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Geodynamics of the Marmara Sea region

Recent tectonic activity and the role of fluids at the western end of the North Anatolian Fault Zone

with 10 figures and 2 tables

MARTIN PFISTER[1)], EMIL GREBER[2)], CONRAD SCHINDLER[3)], CHRISTIAN STRAUB[4)], HANS-GERT KAHLE[5)] & LADISLAUS RYBACH[6)]

Zusammenfassung

Bei der Region Marmara handelt es sich um ein Gebiet mit erhöhter neotektonischer Aktivität. Die aktiven Bewegungen der Erdkruste treten auf in Kombination mit hoher Seismizität, zahlreichen Thermalwasservorkommen und Gasaustritten. Die Neotektonik ist stark durch den Grundwasserfluss und Fluids aus grosser Tiefe beeinflusst. Die wichtigsten neotektonischen Elemente sind: die dextrale Nordanatolische Bruchzone (NAFZ), grossräumige Verformungsmuster, Block Rotationen und die N-S-Extension des Ägäischen Raumes samt West-Anatolien. Basierend auf geologischen Daten belaufen sich die Raten der krustalen Bewegungen an der NAFZ seit Mittlerem Pliocän auf durchschnittlich 1.4–2.0 cm/a, was mit heutigen Raten aus GPS-Untersuchungen übereinstimmt. Die neotektonischen Strukturen folgen zumeist bereits bestehenden, älteren Bruchzonen oder Schwächezonen. Ihre Funktionen dagegen haben sich grundlegend geändert. Das von den GPS-Messungen abgeleitete krustale Deformationsmuster zeigt, dass heute die nördliche Zone der NAFZ, welche eine scharfe Grenze zwischen Eurasien und West-Anatolien bildet, am aktivsten ist. Im Süden verursacht Extension in der krustalen Lithosphäre eine erhöhte Wärmeflussdichte und Thermalquellen-Aktivität. Die meisten Thermomineralquellen sind meteorischen Ursprungs und nehmen Teil am hydrologischen Kreislauf. Bei einzelnen Quellen handelt es sich aber auch um Palaeowässer. Für die Existenz von metamorphen oder primordialen Wasserkomponenten aus grösserer Tiefe liegen keine Anzeichen vor. Es liegen deutliche isotopische Hinweise vor, dass ein Teil der Gase Kohlendioxid, Methan und Helium aus dem oberen Mantel oder tieferen Bereichen der Kruste aufsteigen. Die Fluid-Drucke der Thermomineralwässer des oberflächennahen Systems wie auch jene der aufsteigenden Tiefenfluids (v.a. Kohlendioxid) haben vermutlich einen bedeutenden Einfluss auf das Bruchverhalten und die Seismizität der Marmara Region.

Abstract

The Marmara Sea region is an area of exceptional neotectonic activity. Active crustal movements take place combined with very high seismicity and numerous outflows of thermal waters and gas outputs. Neotectonics is believed to be strongly influenced by groundwater circulation and fluids of deep origin

1) Barerstrasse 53, D-80799 München
2) magma AG, Langstrasse 62, CH-8004 Zürich
3) Schwerzestrasse 7, CH-8618 Oetwil a.S.
4) Swiss Re, Mythenquai 50/60, CH-8022 Zürich
5) Institute of Geodesy, ETH Hönggerberg, CH-8093 Zürich
6) Institute of Geophysics, ETH Hönggerberg, CH-8093 Zürich

in this area. The main neotectonic elements can be defined as: the dextral North Anatolian Fault Zone (NAFZ), regional faulting and tilting, block rotations, and the N-S extension of the Aegean realm including westernmost Anatolia. Since Middle Pliocene, rates of crustal movement along the NAFZ have averaged 1.4–2.0 cm/y based on geological data, close to the present rate of 2.2 cm/y determined from GPS (Global Positioning System) investigations. The neotectonic structures mostly follow pre-existing faults or zones of weakness. Their function, however, has changed completely. The GPS-derived crustal deformation pattern shows that the northern zone of the NAFZ is most active today, forming a sharp boundary between Eurasia and Western Anatolia. To the south, extension of continental lithosphere elevates terrestrial heat flow density and thermal spring activity. Most of the thermo-mineral waters are of meteoric origin and part of the modern hydrologic cycle, some are paleowaters. No evidence exists for involvement of metamorphic or primordial waters. Isotopic evidence suggests that carbon dioxide, methane and helium partly ascend from the upper mantle and lower crustal levels. The fluid pressures of the shallow thermo-mineral waters as well as of the deep-seated carbon dioxide probably play an important role in fault behavior and seismicity in the Marmara Sea region.

1. Introduction

The North Anatolian Fault Zone (NAFZ) forms the tectonic connection between the East Anatolian convergent zone and the Hellenic Arc, where the motion of Asia Minor is compensated by the consumption of oceanic crust (McKenzie 1972). The eastern part of the NAFZ is a narrow strike-slip zone, whereas further in the west, in the Marmara Sea region, the NAFZ splits into a complex fault pattern (Fig. 1). This branching is caused by the transition of the pure strike-slip regime in the east into a stress regime with additional N-S extension. The latter is typical for the Aegean region and responsible for the predominant E-W oriented graben structures in Western Anatolia.

In this paper, we describe the neotectonic activity of the Marmara Sea region. We especially focus on the interaction of neotectonics with groundwater circulation and fluids of deep origin (CO_2, He, CH_4, N_2) and then compare our findings with the situation along the San Andreas Fault System (SAFS).

The present work develops new aspects of the MARMARA Polyproject (Schindler & Pfister 1997).

2. Seismicity

In the Marmara Sea region, historic seismic activity is prominent (Ambraseys & Finkel 1991); many devastating earthquakes have occurred along the NAFZ. The instrumentally covered period shows that in the last decades seismicity of Western Anatolia has been highly active. Detailed investigations of low-magnitude earthquakes reveal swarm-type activity with remarkable clustering in space and time (Ücer et al. 1985, 1997, Sellami et al. 1997). The fault mechanisms of strong earthquakes are associated with major tectonic structures (Jackson & McKenzie 1988, Papazachos & Kiratzi 1996). According to various bulletins and sources the focal depths of the earthquakes range from 0 to 50 km. More accurate localization of selected earthquakes suggest focal depths no deeper than 10 to 15 km (e.g. Eyidogan & Jackson 1985). In the Bursa region, Sellami et al. (1997) located 90 % of the low-magnitude earthquakes in the uppermost 15 km, and only few earthquakes with depths between 15 and 60 km.
Based on the epicenters distribution of Western Anatolia, Crampin & Evans (1986)