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RECENT RESULTS FROM THE SHALLOW UNDERGROUND WATER LEVEL AND TEMPERATURE MONITORING NETWORK OF THE AREA OF VOLVI

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ABSTRACT

A shallow underground water level and temperature monitoring network was installed in the area of the lakes Langada and Volvi, in Northern Greece. The results so far shows that: (a) The atmospheric pressure and earth tides do not affect the observations of the shallow under ground water level in accordance with the results of other investiga tors while the rainfall does, and (b) although there is not a unique response pattern for all the stations of the network, sharp changes in the underground water level and temperature can be related to earth quakes occured in this area as pre- and post -seismic phenomena.

ΣΥΝΟΨΗ

Στην περιοχή των λιμνών Λαγκαδά και Βόλβης της Βορείου Ελλάδος εγκαταστάθηκε ένα δίκτυο παρακολούθησης της συμπεριφοράς των αβαθών υπογείων υδάτων της περιοχής. Τα αποτελέσματα των μέχρι σήμερα μετρήσεων δείχνουν ότι: α)Η μεταβολή της ατμοσφαιρικής πίεσης και οι παλίρροιες του στερεού φλοιού της γης δεν επηρεάζουν τις μετρήσεις της στάθμης των αβαθών υδάτων, σε συμφωνία με ανάλογα αποτελέσματα άλλων ερευνητών, ενώ οι βροχοπτώσεις τις επηρεάζουν και β) Αν και δεν υπάρχει ενιαία ομοειδής ανταπόκριση στις μετρήσεις όλων των σταθμών, απότομες μεταβολές στην στάθμη και την θερμοκρασία μπορούν να συσχετισθούν με την σεισμική δραστηριότητα στην περιοχή σαν προ- ή μετασεισμικά φαινόμενα.

INTRODUCTION

In Northern Greece close to Thessaloniki there is a seismic zone which is associated with the Servomacedonian geological massif. In this zone there is a basin which includes the lakes Lagada and Volvi. This is a very active seismic area in which many large earthquakes have occured in the past.

In order to verify if the well known (Rikitake 1976,1981,Wakita 1982) pre- and post-seismic response of the underground water level and temperature manifest itself in the case of the shallow underground water,a shallow underground water level and temperature monitoring network was installed (Asteriadis and Contadakis 1991) in December of 1983 in this seismic active area and has been followed up ever since.The reason is obvious and has to do with the cheap instrumentation and the low running cost of such a monitoring network.

In this paper we present the work which has been done up today in the frame of this research as well as the respective results.

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THE EXISTING NETWORK AND THE MEASUREMENT

Four KLT-OTT type contact gauges were installed in 1983 by the Department of Geodesy and Surveying, University of Thessaloniki, at selected wells in the seismically active area of Northern Greece, between the latitudes $40^{\circ}.35$ and 41° N and longitudes $22^{\circ}.7$ and $23^{\circ}.85$E.

Figure 1 shows the position of the four villages, Liti, Assiros, Melissourgos and Nymfopetra, where the six selected wells belong. Table 1 displays the position and the depth of the well stations of the network as well as the respective number of measurements which were performed in the time interval between 1983,December 20 and 1991, December 31.

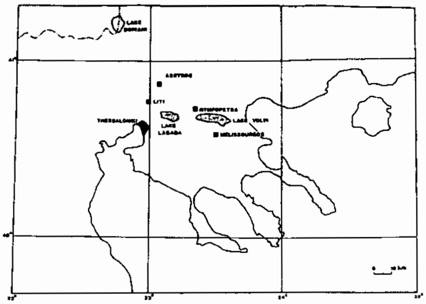


Fig. 1: The location of the network stations.

The continuous daily sampling at the stations of Liti, Assiros 1&2, Melissourgos 1 and Nymfopetra have started on 1983 December 20 and at the station of Melissourgos 2 on 1984 April 16. However it happened that some stations were out of work for some periods of time, mostly because the respective well have became dried due to the drought, as it is happened during the extremely dry year of 1990, where all the wells except that of the Assiros 1 and 2 stations have became dried by the end of May. It should be noted that the well of Liti remain dry until today and we were forced to replace the well in the network.

Two HELLMAN-type rain-gauges for the rainfall measurements were installed in the area in order to study for the influence of the rain in the changes of the underground water level.

The seismic data have been selected from the monthly bulletin of the Seismological Institute of the National Observatory of Athens (SINOA).

Table 1: Position and depth of the wells of the network stations and the total number of the performed measurment.

Monitoring wells

well	φ[°]N	λ[°]E	height (m)	depth (m)	numb/meas
LITI	40.75	22.98	170	11.0	2065
ASS1	40.82	23.03	200	4.2	2726
ASS2	40.82	23.03	200	2.2	2726
MEL1	40.60	23.42	110	4.1	2598
MEL2	40.60	23.42	110	5.1	2483
NYMF	40.69	23.34	90	10.0	2495

These data are for earthquakes with epicentres extending from $\varphi[=40^{\circ}.3$ N to $\varphi[=41^{\circ}.0$ N and from $\lambda=22^{\circ}.7$ to $\lambda=23^{\circ}.8$. During the time period between December 20,1983 and December 31,1990, 409 earthquakes with epicentres in this area occured, 86 from them had magnitudes $M\geq3.0$. The monthly bulletin of SINOA does not provide information about the magnitudes if this is less than about 2.5,and for these cases we assign the value 1.0 to facilitate the computerized graphic work.

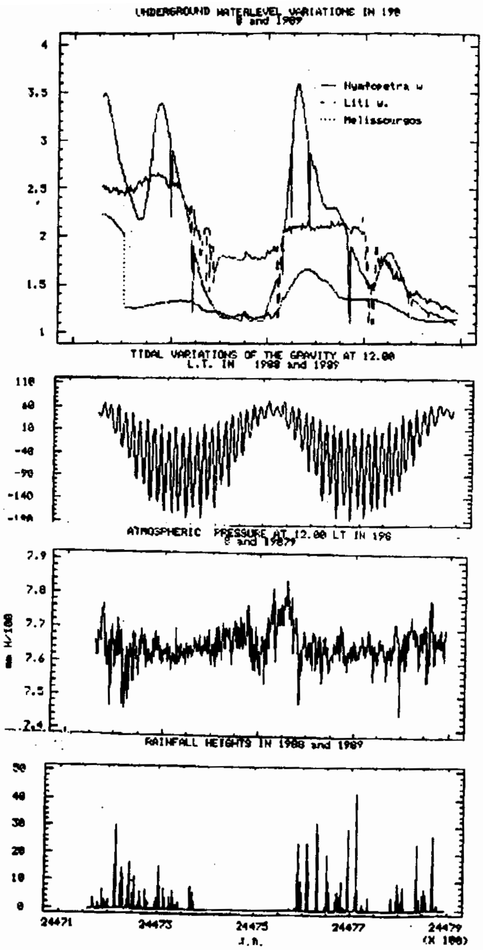


Fig. 2: (a)Water level variations at the wells (b) Tidal gravity variations in μgals, (c) Barometric Variation in mm Hg,(d)Rainfall heights in mm, in 1988 and 1989.

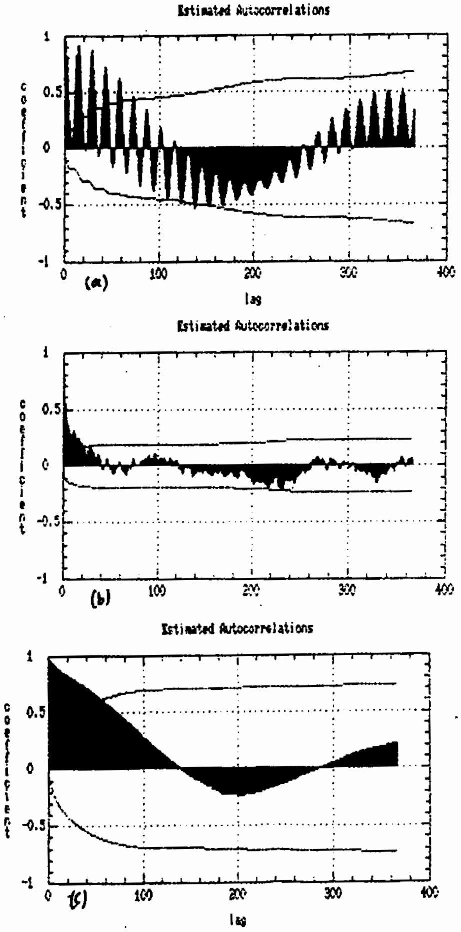


Fig. 3: Autocorrelation function of (a)Tidal gravity variation, (b)Baro-metric variation(c) Water level variation at the well of Liti.Time lag in days.

THE INFLUENCE OF NON TECTONIC FACTORS IN THE WATER LEVEL MEASUREMENTS

Although the exact mechanism of underground water variations is connected with the earthquake is not fully understood it is generally accepted that changes in the tectonic stresses are the main cause. If this is true then it is expected that non tectonic stress sources, such as Earth tides and Barometric pressure will also produce similar variations in the wells water level and a great deal work has been done in this field (see for example Reoloffs, 1988; Roeloffs et. al. 1989; Rojstaczer, 1988).

On the other hand shallow wells, such those of our network, are connected with unconfined aquifers. And horizontal, as well as vertical, flow from the well to the water table and vice versa occur. This fact, together with the

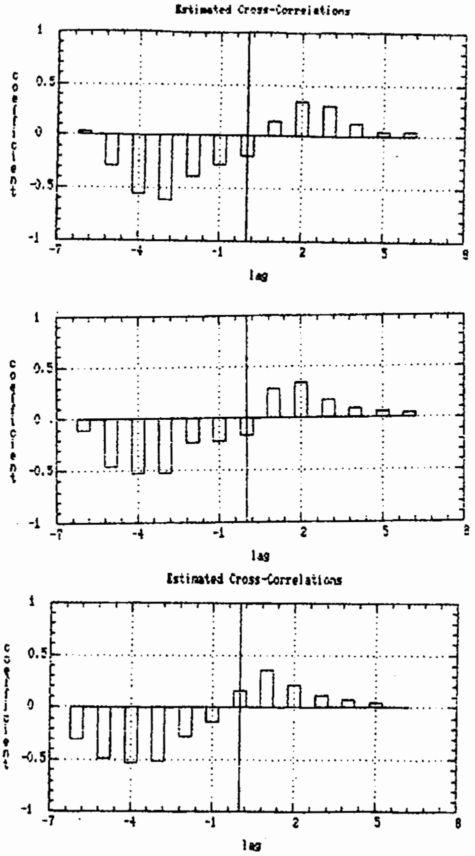


Fig. 4: Cross correlation functions between monthly rainfall heights and mean monthly moving averages of the water level at the well (a) Liti, (b) Nymfopetra and (c) Assiros1, for the year 1988. Time lag in months.

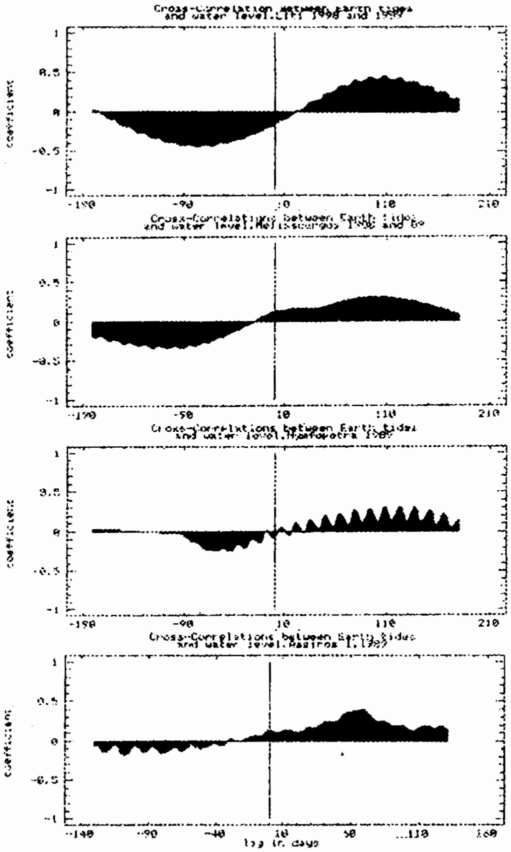
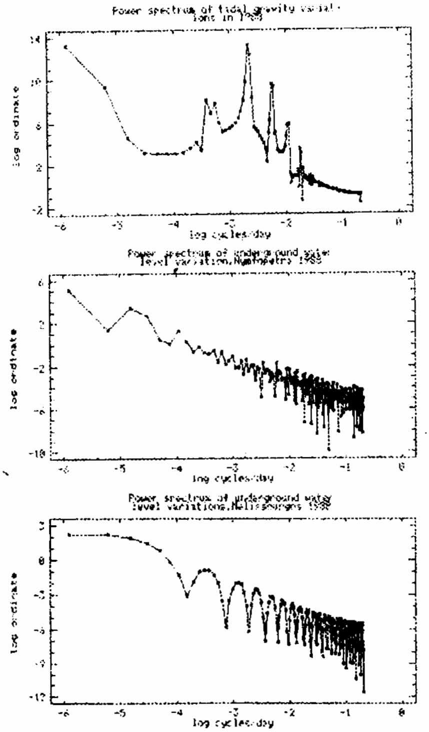


Fig. 5: Cross-Correlation functions between tidal gravity variation and the water level at (a) Liti and (b) Melis-sourgos in 1988, 89 and (c) Nymfopetra and (d) Assiros1 in 1989. Time lag in days.

high porosity of the surface ground, will produce attenuation of the water level variations due to earth tides as well as to barometric pressure (Melchior 1982, Rojstaczer 1988 Roeloffs, 1988). This in turn rises questions about the usefulness of the shallow wells as tectonic stress indicators. Nevertheless, observations shows that shallow wells also may be sensitive to the earthquake activity (Oki and Hiraga 1988, Contadakis and Asteriadis 1993).

In any case the knowledge of the sensitivity of the wells of the network to the precipitation, earth tides and barometric pressure will help to the proper evaluation of the wells water level variations as earthquake precursors. For this purpose we have performed statistical test on the



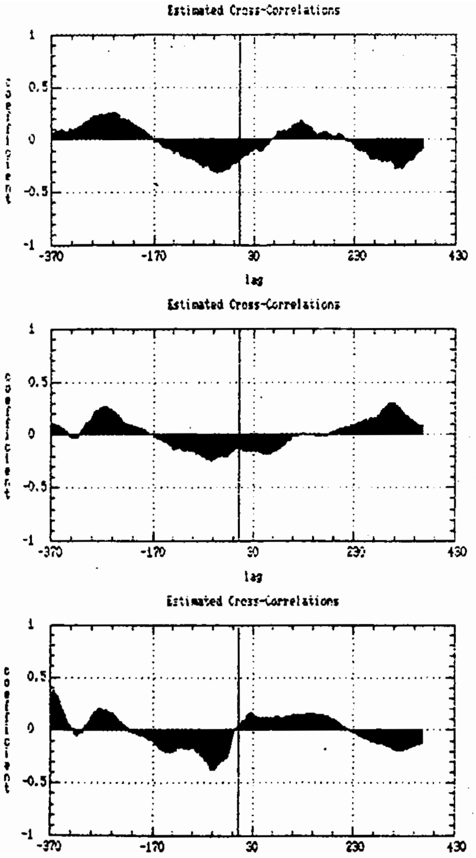


Fig. 6: Power spectra of (a) Tidal gravity variations, Water level variations at the well of (a) Nymfopetra and (b) Melissourgos 1988. Freequency cycles/day.

Fig. 7: Cross Correlation functions between barometric pressure and water level at the wells (a) Nymfopetra, (b) Melis-sourgos and (c) Liti in 1988,89.

observational samples of the involved quantities for the years 1988 and 1989 (Contadakis 1993).Before we proceed to the analysis of the cross correlations between the involved variables we note that all of them present a well (earth tides) or weakly (water level) expressed periodicity of one year (Figure 2), a fact which is also shown on their autocorrelation function graphs (Figure 3).A fact which we have to have in mind in the interpretation of the cross correlation functions.In particular the results of those test are as follows.

a) Rainfall

The cross correlation function between the rainfall heights collected by our rainfall -gauges and the water level variations shows no correlation. This result may be explained by the fact that a threshold amount of rainfall is required in order to initiate the recharge of the aquifer and this was not surpassed by the weak rainfalls as they are spreaded in a relatively long period of time. However the monthly heights of precipitation show a weak correlation with the moving average of the water level in all the wells with a phase lag of two or one month in the case of the well of Assiros (Figure 4),with an exception of the well of Liti for the year 1989 (not showed in this figure).This result is fully understood since rainfall water needs some time to reach the water table moving in the aerization zone.The behavior of the well of Liti is abnormal with respect of rainfall. It should be noted that during the extremely drought year 1990 the Well of Liti became dry and remain dry until today. Therefore it maybe concluded that a permanent change occured on the water table of the well of Liti.

b) Earth tides

The sampling interval of our measurements is too large for a proper investigation of the influence of earth tides on the wells water level. However the existence of such an influence may be detected from our sample using statistical tests. The cross-correlation function between the observed tidal perturbation on the earth gravity field (Arabelos 1991) in the region of the network (the quantity which has to be subtracted from the total gravity field in order to correct for the tidal effect) and the wells level variations shows a weak correlation with a varying phase lag between 2 months for Assirosl and 3 or 3.5 months for Liti Melissourgos and Nymphopetra, (Figure 5). Spectra power analysis shows a 13.6 days component in the spectra of the well water level which is found in the limit of the noise (Figure 6).The Nyquist limit, which is 2 days for our sample, does not allow us to detect any correlation of the well water level with the diurnal and semidiurnal components of earth tides.

c) Barometric pressure

The cross correlation function between the barometric pressure and the well water level shows very weak or no correlation (Figure 7),with phase lag varying to. It should be noted that the power spectrum of the barometric pressure shows the 13.6 and the 27.5 days tidal component.

The above mentioned statistical tests show that earth tides and barometric pressure have a small influence on the water level measurement of the shallow wells of our network. This result is in accordance with the results of the theoretical and observational research in the field, as it was already mentioned in section 3. In addition a phase lag greater of a month is suggested by these tests for the influence of earth tides on the water level. Specific investigation of the influence of earth tides and atmospheric pressure require sampling interval of the order of minute for the observations and of course more sophisticate instrumentation than the one of this investigation. The precipitation effect also is small and has a phase lag of one month. It is obvious that the recorded sharp changes on the underground water level can not be attributed to the above mentioned sources if their period is of the order of 7 days or less as it is observed in our case.

RESULTS AND DISCUSSION

During the seismic periods of quiescens, the overall behavior of the underground water level shows a gradual long term variation in water level causing by the rainfalls. This variation has a period of a year in accordance to the rainfall annual periodicity .The underground water temperature

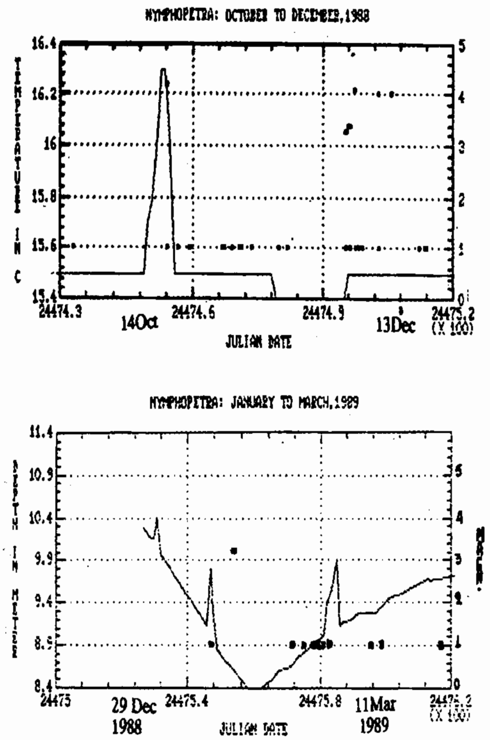


Fig. 8: Underground water temperature(a) and level(b) variations at the well of Nymfopetra for two succesive three months periods around the begeenings of 1989.

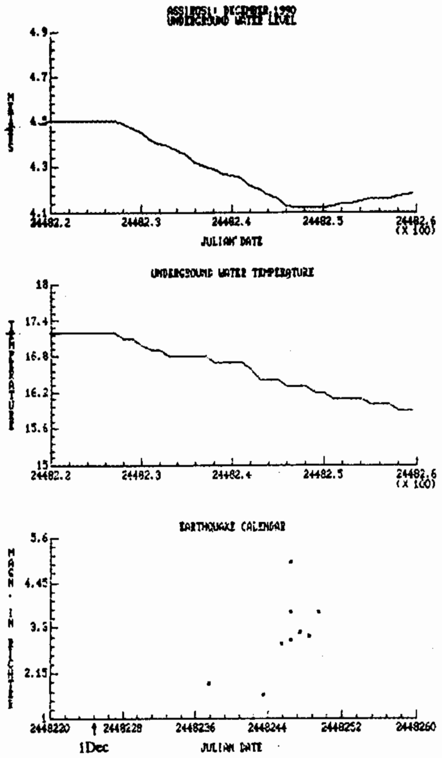


Fig. 9: Underground water level (a) and temperature (b) variations and seismi-city in Dec of 1990.

shows the well known seasonal, one year periodic variation with amplitudes ranging between $0^{o}.6$ C in the deepest well, NYMF(10.0m), up to 8^{o} C in the shallowest well, ASS2 (2.20m), and a phase lag with respect to the atmospheric temperature which depend on the depth of the well. These long term variations do not bother the detection of any sharp change caused by other reasons.

Sharp changes in the underground water level and temperature can be related to earthquakes with epicenters in this area as pre- and post- seismic phenomena (Asteriadis and Livieratos 1989 a, b, Asteriadis and Contadakis 1991). There is not a unique response pattern of these changes for all the wells, a fact which is also reported by others investigators (Wakita 1982,Ma Zongjin et.al. 1990).The magnitudes of these changes vary between a few centimetre to 90 centimetre in the water level changes and from a few tenths up to one degree centigrade in the temperature changes. As an example figure 8a displays the underground water temperature variation at the well of Nymfopetra during the last three months of the year 1988 and figure 8b displays the underground water level variation at the same well during the first three months of the year 1989. Our results indicate that there is a correlation between the magnitude of the change in underground water level and temperature and the magnitude of the shock as well as the epicentral distance of the respective station (Contadakis and Asteriadis 1993). Finally the water level and the temperature changes occur in a time interval up to seven days before or after the associated shock (see also Asteriadis and Zioutas 1990),except the disturbances in underground water level and temperature which correspond to the strongest shock observed during this investigation. This earthquake occured in 1990 December 21, has a magnitude of 5.4 and the corresponding disturbances in underground water level and temperature started 20 days before (Fifure 9).This fact is found in accordance with the suggestion of Zongjin et. al. (1990) that the precursory disturbances in underground water precede the event by 10 to 20 days, if the magnitude of it is 5. In general we may say that the observed time lag of the precursory disturbances in underground water level and temperature are in favour of the suggestion of Zongjin et. al. (1990) that they are correlated with the magnitude of the associated event.

Table 2: The observed sudden changes in underground water level and temperature and the earthquakes which have occurred in the above mentioned area within the time interval 1988, January 1 and 1989, August 31.

	Assiros 1		Liti		Melissourgos		Nymfopetra		Shock	%
	A	B	A	B	A	B	A	B		
W/L	26	3	40	5	30	4	16	1	103	72
Temp	19	5	38	8	21	6	11	6	91	64

Table 2 displays a brief statistics of the network response on the seismic activity of the region in the time interval between 1988, January 1 and 1989, August 31 (Contadakis and Asteriadis 1993). In this time interval all the stations were in work. So we have an homogeneous sample. During this period 143 shocks with epicentres in the area of interest have occurred. In this table the number of the sudden changes in the underground water level (row named "W/L") as well as in the underground water temperature (row named "Temp.") at each well station within the above mentioned time interval are given. Those changes which can be attributed to a particular shock are given in the columns under the heading A while those changes which occur within an earthquake swarm or sequence are given in the columns under the heading B. The number as well as the percentage of the total number of the shocks which can be correlated with a sudden change in water level or in temperature are displayed in the last two respective columns.

During the above mentioned time interval only two water level changes can be hardly attributed to a shock (Nymfopetra and Liti station at J.D 2447516), while no temperature disturbance had ever failed to be correlated with a respective shock. That is the probability that an event follow an observed sudden change in the underground water level or in temperature in a well of the network is practically 1. This means that the necessary condition is fulfilled.

On the other hand 40 shocks cannot be connected with any water level change and 52 shocks failed to be connected with any temperature variation.

This means that the probability that an event will produce an observed water level change in a well of our network is 0.72 and the probability that an event will produce an observed temperature change is 0.64. That is, the sufficient condition is fulfilled with a probability of 0.72 for the underground water level variation and 0.64 for the underground temperature variation. Asteriadis and Zioutas (1990) have found that these two conditions are fulfilled with probabilities 0.88 and 0.65 respectively for the underground water level variation in the period between 1983 December 20 and 1986 August 31. The relative low probability for the verification of the sufficient condition is to be expected in view of the different response pattern of the well stations in the shocks as well as on the dependence of the magnitude of the water level changes on the epicentral distance.

CONCLUDING REMARKS

The results of this investigation indicate that there is a correlation between the underground water level and temperature variation and the microseismic activity in the broader area of the network manifested by sharp changes of these quantities within 7 days before the shock. However the time interval between the 5.4R shock of 1990 December 21 and its associated disturbance in underground water level and temperature, which is 20 days, indicates that a correlation between the event magnitude and the time lag of the associated disturbance may exist.

Crustal movements, expansion or contraction of the ground cause changes in the pore pressure of the underground rocks and deformation of the underground water system Therefore the seismogenic process is expected to cause such a deformation. The exact way that this deformation manifest itself depend on many factors e.g. the epicentral distance the magnitude of the shock and the tectonic environments of the well network. The last factor presumably is responsible for the different response pattern of the different wells of the network.

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