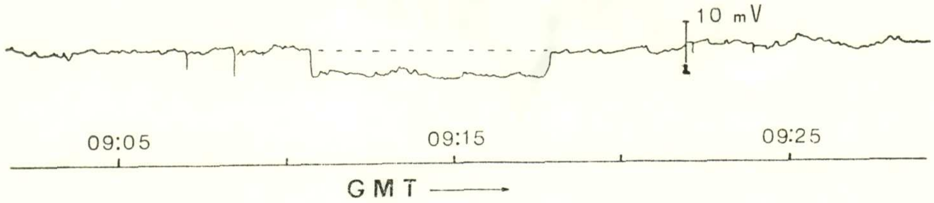

Fig. 9. Signal of Glyfada with abrupt borders. An earthquake (4 R) occured on Jan. 15th 99 : 00 GMT at an epicentral distance of 80 km.

imatively the same (99). By assuming a one to one correspondance a histogramm of the lead times has been made (Fig. 12).

The electric signals can travel for long distances. In Fig. 13 a signal is registered that preceded an EQ with an epicentral distance of 385 km.

A relation has been found between the experimental values of the maximum current intensity $I_{max} \left(\equiv \frac{\Delta V_{max}}{R} \right)$ and the magnitude. In Fig. 14 we plotted the logarithm of the reduced current $\log (I_{max} \cdot r)$ — where r is the epicentral distance — versus the surface magnitude M_s for a number of earthquakes. All the relevant data are given in Table I for various measuring stations. Cases where the values of I_{max} seemed to have a very large experimental error have been ommited. A fitting to a straight line gives a slope of 0.628 with a correlation factor 0.93 and an intercept -0.853. Two points have been left out of this fitting process: Point (5.1, 2.18) was measured while only a single electrode-pair was working so that the true value must be larger. The other point

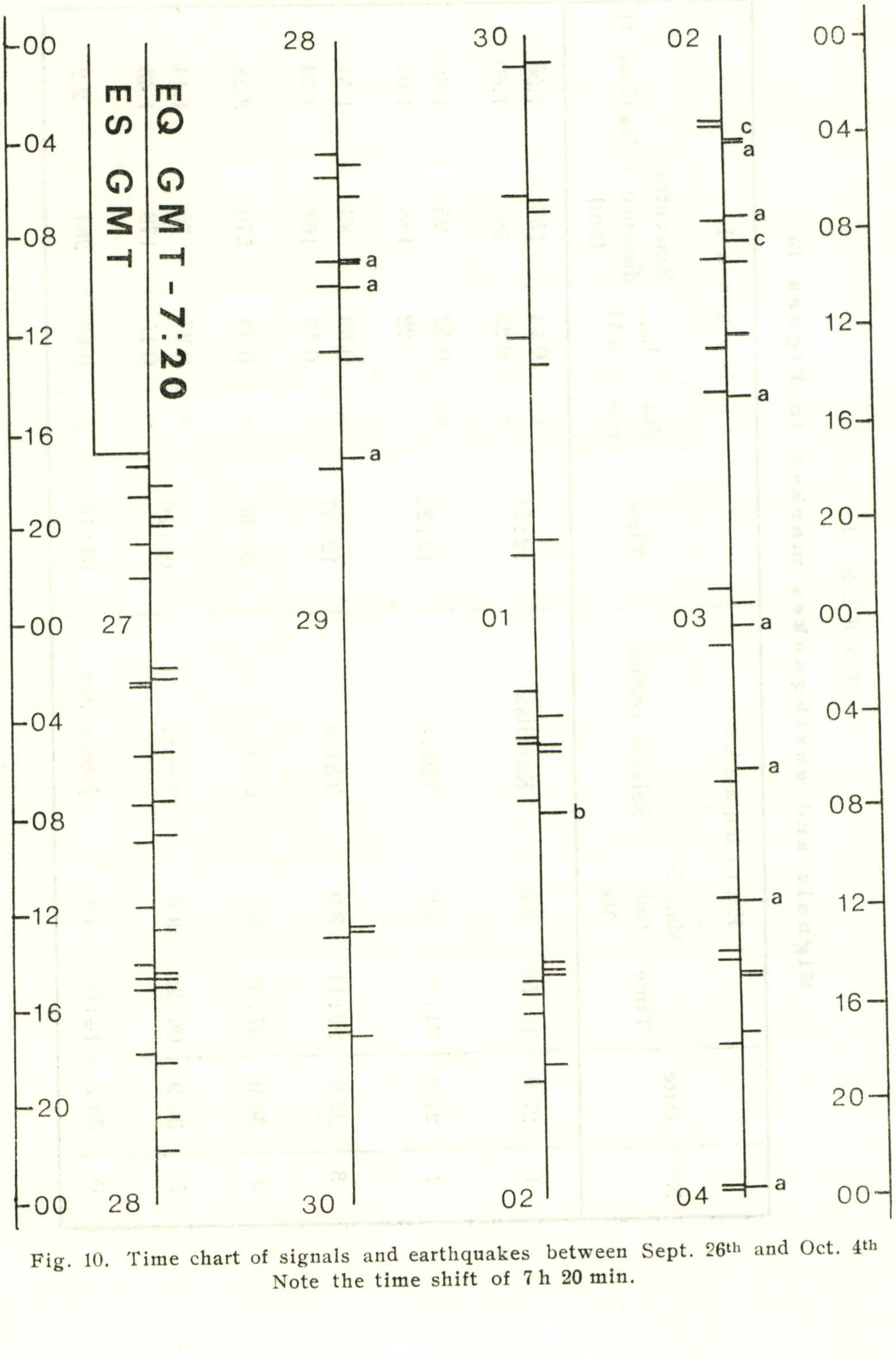

Fig. 10. Time chart of signals and earthquakes between Sept. 26th and Oct. 4th Note the time shift of 7 h 20 min.

TABLE I

Signals and earthquakes marked in Figure 14.

Nº	Date	Earthquake			Signal				
		Time	Magnitude Ms	Seismic region	Time	Station	I_{max} (μA)	Epicentral distance r (km)	$\log(I_{max} \cdot r)$
1	27/9	19:58	3.9	Karditsa	12:51	o ×	0.24 0.22	157 180	1.58 1.60
2	27/9	21:45	3 9	Thiva	13:22	o ×	0.52 0.22	95 188	1.69 1.61
3	29/9	20:11	3.9	Thiva	12:47	o ×	0.39 0.13	83 168	1.51 1.34
4	30/9	07:37	5.1	Crete	00:30	o	0.33	570	2.28
5	30/9	08:22	3.6	Thiva	01:16	o ×	0.37 0.15	75 178	1.44 1.43
6	30/9	14:00	4.8	Jonian Sea	07:15	o	0.56	287	2.2

Tableau I (continued)

N°	Date	Earthquake			Signal				
		Time	Magnitude Ms	Seismic region	Time	Station	I_{max} (μA)	Epicentral distance r (km)	$\log(I_{max} \cdot r)$
7	30/9	20 : 52	3.3	Tripolis	13 : 38	○ × △	0.37 0.29 0.105	34 68 141	1.1 1.29 1.17
8	1/10	11 : 23	3.8	Zakynthos	04 : 16	○ ×	0.21 0.42	162 65	1.53 1.44
9	1/10	21 : 43	3.8	Distomon	14 : 40	○ ×	0.83 0.18	45 126	1.57 1.36
10	2/10	01 : 52	3.2	95 km from Athens	(1/10) 19 : 15	□	0.23	95	1.34
11	3/10	06 : 49	4.1	Zakynthos	(2/10) 22 : 58	○ × △	0.59 0.55 0.7	146 56 84	1.93 1.50 1.77
12	14/10	10 : 59	5.1	295 from Athens	01 : 32	□	0.51	295	2.18
13	7/11	21 : 54	4.3	350 from Athens	13 : 28	□	0.3	350	2.00

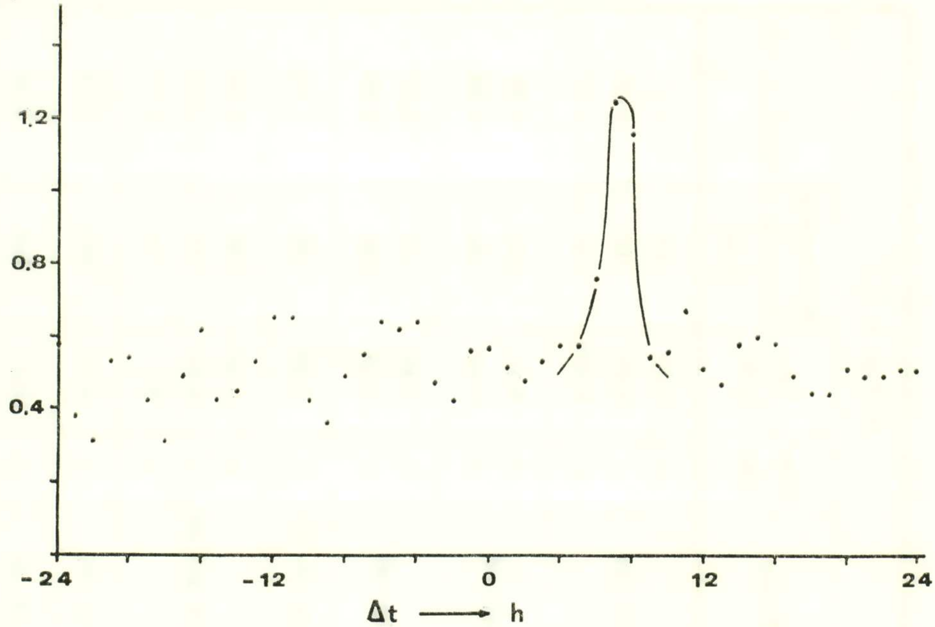

Fig. 11. Degree of correlation between signals and earthquakes in function of time-differences.

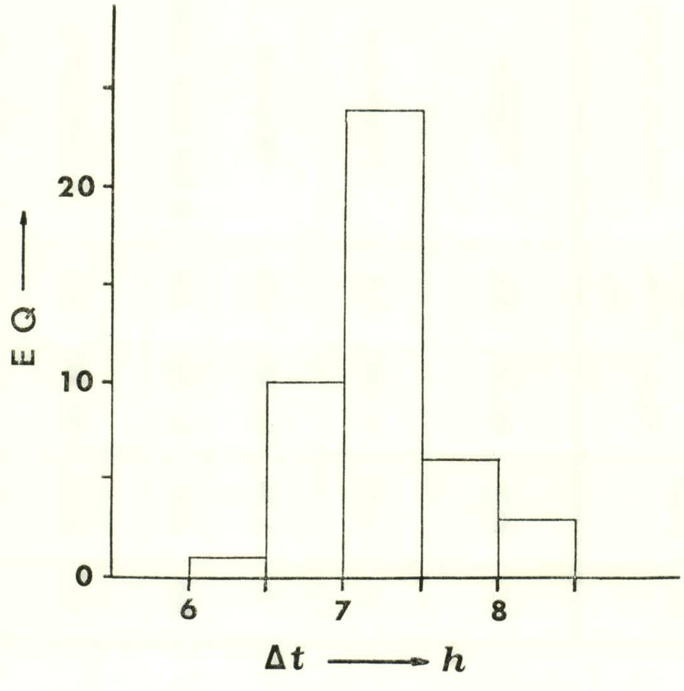

Fig. 12. Histogramm of lead times.

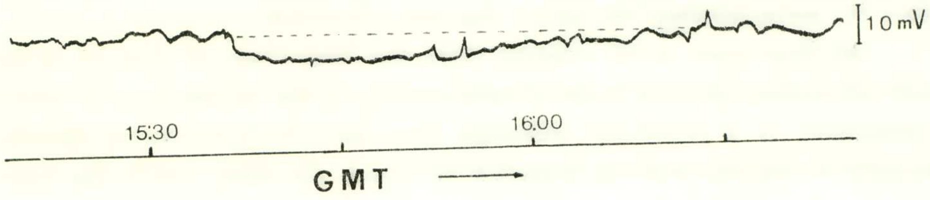

Fig. 13. Signal at Glyfada. An earthquake (5.3 R) occured on Sept. 13th 23 : 26 GMT, SW of Crete.

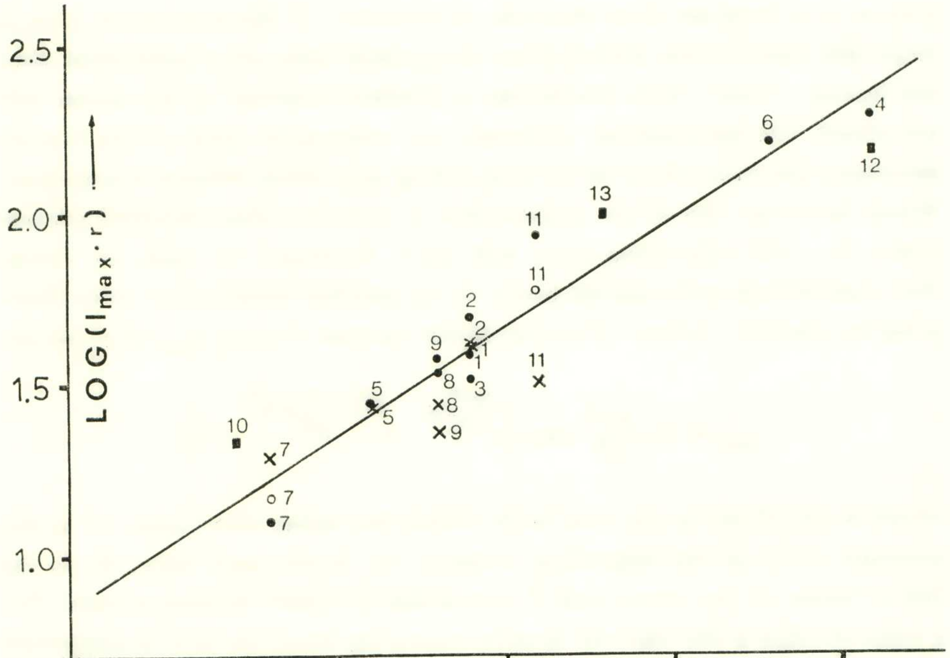

Fig. 14. Relation between reduced signal strength and magnitude. The symbols and numbers are explained in Table I.

(4.1, 1.5) is uncertain because a rainfall must have decreased the resistance R; unfortunately the latter was not measured.

An important point arising from the inspection of Fig. 14 is the self-consistency (within experimental error) of the values $I_{max} \cdot r$ which correspond to a given EQ although they have been measured simultaneously at various stations installed far apart. In other words the value of I_{max} decreases with epicentral distance $\left(I_{max} \sim \frac{1}{r}\right)$ and hence, on this basis, the epicenter of the impending EQ can be determined. Such applications are presented in the next paper.

A tentative explanation of the linear connection seen in Fig. 14 can be given by the thermodynamic theory of pressure - induced depolarisation of ionic crystals containing heterovalent impurities. The polarisation in a constant field depends on pressure. If the relaxation time is large the equilibrium polarisation is reached only after sufficient time has lapsed. Under these conditions a gradual increase of the stress will not effect the polarisation although the relaxation time of the dipoles decreases (provided that the corresponding migration volume is negative). When however the stress approaches a certain value, labelled critical stress P_{cr}, the relaxation time will have decreased to such an extent that equilibrium polarisation tends to be quickly established thus liberating an electric current. The maximum current density j_{max} is given by:

$$j_{max} = \Pi_o \frac{bv^m}{kT} \exp\left\{ e^{\frac{bv^m}{kT}\Delta t} \cdot e^{\frac{(P_r - P_o)\, v^m}{kT}} - 1 \right\}$$

where b ($\equiv$ dP/dt) is the rate with which the stress decreases, v^m is the absolute value of the migration volume, Δt is the lead time, P_o is the initial value of the stress and P_r the stress at which rupture occurs. For a cube of edge a the current density emerging from its face is connected to the total current I_{tot} being liberated by:

$$I_{tot} = j\,\alpha^2 \qquad (1)$$

Due to the fact that at every moment I_{max} is proportional to I_{tot}, EQ (1) can be written:

$$\log I_{max} = \text{const} + \log \alpha^2$$

But, as the magnitude is proportional to $\log \alpha^3$, a linear relation results between $\log I_{max}$ and M provided that the epicentral distance r is constant. Experimentally it was found that for a given EQ the quantity I_{max} is approximately proportional to 1/r; the linearity between $\log (I_{max}, r)$ and M seems therefore to be justified.

Acknowledgments. All seismological data were provided by Prof. J. Dracopoulos, Dr. N. Delimbasis and Mrs. E. Revelioti - Dologlou. Dr. G. Papaïoannou and Mrs. M. Varotsou participated in all the measurements. We express our sincere thanks to all of them.

ΠΕΡΙΛΗΨΙΣ

Πέραν τοῦ παλμοῦ τοῦ γεωρεύματος τοῦ ἐμφανιζομένου μερικὰ λεπτὰ πρὸ ἑνὸς σεισμοῦ (Πρακτικὰ Ἀκαδ. Ἀθηνῶν **56**, 277, 1981) ἀνευρέθη σῆμα προτρέχον κατὰ ἑπτὰ περίπου ὥρας. Δίδονται παραδείγματα τῆς μορφῆς τοῦ σήματος διὰ σεισμοὺς διαφόρων προελεύσεων καὶ ἀποστάσεων, ὡς καὶ ἱστόγραμμα τῶν καθυστερήσεων τοῦ σεισμοῦ ἔναντι τοῦ σήματος. Ἡ σχέσις μεταξὺ τοῦ μεγέθους τοῦ λογαρίθμου τοῦ σήματος καὶ τοῦ μεγέθους τοῦ σεισμοῦ εἶναι περίπου γραμμική.

REFERENCES

1. S. A. Fedotov - G. A. Sobolev - S. A. Boldyrev - A. A. Gusev - A. M. Kondratenko - O. V. Potapova - L. B. Slavina - V. D. Theophylaktov - A. A. Khramov and V. A. Shirokov, Tectonophysics **37**, 305 (1977).
2. Y. Honkura, Bull. Earthq. Res. Inst. (Japan) **53**, 931 (1978).
3. S. Koyama and Y. Honkura, Bull. Earthq. Res. Inst. (Japan) **53**, 939 (1978).
4. P. Varotsos - K. Alexopoulos and K. Nomicos, Praktika of the Academy of Athens **56**, 277 (1981).
5. P. Varotsos - K. Alexopoulos and K. Nomicos, Oslo Conference on Basement Tectonics, Aug. 1981.