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MEASUREMENTS OF GEOELECTRIC FIELD CHANGES IN THESSALY AND THEIR RELATION TO EARTHQUAKES

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ABSTRACT

Continuous measurements of the geoelectric and the geomagnetic field is performed in Southern Thessalia (Central Greece) with the purpose of identifying any anomalous change of the geoelectric field related to earthquakes. Observations were made on the residual telluric field, after removing the effect of the magnetic field, and 18 anomalous changes were observed during March and April 1993. The duration of these changes vary between 14 minutes and 5 hours. An attempt is made to correlate these signals with small local or larger regional earthquakes which occurred during this time period. The available data do not permit any conclusion for a causative relation between the geoelectric signals and the earthquakes. If, however, such relation exists, then, the electric signals are probably precursory phenomena of earthquakes and the precursory time varies between 1 and 70 hours.

ΣΥΝΟΨΗ

Συνεχής καταγραφή του γεωηλεκτρικού και του γεωμαγνητικού πεδίου υλοποιείται στην περιοχή της Νότιας Θεσσαλίας, με στόχο τον εντοπισμό ανώμαλων μεταβολών του γεωηλεκτρικού πεδίου που μπορούν να συσχετιστούν με σεισμούς. Οι παρατηρήσεις έγιναν στο υπολειπόμενο γεωηλεκτρικό πεδίο, αφού αφαιρέθηκαν οι επιδράσεις που προκαλούνται από τις μεταβολές του μαγνητικού πεδίου. 18 ανώμαλες μεταβολές παρατηρήθηκαν κατά την διάρκεια Μαρτίου-Απριλίου 1993. Η διάρκεια των μεταβολών αυτών ποικίλει από 14 λεπτά μέχρι 5 ώρες. Οι μεταβολές αυτές συσχετίστηκαν με μικρούς τοπικούς, και μεγαλύτερους μακρινούς σεισμούς που έγιναν σ' αυτή τη περίοδο. Τα διαθέσιμα δεδομένα δεν επέτρεψαν την εξαγωγή συμπεράσματος που θα αφορούσε αιτιατή σχέση μεταξύ γεωηλεκτρικών σημάτων και σεισμών. Εάν παρ' όλα αυτά υπάρχει τέτοια σχέση, τα γεωηλεκτρικά σήματα είναι πιθανότερο να θεωρηθούν σαν πρόδρομα φαινόμενα σεισμών, με χρόνο εμφάνισης πριν από τους σεισμούς μεταξύ 1 και 70 ωρών.

INTRODUCTION

Observations on the geoelectrical anomalies related to earthquakes were reported since the last decades of the 19th century (Yamazaki, 1977). One of the earlier but very interesting such research was that of Nagata (1944), who reported that earthquake swarms were observed after anomalous variations, showing a duration of several minutes up to several hours.

Since then, the behaviour of electric signals as earthquake precursors has been intensively studied (Fedotov et al, 1969; Myachkin et al., 1972; Sobolev, 1975; Raleigh et al., 1977; Ralchovsky and Komarov, 1988, 1989, 1993; Uyeshima

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et al, 1989; Ernest et al., 1993; Kawase et al., 1993; Arvidsson and Kulhanek, 1993).

Relevant research in Greece has been carried out during the last two decades (Ginis et al., 1982; Papazachos et al., 1988; Chouliaras and Rasmussen, 1988; Antonopoulos et al., 1993; Hadjioannou et al, 1993; Drakopoulos et al, 1993; Thanassoulas and Tselentis, 1993). The so called VAN group published a series of papers in this subject (Varotsos et al., 1982; Varotsos et al., 1983; Varotsos and Alexopoulos, 1984a,b; Varotsos et al., 1993 a,b, among others) and claimed that all three parameters of earthquakes (epicenter, time, magnitude) can be predicted by the use of such signals. However, the opinions of other scientists for this claim vary very widely (Mulargia and Gasperini, 1992; Maron et al., 1993; Hamada K., 1993).

During the last two years, monitoring of the triaxial magnetic field and the two perpendicular components of the electric field is carried out by the Geophysical Laboratory of the Aristotle University of Thessaloniki, in the southern-eastern margins of Thessaly basin. The induction effects caused by the variation of the magnetic field were removed, using a custom built software. An attempt is made in the present paper to examine the probable correlation of the residual electric field with seismic events which occurred during the specific time period when the measurements are referred (March-April 1993).

EQUIPMENT USED

The southern part of Thessaly is seismically one of the most active regions in Greece and surrounding area (Papazachos and Papazachou, 1989). For this reason, the area of the Village "NERAIDA", near Farsala of southern Thessaly, was chosen to install the magnetotelluric station (Fig. 1).In this area, a

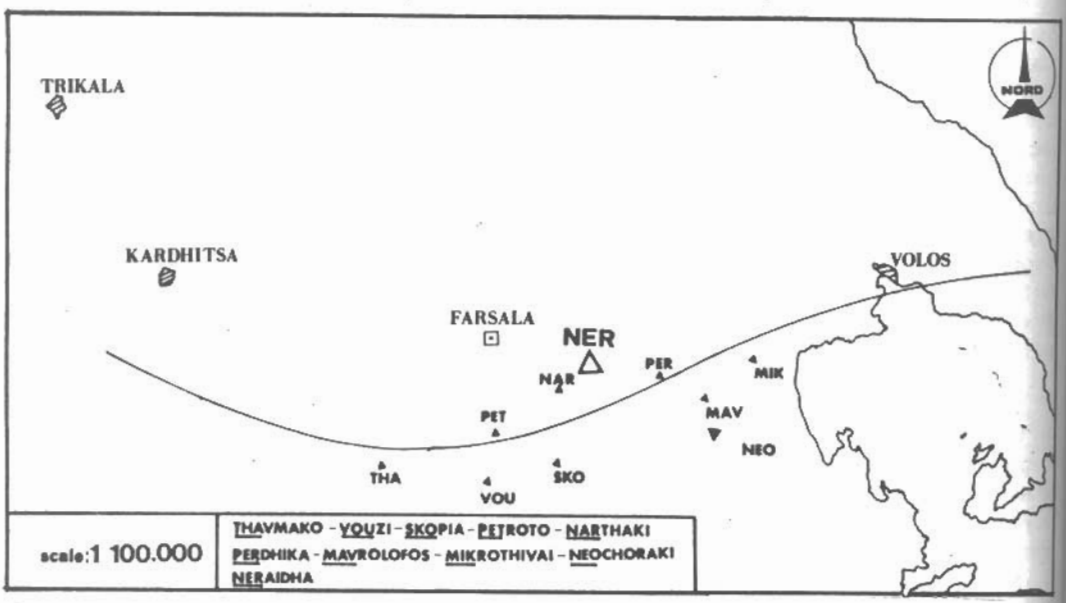

Fig. 1: Location map of the magnetotelluric station of "NERAIDA" in the south margins of Thessaly basin. The station is named as NER.

Σχ. 1: Χάρτης της θέσης του μαγνητοτελλουρικού σταθμού της Νεραΐδας, στο νότιο τμήμα της λεκάνης της Θεσσαλίας. Ο σταθμός είναι σημειωμένος με το όνομα NER.

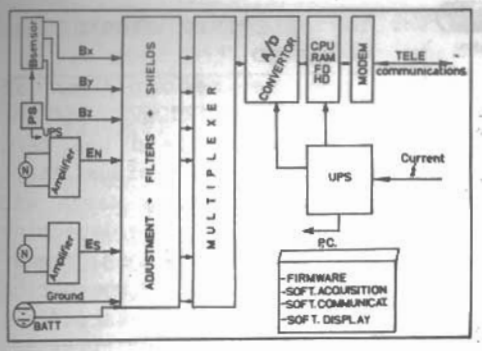

Fig. 2: Sketch showing the logical diagram of the monitoring system installed to Neraida station.

Σχ. 2: Λογικό διάγραμμα του καταγραφικού συστήματος που εγκαταστάθηκε.

specific site was selected to avoid undesired noises i.e. to avoid human activity and in particular any industrial interference.

The equipment, which is used at the station, consists of a triaxial magnetometer (Bartigton) and of a recording system, where the measurements of the telluric lines are also stored. The recording system was built by ILPRA SA (Electronic Realisations SA) after the responsibility of the Electrician Engineer Dr George Sergiadis. Figure 2 shows the sketch diagram of the whole system.

Two pairs of non-polarised electrodes Cu-CuSO4 have been used to measure the two horizontal telluric components. The first pair is along the North-South direction and the second one along the East-West. The distance between the probes on each pair is 50 meters. The two pairs of electrodes and the magnetic sensor are buried at a distance of 150 meters away from the station in order to avoid influences on the measurements. The sampling of the fields is with a frequency of 0.03 Hz and the records are stored in a hard disk of a local PC in separate files every 3 hours. The data correlated with earthquakes at this paper refer to the time period of March and April 1993. Totally 480 files approximately were interpreted.

REMOVAL OF INDUCED ELECTRIC FIELD

Besides the man made effects on the telluric lines, the influence of the abnormal changes of the magnetic field cause significant changes on the electric field. Thus, these induced effects must be computed and removed from the electric measurements.

The impedance tensor elements from measured data are estimated using a computer program developed by the authors and based on Chouliaras and Rasmussen (1987).

Initially, the linear trends are removed and then the time series are Fourier transformed. The cross and auto spectra are calculated within each band of frequencies and then the impedance tensor elements are calculated from each band. The estimated impedance tensor elements are input data to a subroutine which computes the differences ΔEx, ΔEy and ΔHz between the observed electric and vertical magnetic components and those predicted by the horizontal magnetic field components. E and H are the telluric and the magnetic components, respectively, while the subscripts x and y denote the NS and EW directions.

The computation of the residual field is performed using the relations:

$$\Delta Ex = Ex - ZxxHx - ZxyHy$$
$$\Delta Ey = Ey - ZyxHx - ZyyHy$$
$$\Delta Hz = Hz - AHx - BHy$$

These residuals were finally transformed into the time domain and plotted versus time. Figure 3 shows three examples of raw and reduced data.

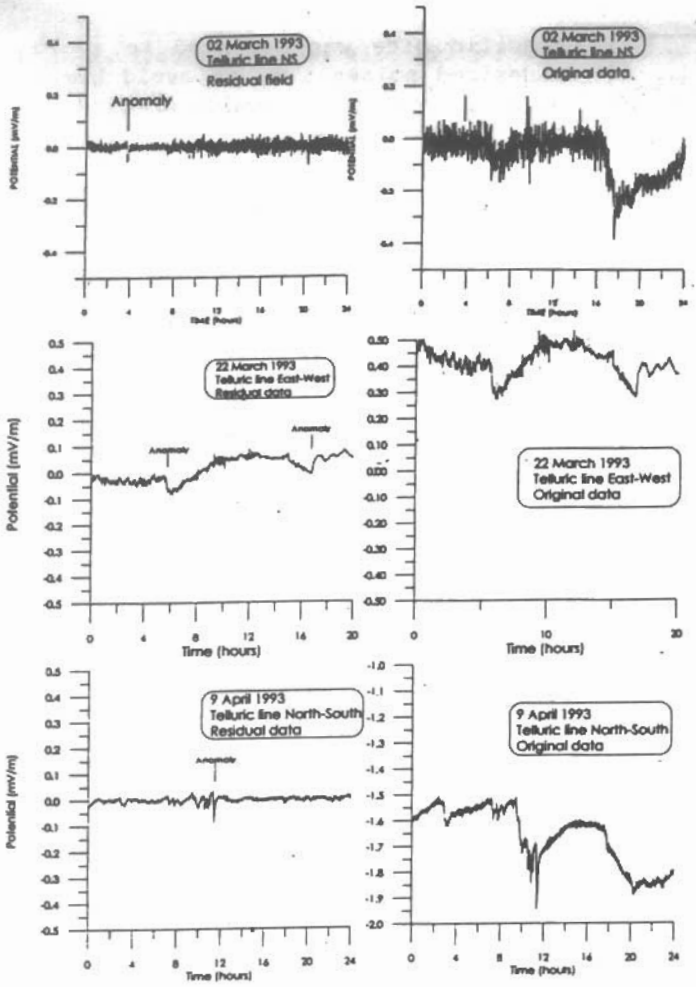

Fig. 3: Raw and interpreted data, showing three telluric anomalies.

Σχ. 3: Καταγραφές (επεξεργασμένες και μη), όπου σημειώνονται τρεις γεωηλεκτρικές ανωμαλίες.

ELECTRIC SIGNALS OBSERVED

The recognition of anomalous changes of the electric field has been made on the residual field plots. During March and April 1993, the detecting instruments were in operation for the time period 1.3.93-25.3.93 and 9.4.93-30.4.93. During these periods, eighteen (18) anomalous changes of the electric field were observed. The records of three such signals are shown in figures where the original records (raw data) and the residual field are presented. The characteristics of these 18 signals are described in table (I).

It is observed that the amplitude of the electric signals varies between 0.01 and 0.17 mV/m and its duration between 14 minutes and about 5 hours.

EARTHQUAKES IN GREECE DURING THE PERIOD OF ELECTRIC SIGNAL DETECTION

Earthquakes of several magnitudes occurred in the area of Greece (34° N-42°N, 19°E-27°E) during the period of the electric signal detection in Neraida. Many of these earthquakes are very small or are located in a relatively large distance from Neraida and therefore cannot probably cause any detectable signal in Neraida. For this reason, only the following earthquakes were considered in the present study.

A: Events with MS≥3.5 and Δ<160 km.

B: Events with MS≥4.0 and Δ<330 km.

C: Events with MS≥4.7 in the area of Greece

where MS is the surface wave magnitude and Δ the distance from Neraida.

There are 31 such earthquakes for which some characteristics are given on table II.

This information is based on the monthly bulletin of the Geophysical Laboratory of the Aristotle University of Thessaloniki and on the preliminary listings of the Seismological Institute of the National Observatory of Athens. Figure (4) shows a map where the epicenters of these 31 earthquakes are shown. Symbols of

TABLE I: Anomalous changes of the electric field during the time period March-April 1993 and their characteristics.

DATE	COMPONENT	TIME	AMPLITUDE (mV/m)	DURATION
02.03.93	N-S	06h 14'	0.07	00h 14'
03.03.93	N-S	20h 01'	0.08	02h 40'
05.03.93	N-S	17h 53'	0.07	01h 17'
08.03.93	E-W	21h 27'	0.07	00h 21'
11.03.93	E-W	04h 34'	0.17	05h 17'
17.03.93	E-W	05h 31'	0.08	11h 46'
22.03.93	E-W	07h 00'	0.07	02h 42'
22.03.93	E-W	16h 17'	0.07	02h 07'
09.04.93	N-S	09h 42'	0.11	02h 19'
10.04.93	N-S	01h 26'	0.07	02h 08'
16.04.93	E-W	07h 07'	0.06	01h 46'
17.04.93	N-S	07h 54'	0.06	00h 37'
18.04.93	N-S	14h 13'	0.01	01h 04'
19.04.93	E-W	21h 28'	0.06	01h 04'
21.04.93	N-S	18h 26'	0.02	00h 21'
22.04.93	E-W	22h 58'	0.05	00h 41'
26.04.93	E-W	03h 44'	0.03	00h 22'
27.04.93	E-W	12h 43'	0.09	03h 12'

Table II: List of earthquakes occurred during the recording period.

DATE	LOCAL TIME	LATITUDE	LONGITUDE	Ms
01/03/93	23:11	38.14	23.23	3.7
02/03/93	09:12	39.79	25.55	4.1
04/03/93	13:28	40.39	21.59	4.0
05/03/93	08:55	37.12	21.48	5.3
05/03/93	15:20	38.95	21.83	3.8
07/03/93	10:34	38.27	21.80	3.6
09/03/93	08:10	37.87	21.04	4.4
09/03/93	10:57	37.78	20.82	4.0
09/03/93	15:52	37.85	20.85	4.0
11/03/93	00:44	37.78	20.94	4.2
14/03/93	04:20	38.12	22.38	3.8
14/03/93	04:33	39.20	24.10	3.8
18/03/93	03:36	39.19	23.66	3.7
18/03/93	09:51	40.38	26.88	4.8
18/03/93	17:47	38.33	22.28	5.5
24/03/93	16:44	37.78	21.09	3.9
25/03/93	07:44	37.58	21.35	4.5
26/03/93	13:45	37.57	21.40	4.9
07/04/93	14:15	34.27	25.25	4.8
11/04/93	15:25	38.54	23.84	3.7
12/04/93	03:23	37.91	20.91	4.1
12/04/93	17:58	37.66	21.16	4.2
13/04/93	23:51	39.20	22.18	3.6
23/04/93	02:52	35.39	25.89	4.8
23/04/93	07:22	37.63	22.16	4.1
24/04/93	08:20	38.77	23.57	3.9
26/04/93	20:54	37.57	20.51	4.1
27/04/93	21:22	38.28	23.99	4.2
29/04/93	09:54	37.69	21.41	4.8
30/04/93	00:12	38.74	22.58	4.2
30/04/93	07:50	39.03	21.40	3.8

Fig.4: Location of the epicenteres of the earthquakes occurred in the recording time period.

Σχ. 4: Χωροθέτηση των επικέντρων των σεισμών που έγιναν κατά το διάστημα καταγραφής των σημάτων.

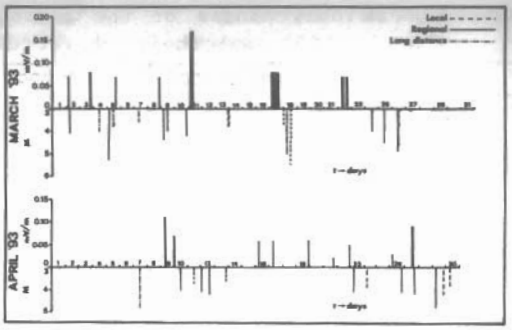

Fig 5: Correlation between electrical anomalies and earthquakes, during the time period of March-April 1993.

Σχ. 5: Συσχέτιση γεωηλεκτρικών ανωμαλιών και σεισμών για το χρονικό διάστημα Μαρτίου-Απριλίου 1993.

three sizes are used to denote three magnitude sizes (3.5-3.9, 4.0-4.6, 4.7-5.5). The two circles with center at the station in Neraida and radians 160 Km and 330 Km are also shown in this figure.

RELATION OF ELECTRICAL SIGNALS AND EARTHQUAKES

Figure (5) shows the variation of the amplitudes of the electrical signal (table I) and the magnitudes of the earthquakes (table II) with respect to their time of occurrence. We cannot decide from this plot whether the signals precede or follow the earthquakes. For this reason we make both assumptions to see the results.

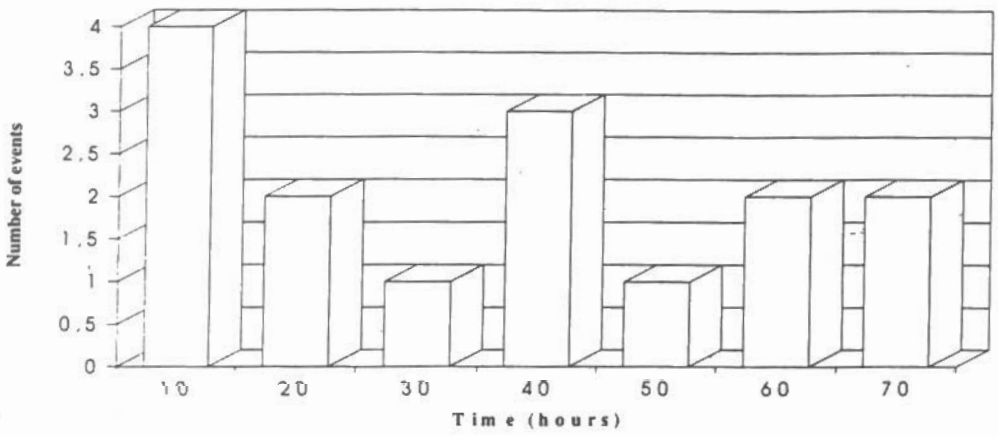

Fig. 6: Frequency diagram of lag times (signals preceding earthquakes).
Σχ. 6: Διάγραμμα συχνοτήτων των χρόνων υστέρησης (σήματα μετά από σεισμούς)

According to the first hypothesis, an electric signal which occurred in the time interval between two earthquakes is related to the second earthquake. If two or more signals are between two earthquakes the one which is closer (in time) to the second earthquake is related to this earthquake.

Table III gives information on these signals and on the corresponding earthquakes which follow these electric signals. The last column of the table gives the lag time. Figure (6) shows the frequency diagram of this time lag. It is observed that this time lag is rather randomly distributed between 1 and 70 hours.

According to the second hypothesis, an electric signal which occurred between two earthquakes is related to the first earthquake. If two or more signals are between two earthquakes the one which is closer (in time) to the first earthquake is related to this earthquake. The same procedure was followed as in the first case and it was found again an almost random

Table III: Correlation between electric anomalies and earthquakes, assuming that the signal appears before an earthquake.

a/a	DATE	TIME	DATE	TIME	REGION	LAG TIME
1	02.03.93	06:14	2.3.93	09:12	East Limnos	-03h 08'
2	03.03.93	20:01	04.03.93	13:28	Amynteo	-17h 28'
3	05.03.93	17:53	07.03.93	10:34	Nafpactos	-40h 41'
4	08.03.93	21h 27'	9.3.93	08:10	Killini	-10h 43'
5	11.03.93	04:34	14.03.93	04:20	W. Kiato	-71h 46'
			14.03.93	04:33	Sporades	-71h 59'
6	17.03.93	5h 31'	18.3.93	03:36	N. Sporades	-22h 05'
			18.3.93	17:47	Itea	-36h 16'
7	22.03.93	07:00	24.03.93	16:44	Killini	-57h 44'
8	09.04.93	09:42	11.04.93	15:25	C. Evia	-59h 43'
9	10.04.93	01:26	12.04.93	03:23	SW Kalavrita	-49h 57'
10	21.04.93	18:26	23.04.93	02:52	C Peloponesos	-32h 26'
11	22.04.93	22h 58'	23.4.93	07:22	N. Tripoli	-08h 24'
12	26.04.93	03h 44'	26.4.93	20:54	Zakinthos	-17h 10'
13	27.04.93	12h 43'	27.4.93	21:22	C. Evia	-08h 39'

distribution of the lag time but this time is distributed between 5 and 123 hours. Figure (7) shows the frequency diagrams of the lag times for this case.

Amplitudes and duration of the signals were plotted against magnitudes for both cases but no significant correlation was observed.

DISCUSSION AND CONCLUSION

The hypothesis that the observed electric signals precede earthquakes and that in this case the lag time is up to 70 hours is compatible with current theories for a stage of physical preparation at the focal region of an earthquake before its generation. On the contrary, it is difficult to have a physical explanations for signals which occur up to 130 fours after earthquakes and are related to the generation process of these earthquakes.

Therefore we can conclude that if the observed in the present study electric signals (table I) are related to the earthquakes (table II), it is more probable that these signals are precursory phenomena. The problem of causative relation between these signals and the earthquakes cannot be solved by the information available at present.

Simultaneous recording of such electric signals at different places can

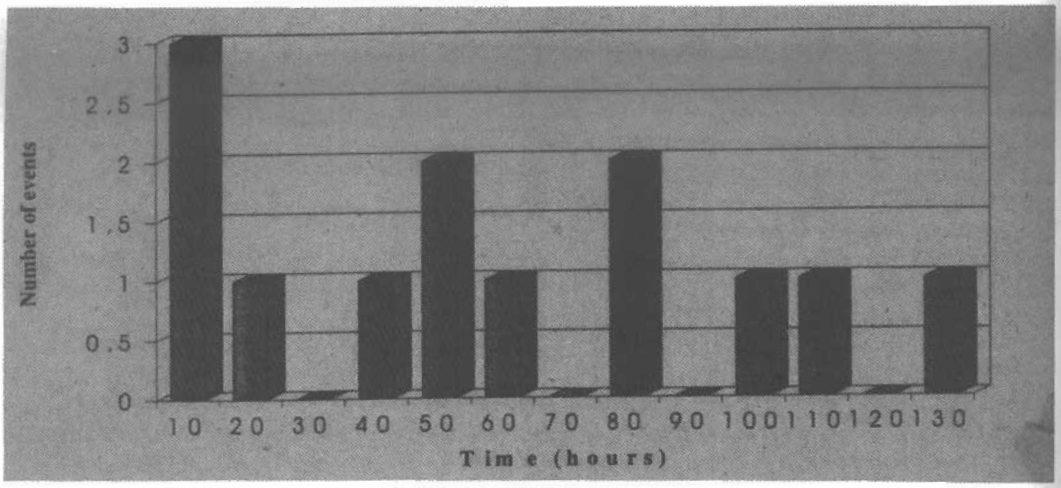

Fig. 7: Frequency diagram of lag times (signal follwoing earthquakes.
Σχ. 7: Διάγραμμα συχνοτήτων των χρόνων υστέρησης (σήματα μετά από σεισμούς).

probably contribute to the solution of this problem. For this reason, the establishment of stations, similar to that of Neraida, in other places is already in progres.

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REFERENCES

ANTONOPOULOS, G., KOPANAS, J., EFTAXIAS, K. and HADJICONTIS, V. (1993). On the experimental evidence for the SES vertical component, *Tectonophysics*, 224,47-49.

ARVIDSSON, R. and KULHANEK, O. (1993). Enhancement of seismic electric signals using magnetotellurics, *Tectonophysics*, 224, 131-139.

CHOULIARAS, G. and RASMUSSEN, TH. (1988). The application of the magneto-telluric impedance tensor to earthquake prediction research in Greece, *Tectonophysics*, 152, 119-135.

DRAKOPOULOS, J., STAVRAKAKIS, G.N. and LATOUSSAKIS, J. (1993). Evaluation and interpretation of thirteen official VAN-telegrams for the period September 10, 1986 to April 28, 1988, *Tectonophysics*, 224, 223-236.

ERNST, T., JANKOWSKI, J., ROZLUSKI, C. and TEISSEYRE, R. (1993). Analysis of the electromagnetic field recorded in the Friuli seismic zone, north-east Italy, *Tectonophysics*, 224, 141-148.

FEDOTOV, S.A., DOLBILKINA, N.A., MOROZOV V.N., MYACHKIN V.I., PREOBRAZENSKY , V.B. and SOBOLEV, G.A. (1969). Investigation on Earthquake prediction in Kamchatka, *Tectonophysics*, 9, 249-258.

GINIS, S., AUGOUSTIS, G., ZISOS, A., LAZARIDOU-VAROTSOU M., DOLOGLOU-REVELIOTI, E., ECONOMOPOULOS, P., KARAPANOS, P. and GIAKOUMAKIS, G., (1982). Efficiency of the prediction of earthquakes from electrotelluric signals collected at distant stations, *Praktika of the Athens Academy*, 57, 372-379.

HADJIOANNOU, D., VALIANATOS, F., EFTAXIAS, K., HADJICONTIS, V. and NOMICOS,

K., (1993). Subtraction of the telluric inductive component from VAN measurements, *Tectonophysics*, 224, 113-124.

HAMADA, K. (1993). Statistical evaluation of the SES predictions issued in Greece: alarm and success rates, *Tectonophysics*, 224, 203-210.

KAWASE, T. UYEDA, S. UYESHIMA, M. and KINOSHITA, M. (1993). Possible correlation between geoelectric potential change in Izu-Oshima Island and the earthquake swarm off the east Izu Peninsula, Japan, *Tectonophysics*, 224, 83-93.

MARON, CH., BAUBRON, G., HERBRETEAU, L. and MASSINON, B. (1993). Experimental study of a VAN network in the French Alps, *Tectonophysics*, 224, 51-81.

MULARGIA, F., GASPERINI, P., (1992). Evaluating the statistical validity beyond chance of "VAN" earthquake precursors, *Geophysical Journal International*, 111,32-44.

MYACHKIN, V.I., SOBOLEV, G.A., DOLBILKINA, N.A., MOROZOW, V.N. and PREOBRAZENSKY V.B., (1972). The study of variations in geophysical fields near focal zones of Kamchatka, *Tectonophysics, 14*, 287-293.

NAGATA, T., (1944). Variation in earth-current in the vicinity of the Sikano-fault, *"Bull. Earthq. Res. Inst.", Univ. Tokyo*, 22, 72-82 (in Japanese).

PAPAZACHOS, B.C., KARAKAISIS, G.F., KARAKOSTAS, B.G., PAPADIMITRIOU, E.E., CHATZIDIMITRIOU, P.M., COMNINAKIS, P.E. and TASSOS, S.T. (1988), Study of the abnormal variations of the geoelectric field for earthquake prediction, *"Bulletin of the Geological Society of Greece"*, Vol. XIX, 401-430.

PAPAZACHOS, B.C. and PAPAZACHOU, K. (1989). The earthquakes of Greece, *ZITI Publications*, 1-356.

RALCHOVSKY, T. and KOMAROV, L. (1988). Periodicity of the earth electric precursor before strong earthquakes, *Tectonophysics*, 145, 325-327.

RALCHOVSKY, T. and KOMAROV, L. (1989). Strong Earthquakes on the Balkan Peninsula and the Earth' s Electromagnetic Activity, Bulgarian Academy of Sciences, *Bulgarian Geophysical Journal*, Vol. XV. No 1, 60-69.

RALCHOVSKY, T. and KOMAROV, L. (1993). SES activity and the Earth's electric potential, *Tectonophysics*, 224,95-101.

RALEIGH, B., BENNETT, G., CRAIG, H., HANKS, T., MOLNAR, P., NUR, A., SAVAGE, J., SCHOLZ, CH., TURNER, R. and WU, F. (1977). Prediction of the Haicheng earthquake, *"Trans. Am. Geophys. Union"*, 58, 236-272.

SOBOLEV, G.A., (1975). Application of Electric method to the tentative short-term forecast of Kamchatka earthquakes, *"Pageoph."*, 113, 229-235.

THANASSOULAS and TSELENTIS, G. (1993), Periodic variations in the Earth's electric field as earthquake precursors: results from recent experiments in Greece, *Tectonophysics*, 224, 103-111.

UYESHIMA, M., KINOSHITA, M., IINO, H. and UYEDA, S., (1989). Earthquake Prediction Research by Means of Telluric Potential Monitoring. Progress Report No. 2: Preliminary Study on Teshikaga Channel 2 Signals and the Seismicity in the Region off Kushiro (in English), *Bulletin of the Earthquake research Institute, University of Tokyo*, Vol. 64, Part 4.

VAROTSOS, P., ALEXOPOULOS, K. and NOMICOS, K. (1982). Electrotelluric precursors to earthquakes, *Praktika of the Athens Academy*, 57, 341-362.

VAROTSOS, P., ALEXOPOULOS, K., NOMICOS, K., DOLOGLOU-REVELIOTI, E. and LAZARIDOU-VAROTSOU, M. (1983). Parameters of the electrotelluric precursors to earthquakes of Kefallinia. *Praktika of the Athens Academy*, 58, 250-257.

VAROTSOS, P. and ALEXOPOULOS, K. (1984a), Physical properties of the variations of the electric field of the earth preceding earthquakes, I. *Tectonophysics*, 110, 73-98.

VAROTSOS, P. and ALEXOPOULOS, K. (1984b), Physical properties of the variations of the electric field of the earth preceding earthquakes, II. Determination of epicentre and magnitude. *Tectonophysics*, 110, 99-125.

VAROTSOS, P., ALEXOPOULOS, K., LAZARIDOU-VAROTSOU M. and NAGAO T., (1993a). Earthquake predictions issued in Greece by seismic electric signals since February 6, 1990, *Tectonophysics*, 224, 269-288.

VAROTSOS, P., ALEXOPOULOS K. and LAZARIDOU M.,(1993b). Latest aspects of earthquake prediction in Greece based on seismic electric signals, II. In: P. Varotsos and O. Kulhanek (Editors), Measurement and Theoretical Models of the Earth's Electric Field Variations Related to Earthquakes. *Tectonophysics*, 224:1-37.

YAMAZAKI, Y., (1977). Tectonoelectricity. *Geophysical Surveys 3*, 123-142.