Physico-chemical behaviour of underground waters after the October 1, 1995 Dinar earthquake, SW Turkey (*)(**)

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Summary. — On the evening of October 1, 1995, a $M_S = 6.1$ earthquake destroyed the city of Dinar, SW Turkey. Within 48 hours after the main shock, a team of the German Earthquake Task Force arrived in the area to investigate possible earthquake-related changes in the physico-chemical composition of shallow and deep groundwaters. A mapping was performed to characterise different groundwater types and a continuously monitoring station was installed within the geothermal field of Afyon. Repeated measurements, performed 1, 6, 12 and 18 months after the event, reveal post-seismic changes in water discharge, water temperature, and conductivity. We will focus on the changes of spring water discharge observed in the vicinity of the epicentre. In the first month after the earthquake the groundwater discharge increased at springs located within the down-thrown block, whereas a slight decrease was observed at sites on the hanging wall.

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1. – Introduction

Groundwater anomalies belong to the oldest reported precursors to earthquakes. Gold and Soter (1984/85) collected hundreds of historical observations dating back to the year 1663. The first anomalies associated with earthquakes were detected without sophisticated equipment: changes in temperature, taste or colour of the groundwater, up-welling gas bubbles, water level changes in wells were frequently observed before, during and after seismic events. The Task Force "Hydrogeology" aims at the detection and understanding of earthquake-related changes of physico-chemical groundwater parameters. Mixing of different water types is the most accepted model to explain seismo-tectonically induced groundwater anomalies (Thomas, 1988). These changes might be permanent or transient. An example for the first kind of anomalies was given

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by O'Neil and King (1981), who found a different isotopic composition of groundwater before and after an earthquake in California. Changes in the hydraulic heads within different aquifers are proposed to be the driving force to create the second class of anomalies by shifting the mixing ratio of two or more components feeding a groundwater system (Thomas, 1988; Roeloffs, 1988). A recent example of such spike-like anomalies was observed during the Kobe earthquake of January 17, 1995 when the concentration of chloride in a bottled groundwater increased before the earthquake and thereafter decreased (Tsunogai and Wakita, 1995) until the original level was reached again in the fall of 1995 (*). Because the duration of such earthquake-related anomalies might be limited to a few days or weeks, it is necessary to be on-site as soon as possible after the event.

2. – Methods

The first mission of the German Earthquake Task Force "Hydrogeology" started on October 3, 1995 with a mapping of more than 50 thermal and mineral waters on a regional scale and about 30 shallow groundwaters locally around Dinar, SW Turkey (fig. 1). The following parameters were determined directly in the field: spring discharge, water temperature, specific electrical conductivity, pH, E_H (redox potential),

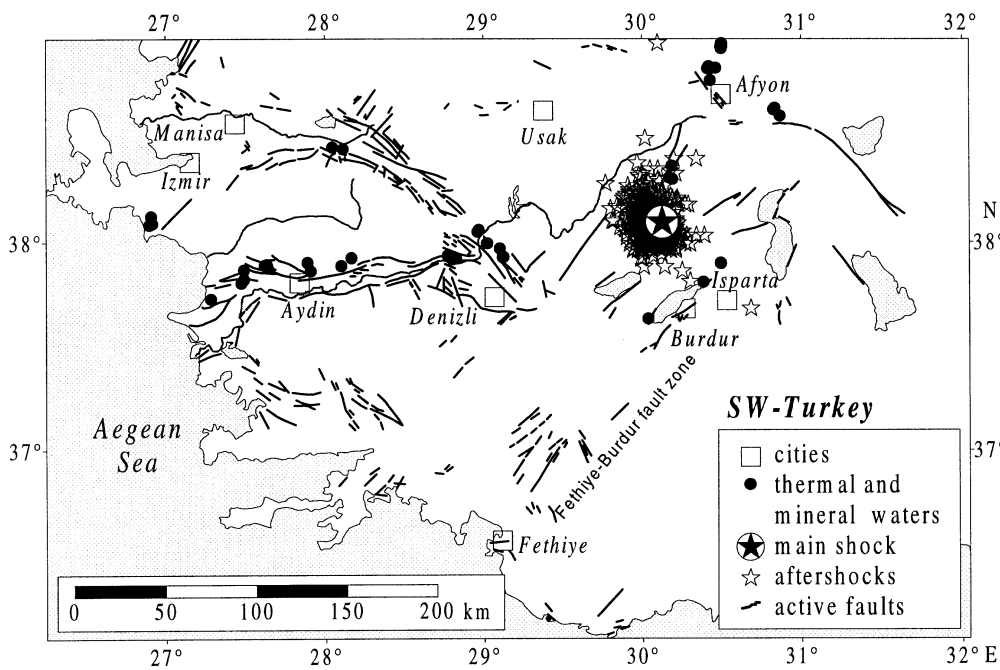

Fig. 1. – Location of the investigated thermal and mineral waters in SW Turkey. Stars indicate the distribution of about 700 aftershocks (data from Demirtas *et al.*, 1995). The solid lines mark the active fault lines according to Saroglu *et al.* (1992).

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HCO_3^-, F^- as well as the amount of the dissolved gases oxygen, CO_2, and radon. Water samples were taken to determine the major constituents Ca, Mg, Na, K, Si, Cl, and SO_4. Repeated measurements were performed during October/November 1995, March/April 1996, October 1996 and April 1997. After the first mapping campaign a continuously monitoring station had been installed at a thermal spring within the geothermal field NW of Afyon which is located about 120 km N of the epicentre. The decision for Afyon was based on the information that an artesian hot-water well dried up a few days before the Dinar earthquake. About 250 m NW of this bore hole, a natural hot spring was chosen to monitor radon in the gaseous phase, the total gas content, temperature, *p*H, and the conductivity of the water. The data are stored in 10 minute intervals and transmitted every hour via satellite to Potsdam.

3. – Results and discussion

As expected for deep groundwaters, the majority of the investigated thermal and mineral waters did not show any changes at all. At a few sites significant variations of the specific electrical conductivity were observed, which could be related to seasonal effects. Anomalies (*e.g.*, decreasing temperature and spring discharge) within the geothermal field of Afyon could be explained by a reduced reservoir pressure due to stress release after the earthquake. However, this assumption has to be checked against the potential effects of the beginning exploitation of the geothermal field (Woith *et al.*, 1998). In the following we will focus on temporal variations of the shallow groundwaters around Dinar.

The cold springs in the area around Dinar are typically shallow groundwaters of Ca-Mg-HCO_3 type. High nitrate concentrations (above 50 mg/l) were found in 20% of the investigated sites indicating the quick response of the aquifers to human activities, namely the use of fertilisers.

A karstic spring located in NE Dinar showed the most remarkable changes. The spring is named "Sucikan" and feeds a little artificial lake. In September 1995 the level of this lake was reportedly lower (*) than after the earthquake when a discharge of about 2000 litres per second was estimated. The lake level dropped 20 cm between October 13, 1995 and November 2, 1995 and additional 30 cm until April 3, 1996. A discharge of 2000 l/s seems to be unusually high. Reporting about a field campaign carried out during summer 1986, Hobbs (1987) wrote about this spring: "At Dinar, there is a second tributary to the Büyük Menderes Nehri. The spring issues from a fracture in the hillside at around 50 l/s into an artificial lake". The second remarkable thing is that a decreasing spring discharge during the rainy season is unusual for a karstic aquifer system.

According to information of some inhabitants, springs located near the surface rupture showed a considerable increase in water discharge after the earthquake. Others reported about decreasing discharges. These contradictory statements were confirmed by our measurements (fig. 2). The majority of springs located to the SW of the surface rupture, *i.e.* within the down-thrown block, showed increasing values, whereas most springs to the NE of the rupture are characterised by decreasing values. This pattern seems to correlate with the focal mechanism of the main shock. The fault

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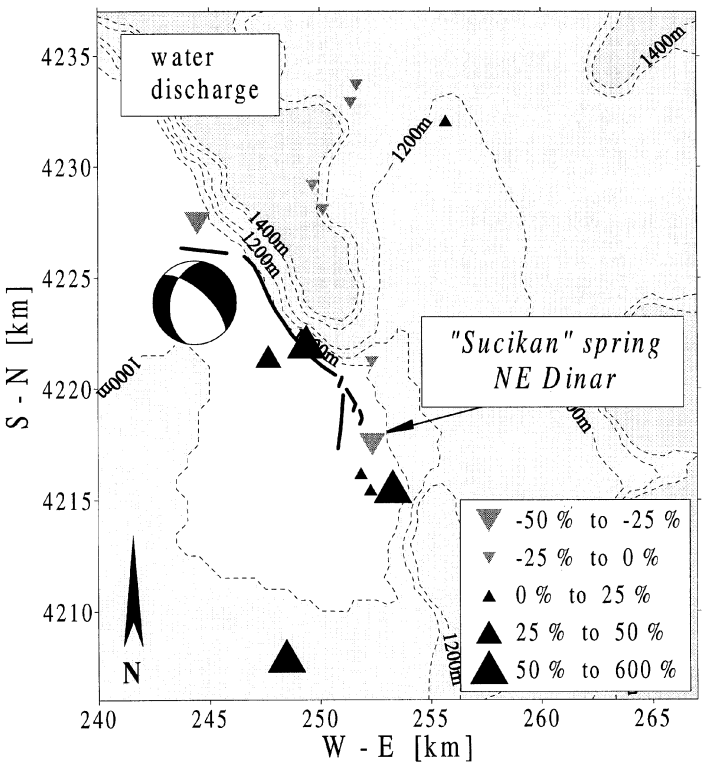

Fig. 2. – Changes in the spring discharge of shallow groundwaters around Dinar. Shown are differences between the first measurement (October 12-15, 1995) and the second measurement (November 1-3, 1995) relative to the first measurement. The "ball" depicts the location and the focal mechanism of the main shock (*Harvard CMT solution*). The bold lines mark the surface ruptures mapped by Demirtas *et al.* (1995).

plane solution revealed a mechanism of predominantly normal faulting with a small strike-slip component (see "ball" in fig. 2). A vertical offset between 20 cm and 50 cm and a horizontal displacement of 5–10 cm could be determined in the field. Pinar *et al.* (1996) and Eyidogan and Barka (1996) agree that the rupture started near Dinar (first subevent at a depth of 8 km) and then propagated about 10 km to the NW, where the major subevent took place at a depth of 12 km. A possible explanation for the observed pattern is that the groundwater is squeezed out to the Earth's surface within the down-thrown block, whereas the water level is supposed to drop in the hanging wall. This characteristic behaviour of the spring discharge is not observed for any other groundwater parameter: no significant correlation is found between the changes of the discharge and changes of the water temperature, the specific electrical conductivity, the *p*H, the redox potential or the amounts of dissolved oxygen and radon.

4. – Conclusions

Post-seismic changes in water discharge, water temperature, and conductivity were observed during repeated surveys in the Dinar area and the Afyon geothermal field after the earthquake of October 1, 1995. These variations indicate changed mixing ratios of different aquifers which might be caused by i) meteorological/seasonal effects, ii) the creation of new underground flow paths and/or the closure of existing ones, iii) a stress redistribution creating differences in the pressure heads of deeper aquifer systems, and iv) artificial effects. We explain the observed changes in the spring discharge of shallow groundwaters around Dinar as type ii) anomalies.

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