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Multiparameter Changes in the Earth's Crust and Their Relation to Earthquakes in Denizli Region of Turkey

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ABSTRACT

It is a well known phenomenon that some changes within the earth crust occur before and during strong earthquakes. This was experienced well in Turkey during the Marmara and Bolu-Düzce Earthquakes in 1999, Çay-Eber earthquake in 2002 and Buldan earthquake in 2003. Multi-parameter measuring stations were established in Denizli basin in order to investigate relationship between earthquake activity and changes whitin the earthcrust in the region. The measurements have been taken in five minutes of interval. The measured parameters are; temperature of thermal waters, electric field measurements from soil and rock, an acoustic emission numbers of a bubling sink hole of Tekkehamam thermal spring area, and on the fault plane of Honaz. During Çay-Eber earthquake in 2002 and Buldan earthquake in 2003, some changes in temperature of thermal waters, electric field value and acoustic emission numbers were measured at the multi-parameter stations in Denizli. The results showed that there is a strong relation between the earthquake activity and the changes whitin the earthcrust in Denizli Region.

1. INTRODUCTION

Short interval of field data collection such as temperature, groundwater level change, chemical and physical properties of thermal waters, electric potential changes of ground have been investigated to find a relationship between the collected data and earthquakes. It is reported that temperature rises occur particularly at hot springs, which bring underground water to the surface from depths greater than 1 km as a result of micro-seismic activity. Therefore it is pointed out that the temperature observations at hot springs may be good indicators of forecoming large earthquakes (Wakita, 1995; Aydan and Ulusay, 2000; Şimşek and Yıldırım, 2000).

Electrical resistivity variation of ground before and during earthquakes was pointed out by Sobolev (1975) and it was used for the prediction of earthquakes in Kamchatka. He and his co-workers used some set-up aligned in the directions of NS and EW to measure electric potential and electrical resistivity of ground. This method was further elaborated by Varotsos and his co-workers and applied to actual earthquake predictions (Varotsos et al. 1984). This method is called VAN-method. This method assumes that seismic electric signals (SES) preceeds before main shocks. The amplitude of these signals and locations of observation stations are used to predict the location, magnitude and time of earthquakes. Some experimental studies were undertaken with the sole purpose of explaining why such signals and electric field variations occur. Aydan et al. (2001a, 2002, 2003) carried out a series of rock mechanics tests and pointed out that the deformation and fracturing processes induce electric potential in geometarials. Uyeda et al., (2002) stated that, there is a relationship between earthquakes and changes of electric potential and magnetic field value measured in Izu area in Japan.

Accoustic emission method was first time developed by Kaiser in 1953. Application of this method to rock mechanics was done by Kanagawa et al., 1977. This method was modified by Watanabe ve Tano (1999).

It is well-known that accoustic emissions occur during the fracture propagation in rocks. Therefore, it has some relevance to fracturing phenomenon in the earth’s crust. Since the acoustic emission sensors are designed for high frequency waves resulting from micro-fracturing, they can not be used in earthquake prediction due to their rapid decay of these waves as distance increases from the source of fracturing. However, the hot springs reflect the situation at depths more than 3000m. The acoustic emission method is applied hot springs with a slight modification of the original method in this study to monitor the variations in the earth’s crust

The influence of temperature of the thermal waters and the earthquake activity of Denizli basin was studied by Aydan, et. al. (2001b) and Kumsar et. al. (2003). They found that there are relationships between the earthquake activity and the temperature changes of the thermal waters.

2. GEOLOGY

Denizli city is located in an earthquake active area in western Turkey (Figure 1). Denizli basin is a graben valley located at east of Büyük Menderes and Gediz grabens in the Aegean extensional province and, bounded by active normal faults in the north and in the South (Eşder, 1995). There are thermal water springs discharging through fracture zones along the active fault lines (Figure 2).

The rock units are classified in three main groups in terms of their age; 1) basement rocks of pre-Neogene, 2) Neogene units and 3) Quaternary and Holocene units (Figure 2). The pre-Neogene formations are made up of mainly gneiss, schist and marbles of Paleozoic metamorphic rocks, and Mesezoic carbonates. Neogene rocks are deposited within the all of the graben basins in western Anatolia. Quaternary sediments are deposited in front of the fault zones bounding the basin sides, and loose sediments deposited within stream beds. There are hot and mineral water springs discharging through fracture and fault zones bounding the Denizli basin at the north.

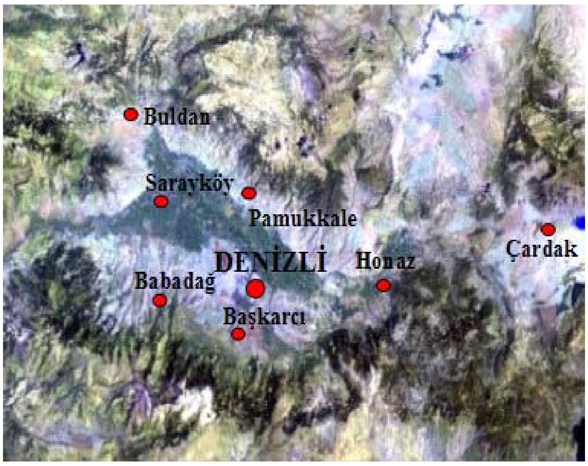

Figure 1: Landsat image of Denizli basin

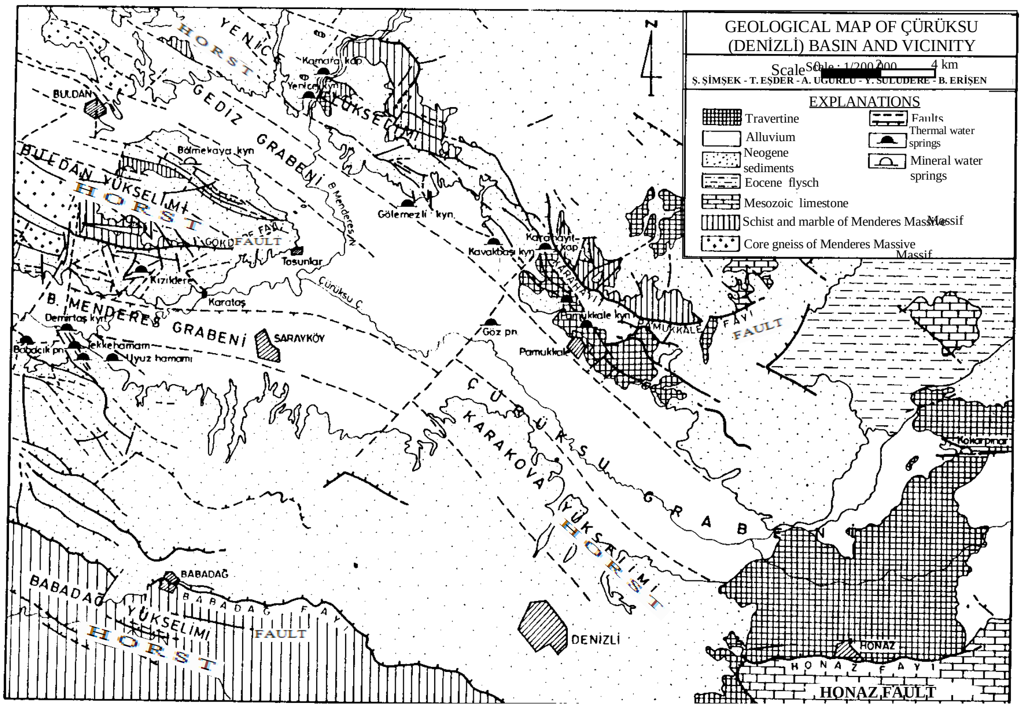

Figure 2. Geological map of Denizli basin and its tectonic structure (after Eşder, 1994)

The chemical composition of these waters, whose temperatures vary between 28°C 98°C, is composed of calcium bicarbonate (Özkul et al., 2000).

As a result of the extensional tectonic regime, normal faults and tension cracks trending E-W and NW-SE developed, and after that horst and graben systems formed. This extensional province is one of the fast extending area in the world. The faults bounding the basin from north and south, are in form of segments.

3. SEISMICITY OF DENIZLI REGION

Denizli city is located in an earthquake prone area in western Anaotolia in Turkey. The settelement place of the city is in a graben basin where there are active normal faults at the north and the south of the basin.

There are antique and modern settlement places in the graben basin. The antique settlement places were all left as a result of strong earthquakes caused collapse of the structures in the cities in the history. Today, the earthquake activity in the region is still continuing.

A Roman antique city called Hierapolis (today named as Pamukkale) was collapsed and rebuilt in the history. The strong earthquakes in the history can be summuraised as follows: In 17 A.D., a strong earthquake caused most of Pamukkale city to collapse, and it was rebuilt there after. The city was also damaged as a result of earthquakes occurred in 60 A.D., 300 A.D. and 700 A.D. In 1358, Pamukkale city was collapsed as a result of a strong earthquake and people left the place and settled in Laodikea 20km south of Pamukkale. The magnitude of the earthquakes occurred between 1900-2003 are not higher than 6 within Denizli Basin (Figure 3).

4. MULTI-PARAMETER MEASUREMENT SYSTEM IN DENİZLİ

In order to ivestigate the relation between earthquakes and the changes within the earthcrust in Denizli region, seven data collection stations were established (Figure 4). To start with temperature recording stations of thermal waters were constructed in Pamukkale-Çukurbağ in January 2001 (Figure 5), Yenice-Kamara and Sarayköy-Tekkehamam

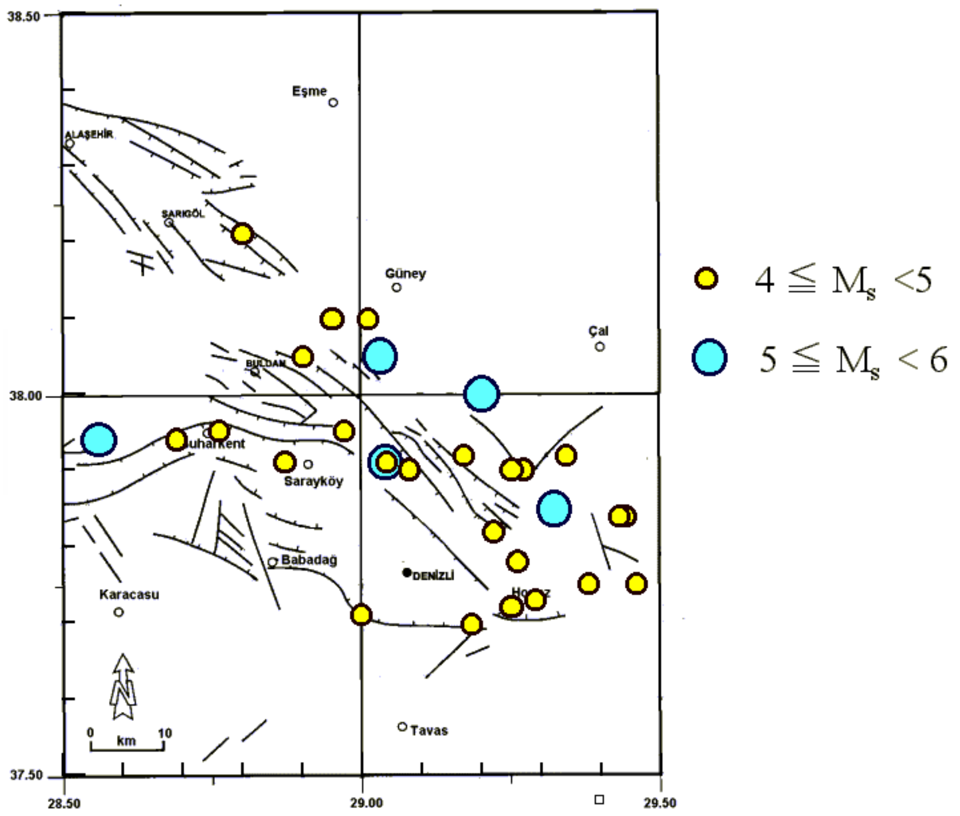

Figure 3: Epicentre of earthquakes occurred between 1900-20.07.2003 and the tectonic structure of Denizli basin (Tectonic map taken from MTA, 1992.

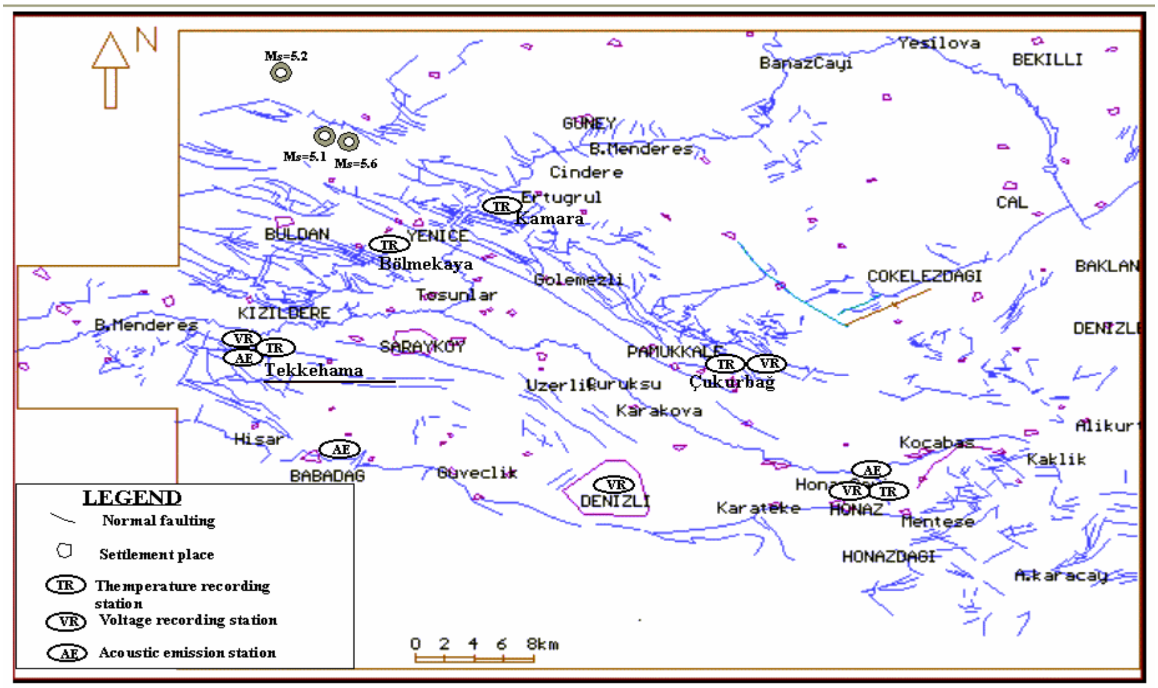

Figure 4: Multi parameter data measurement stations and tectonic structure of Denizli Basin (tectonic map taken from Aydın, 1991)

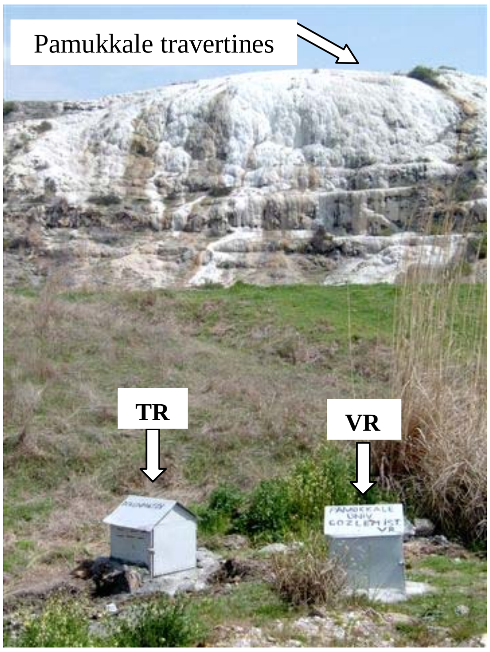

Figure 5. Cotton white colored travertines and Pamukkale-Çukurbağ temperature (TR) and voltage recording (VR) stations

thermal springs (Figure 6) in Denizli (Aydan et al., 2001b). After taking measurements for one year, multiparameter measurements for the selected stations were required. Voltage recorder measurement stations were established in Çukurbağ, Tekkehamam and Denizli city centre. An acoustic emission station on a bubling sink hole of Tekkehamam thermal spring area was constructed in March 2002. This station was called as "Tekkehamam Puf-Puf Station" (Figure 7). In August 2002 two acoustic emission stations were constructed in an active land slide area in Babadağ District known as the capital city of Textile Industry. The Babadağ Acoustic Emission Stations were constructed to measure acoustic data related to the displacement of a land slide in Babadağ. In addition to that, as one of the active fault of Denizli basin cuts through Babadağ town, the acoustic emission data were also used for the earthquake activity investigation.After one year, the research group decided to construct a new station on an active fault zone in Honaz District. In this station there are acoustic emission, electric potential and temperature measurements from the rock body of Honaz fault (Figure 8). After the Buldan earthquake on 26 July 2003, a temperature measurement station was built in Buldan-Bölmekaya thermal water spring whose temperature is 36^{o}C. obtained satisfactory performance in in-situ electric fieldmeasurements.

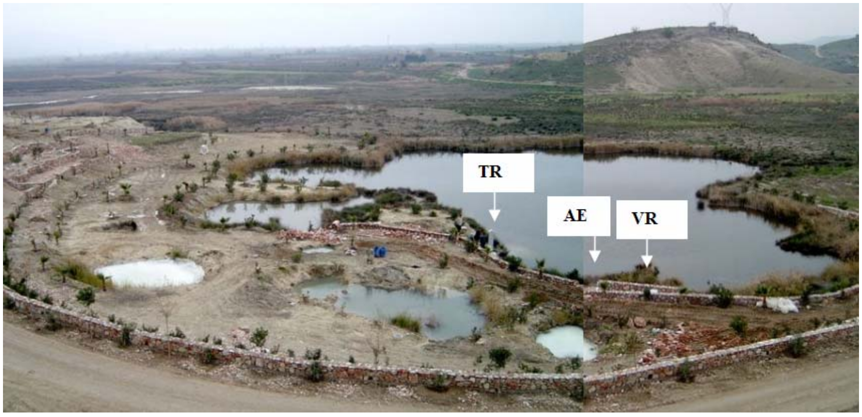

Figure 6. General view of Tekkehamam stations (TR: temperature, AE: Acoustic emission, VR: voltage recorders)

Figure 7. (a) The stations, (b) a close up view of the acoustic emission (Tekkehamam puf-puf) station.

(a) (b)

Figure 8. a: Installation of AE, TR and VR logging systems at Honaz station, b: Honaz station after the installation.

5. MEASUREMENT ITEMS AND DEVICES

5.1 Temperature Measurement System

Temperature measurement system is produced by T&D Corporation of Japan and the model of the system is TR-71S. The temperature sensors can measure temperatures from –60 to 155^oC. The measurable temperature variation is 0.1^oC. Time interval can be selected as desired and it has two channels. One of the channel is used to measure the air temperature while the other channel is used to measure the temperature at the ground level of the hot spring in a steel pipe casing. Each channel of the TR-71s can store up to 8000 data.

5.2 Electric Field Measurement System

Electric field measurement system is also produced by T&D Corporation of Japan and the model of the system is VR-71. It is a simple voltage recorder measuring voltage as DC. The measurable smallest unit by the device is 1 mV. The input impedance of the device is in the order of several Mega Ohms. Although its input impedance is low for laboratory electric field measurements, Aydan et al., (2002) 5.3 Acoustic Emission Measurement System

Acoustic emission measurement system was developed by the third author (Hisataka Tano of Nihon University). The system consists four main components:

1) Stainless steel wave guide
2) Acoustic emission sensors (active and dummy sensors)
3) Amplifier unit, and
4) Logger unit.

6. MEASUREMENT RESULTS

An earthquake with a magnitude of 6.0 occurred in Çay district of Afyon city 160 km far from Denizli city (Ulusay et al., 2002). This earthquake activity and its aftershocks caused increase in the temperature of the thermal spring water at Pamukkale-Çukurbağ station. An increase of 0.5 ^oC of temperature of thermal water occurred just after the earthquake (Figure 9). There were also small changes realted to aftershocks.There was an earthquake activity in Buldan and surrounding in Denizli on 23rd of July 2003. An earthquake with a magnitude of 5.2 occurred at 07:56 a.m. on 23 July 2003. There were after shocks with the magnitudes of 4.1 on the following days. On 26nd of July 2003, another earthquake with a magnitude of 5.6 happened near Buldan at 11:26 a.m. with the local time. This earthquake caused, no life loss, but some damages to kerpiç and stone wall houses. Kerpiç and stones were joined each other with clayey mortar material.

The epicentre of the earthquakes scattered north of Buldan (Figure 10) The nearest station to the earthquake activity was Yenice temperature station. Tekkehamam station was also near to the area. Figure 11 shows relation between theoretical tidal wave height at İzmir (210 km far from Buldan) and the time and magnitude of Buldan earthquakes in Denizli. As seen from the figure the earthquakes occurred when the height of the tidal wave was at low level. This can be interpreted as the global position of the earth relatively to the sun and the moon can affect the earthquake activity on the earth surface.

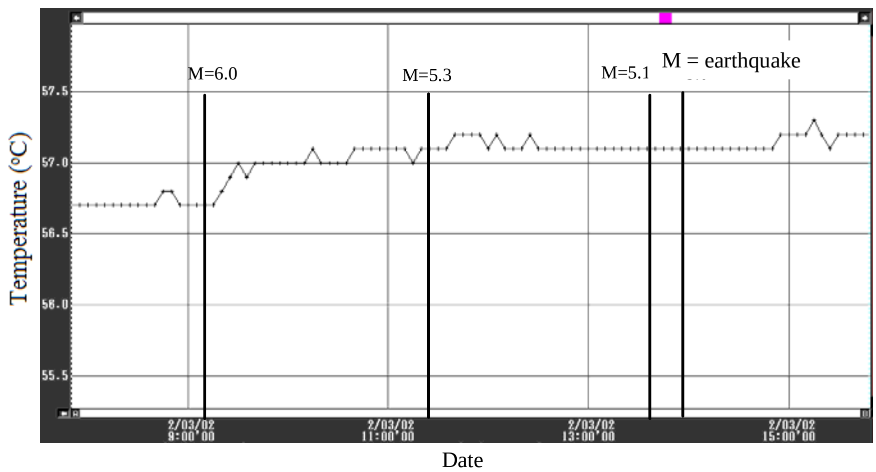

Figure 9. Temperature changes of Pamukkale-Çukurbağ station during Afyon Çay-Eber earthquake in 2002.

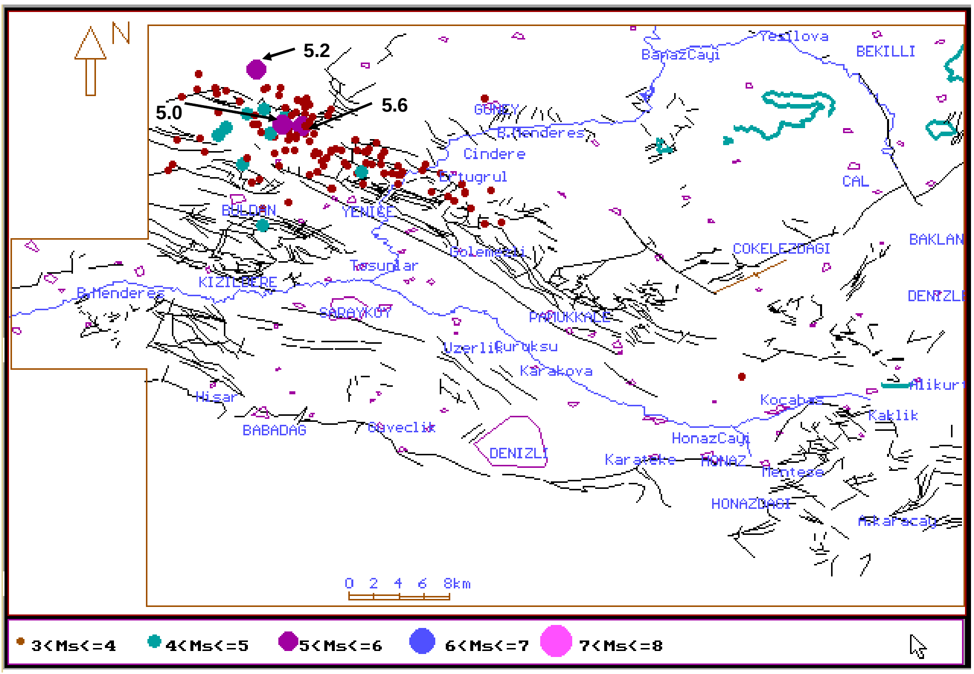

Figure 10. Tectonic map of Denizli region and epicentre distribution of July 2003 Buldan Earthquakes (tectonic map taken from Aydın, 1991)

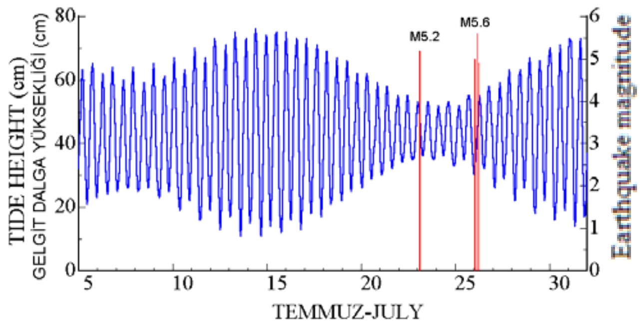

Figure 11:. The relation between theoretical tidal wave height at İzmir and the time and magnitude of Buldan earthquakes.

A parameter called Magnitude-Distance Index (MRI) is xpressed as follows: $MRI = \frac{M}{R} x100$

Where M and R are magnitude and hypocenter distance of earthquake. This parameter is considered to be an appropriate parameter to take into account the effect of earthquake on puf-puf count rate of the station.

Tekkehamam Puf-Puf count is defined as the acoustic emission count in a unit time of gas pressure of thermal spring mud bubbles. Normally Puf-puf count has a similar response that resembles changes of tidal wave. If there is an extra ordinary difference on the AE count, this can be related to an earthquake activity in the region. There is an important increase of the puf-puf numbers 2 days before the 5.2 earthquake in Buldan. The activity of the puf-puf count continued as the earthquake activity was on. After 3 days, an earthquake with a magnitude of 5.6 occurred. When the afterschocks down to less than 3.5 magnitude, the puf-puf count was down to low level (Figure 12 a, b). This shows that there is a relation between the earthquake activity of the region and the puf-puf count changes.

The electric potential data variations of Honaz, Tekkehamam and Çukurbağ stations look like the change of tidal wave height. During the measurements there are some unwanted artificial sudden voltage changes due to human touch. At Çukurbağ station there are electric potential changes which are thought to be related to the 5.2 and 5.6 magnitudes (Figure 13). At Tekkehamam station there are sudden changes.The changes at EW direction of Honaz station and NS direction at Çukurbağ station started at the same time 2 days before the 5.2 magnitude. When the 5.6 magnitude of earthquake occurred, the Honaz station NS direction value was down to minumum voltage value and than the graph started to increase. This type of changes was also obtanined by Aydan et.al, (2001a, 2002, 2003) from the laboratory uniaxial tests as well. The changes at the Honaz and the Çukurbağ stations point out the possible changes of the regional stress. Figure 14 shows temperature changes of thermal water springs and atmosphere within the safety boxes of the thermo recorder loggers at Yenice, Çukurbağ and Tekkehamam. There is a change of 2 degrees at Yenice station on 13th of July. On the same day there are also changes of the thermal waters at Çukurbağ and Tekkehamam. There is a decrease at Tekkehamam between 20-25th of July. At Çukurbağ thermal spring, there is an increase of the temperature. Before 5.2 magnitude of earthquake, there is not a measurement from the thermal spring due to a technical problem with the probe. There is a temperature decrease after 5.6 magnitude of earthquake at Çukurbağ thermal spring. The temperature increase of the thermal waters can be related to the increase of the stress loading within the earth crust around Buldan region. The decrease of the thermal water temperatures are related to the stress relief of the region.

7. CONCLUSIONS

As the Denizli basin is surrounded by active faults from South and North, the region has been under the influence of earthquake activity for decades.

A multi parameter measurement system was established in order to investigate the relationship between earthquake activity and some changes in the earth"s crust of Denizli basin. The changes of temperature of thermal waters, electric potential of ground and acoustic emission counts from water and rock have been continuously monitored.

The changes in thermal water temperature of Pamukkale-Çukurbağ station during the Afyon Çay-Eber earthquake activity shows that regional influences can occur during strong earthquakes.

There was an earthquake activity of Buldan in Denizli in July 2003. Earthquakes with magnitudes of 5.2 and 5.6 occurred. There is a sharp increase on Tekkehamam puf-puf AE counts 2 days before the 5.2 earthquake in Buldan. The AE count reached to maximum with the 5.6 magnitude of earthquake occurred 3 days after. Electric potential and temperature of thermal water changes seem to be related with the earthquake activity of the region.

As the active fault lines are in a number of fault segments, it is also required to have additional multiparameter measurement station for the fault segments located on active fault zones. On line data monitoring system of the measurement stations is also necessary for real time monitoring.

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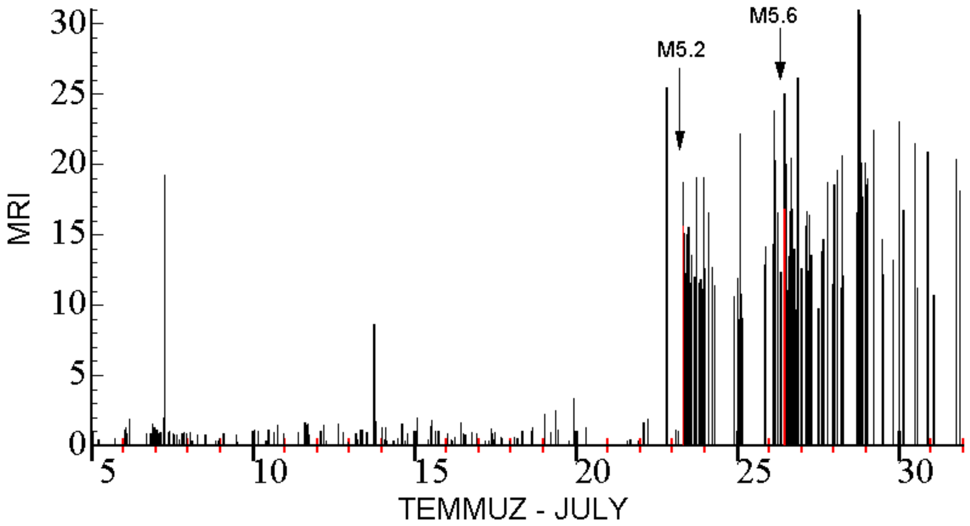

Figure 12(a): The variation of MRI at Tekkehamam station

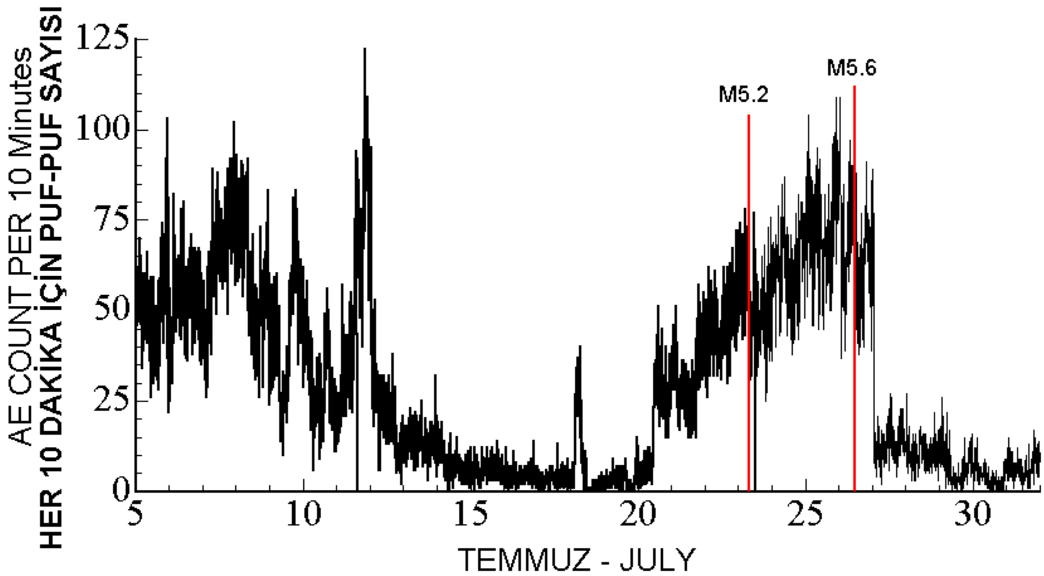

Figure 12(b):. The variation of puf-puf count with time during July at Tekkehamam station

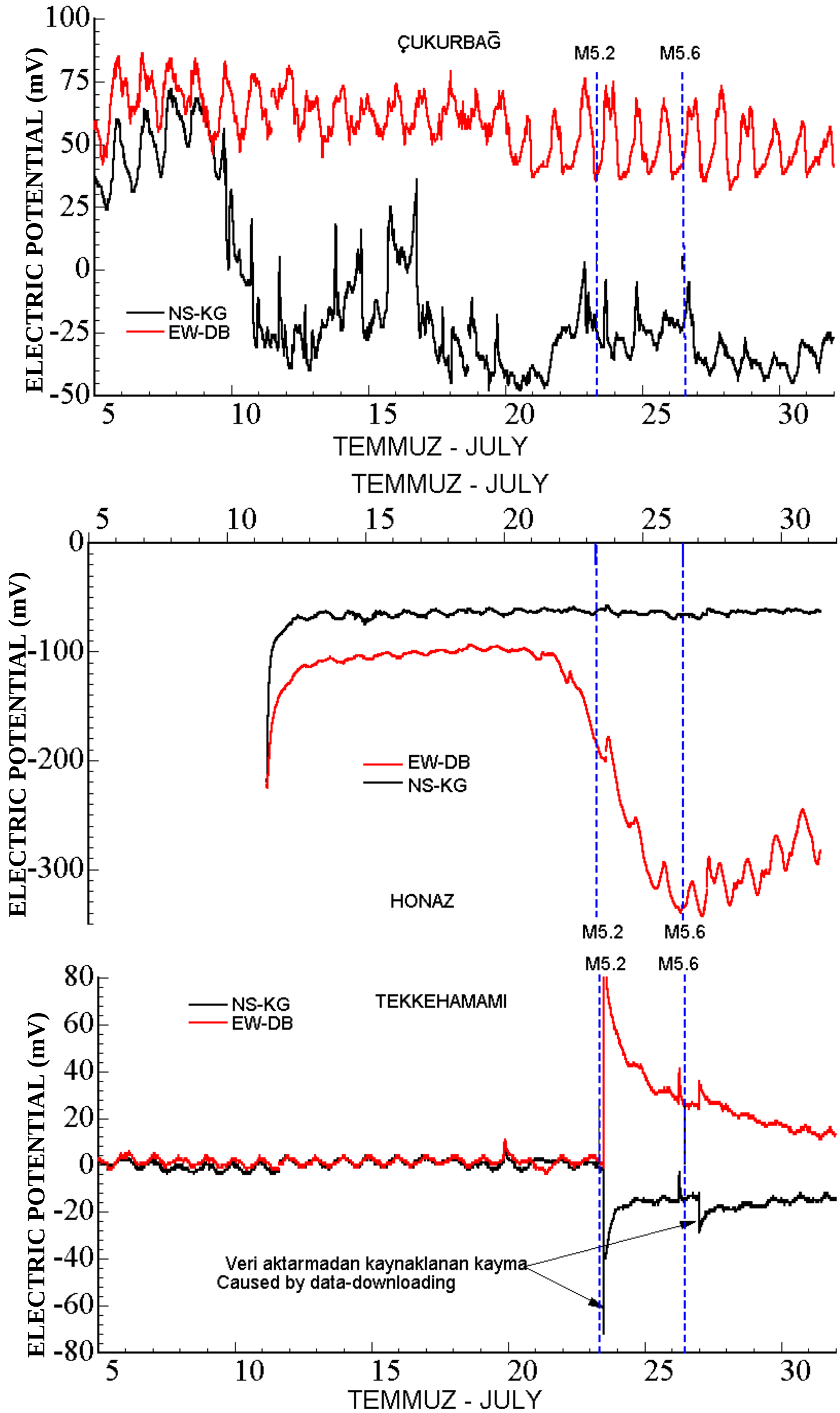

Figure 13: Electric potential variations at Honaz, Çukurbağ and Tekkehamam stations.

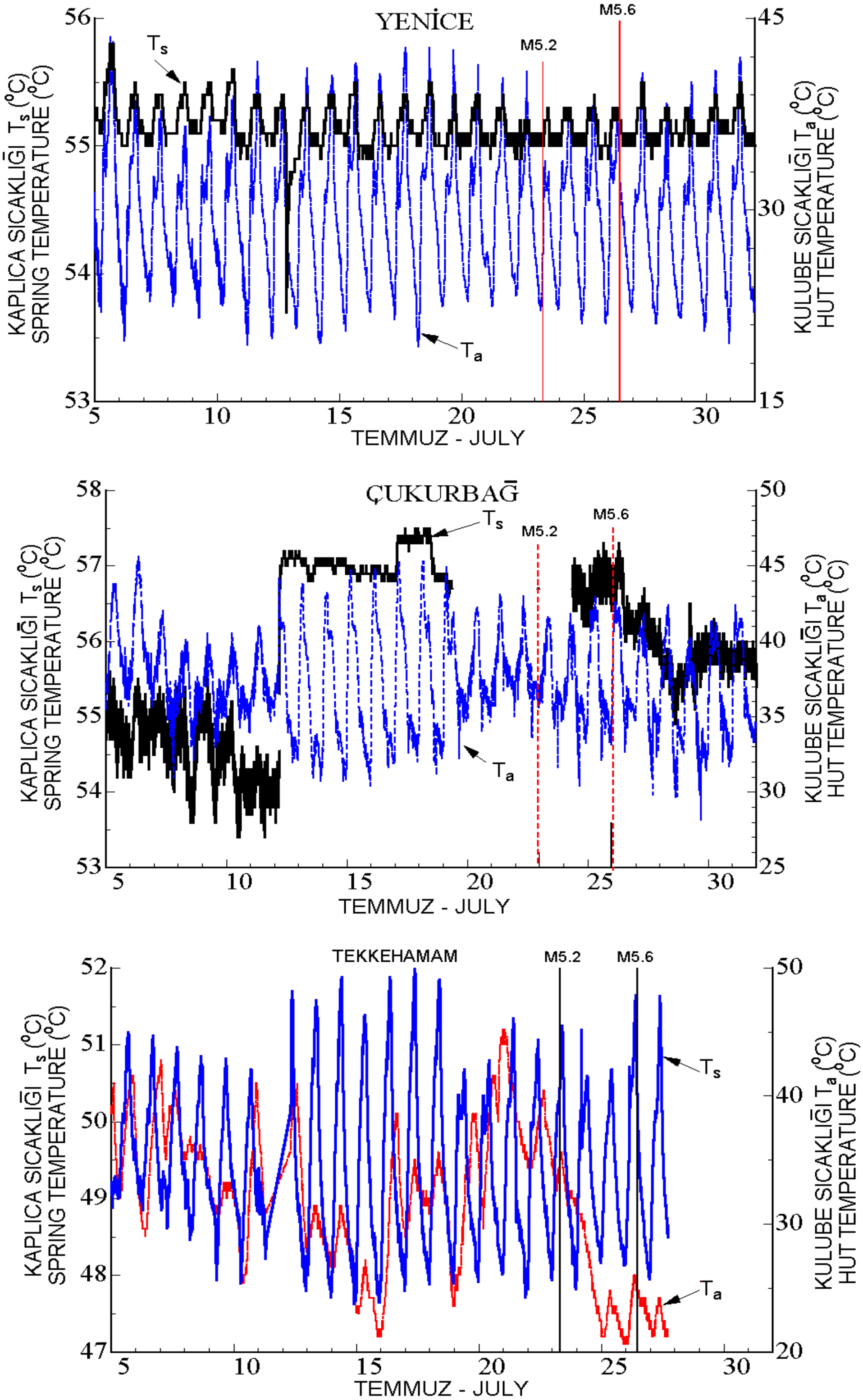

Figure 14. Temperature variations at Yenice, Çukurbağ and Tekkehamam stations (T_s: hot spring temperature; T_a: Hut temperature).