HIGH BORON CONTENTS OF THE KIZILDERE GEOTHERMAL WATERS, TURKEY

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ABSTRACT: The thermal waters of Kizildere Geothermal Power Plant have boron contents of up to 32 mg/Land flow at a rate of about 500 L/s into Büyük Menderes River. They pollute river water by elevating boron contents up to 4.4 mg/L for a river- flow rate of 2 m/s. These high boron contents can be attributed to unstable boron-bearing mineral phases (e.g. feldspars, muscovites, tourmalines, hornblendes, and biotites) in the metamorphic rocks, proven by experimental leaching tests of various rocks, and a magmatic input, corroborated by isotope analyses of δ^{11}B, δ^{13}C, and δ^{34}S of the thermal waters. Additionally, Neogene boron deposits in NW Turkey have to be taken into consideration as possible further source of boron, which contribute to these contents.

1 INTRODUCTION

High-temperature thermal waters in the rift zone of the Büyük Menderes within the Menderes Massif are characterized by boron concentrations up to 32 mg/L. Due to toxic effects of boron, the economic utilization of the thermal waters is less favorable in the area as long as the geothermal waters are not reinjected in the main reservoirs; therefore, high boron concentrations such as these poison some plants such as citrus fruits in the rift zone of the Büyük Menderes. The waste waters from the geothermal power plant of Kizildere flow at a rate of 500 L/s into the Büyük Menderes river.

In order to explain the origin of the high boron contents in the thermal waters of this continental rift zone of the Büyük Menderes, we have investigated the thermal field of Kizildere and its environs in combination with a study of the origin and evolution of the thermal waters (Fig. 1).

A research carried out from 1994 to 2003 was divided into two main fields: (i) geological and geochemical investigations based on detailed mapping and rock sampling and (ii) comprehensive hydrogeological and hydrogeochemical investigations with sampling of groundwaters, thermal waters and river waters in the rift zone of the Büyük Menderes.

Figure 1. Panorama view of steam fountaines in the geothermal field of Kizildere.

2 GEOLOGIC SETTING

The study area is located in the northern flank of the eastern part of the Büyük Menderes rift zone within the Menderes Massif (Figs. 2 & 3). In this area, the metamorphic basement of Paleozoic gneisses and several schists is overlain discordantly by Pliocene clastic sediments. These sediments are of fluvial and lacustrine character and consist of (i) the 200-m thick Kizilburun Formation, representing cycles of red and brown conglomerates, sandstones, shales, and lignites; (ii) the Sazak Formation, with a thickness from 100 to 250 m, consisting of intercalated grey limestones, marls, and siltstones; (iii) the Kolonkaya Formation, having a range of thickness from 350 to 500 m, which contains yellowish green marls, siltstones, and sandstones; and (iv) the 500-m-thick Tosunlar Formation comprising cycles of conglomerates, sandstones and mudstones with fossiliferous clay units. The gneiss is distinguished by the minerals quartz, feldspar, white and black micas, tourmaline and accessory minerals. The mica schists also contain garnets.

The thermal field is regionally controlled by E-W trending faults. Locally, NW-SE or NE-SW trending faults have been active in the field (Özgür et al. 1998a, b). The development of these faults lead to compression, which was generated by the extension during the formation of the rift zone of Büyük Menderes (Özgür et al. 1997, Özgür 1998).

In the thermal field of Kizildere, the metamorphic andsedimentary rocks are characterized by intense hydrothermal alteration, which is represented by phyllic, argillic, and silicic ± hematitic alteration zones. Carbonatization must be considered as a new type alteration in the thermal field of Kizildere (Özgür et al. 1998b).

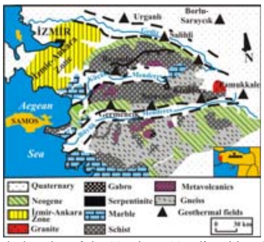

Figure 2. Geological setting of the Menderes Massif and location map for the Kizildere geothermal field.

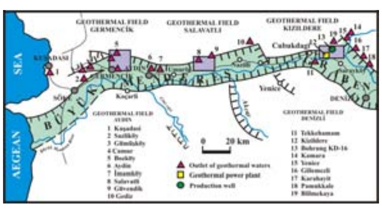

Figure 3. Location map and distribution of the thermal waters of the Büyük Menderes.

3 BORON GEOCHEMISTRY

To investigate the origin of the high boron concentrations in thermal waters, more than 250 rock samples were collected within the study area. Boron contents in rocks, groundwaters, thermal waters, and river waters were analyzed by spectrophotometry (Robert Riele, PM 210) using reagents of calibration standards, spectroquant® 14839, and curcumin in the Freie Universität Berlin, Germany (Gallo 1998, Özgür 2001) and Süleyman Demirel Üniversitesi, Turkey (Yaman, in prep.). The Precambrian to Cambrian metamorphic rocks differ from the Pliocene sedimentary rocks by their high boron contents. Boron contents in the gneisses range from 6 - 28151 ppm, with a background value of 191 ppm (Fig. 4, Özgür 1998, 2001). For comparison, the Igdecik Formation, which is composed of mica schists, quartzites and marbles, has a range of boron from 6 - 240 ppm and a background value of 170 ppm. The background values are 53 ppm in Kizilburun Formation (range: 9 - 79 ppm), 16 ppm in Sazak Formation (range: 4 - 24 ppm), 15 ppm in Kolonkaya Formation (range: 2 - 680 ppm) and 48 ppm in Tosunlar Formation (range: 15 - 63 ppm). Recent mineral precipitates in the thermal waters of Kizildere and its environs show a background value of 56 ppm in a range from 5 - 2846 ppm.

The plot of B versus SiO_2 and Al_2O_3 indicates a close positive correlation between boron contents and the rock-forming minerals quartz, feldspar and micas in the study area of Kizildere (Özgür 2001), which can be confirmed by plots of B versus Na_2O and K_2O. Boron may be incorporated in the crystal lattice instead of Si and Al (Christ 1965).

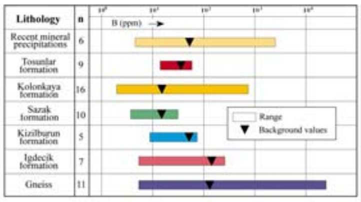

Figure 4. Range and background values for boron in Precambrian-Cambrian and Pliocene sedimentary rocks of Kizildere and environs. For B analyses in hard rocks, see Özgür (1998).

The plot of B versus SiO_2 and Al_2O_3 (Fig. 5) indicates a close positive correlation between boron contents and rock-forming minerals of quartz, feldspar and micas in the study area of Kizildere, which can be confirmed by plot of B versus Na_2O and K_2O (Fig. 6). Boron may be incorporated in the crystal lattice instead of Si and Al (Christ, 1965); besides, the size of lattice depends upon Al-oxide and B-oxide of 1,76 A° and 1,48 A° in ion radius respectively.

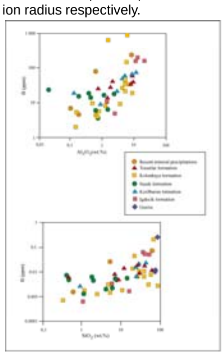

Figure 5. Plot of B versus SiO_2 and Al_2O_3 in metamorphic and sedimentary rocks of Kizildere.

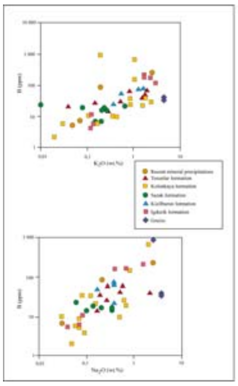

Figure 6. Plot of B versus Na_2O and K_2O in metamorphic and sedimentary rocks of Kizildere.

4 BORON HYDROGEOCHEMISTRY

In the thermal field of Kizildere and its environs, boron contents of 200 samples of groundwaters, thermal waters and river waters of Büyük Menderes were analyzed by spectrophotometry, in March 1996, October 1996, March 2002 and October 2002 for at least two different seasons. For comparison, 75 samples from the thermal fields of Salihli, Bayindir, Salavatli and Germencik (Özgür 1998. Özgür et al. 1998a) have been used.

In March 1996, boron concentrations in the river waters, which are supplied by the thermal waters of the geothermal power plant of Kizildere, are up to 0.76 mg/L (Fig. 7, Özgür 2001). In comparison, the boron concentrations in the river waters increased up to 1.3 mg/L in October 1996 (Fig. 8, Özgür 2001). There is a close correlation between boron contents in various rocks and boron concentrations in leachates of the different rocks (Özgür 2001). These leaching tests indicate a distinct dependence upon the temperature; high temperature and buffering effects play important roles.

Figure 7. Boron contents of groundwaters in March 1995, thermal waters and river waters of Kizildere and environs. For B analyses of these waters, see Özgür (1988) and Gallo (1998).

Figure 8. Boron contents of groundwaters in October 1995, thermal waters and river waters of Kizildere and environs. For B analyses of these waters, see Özgür (1988) and Gallo (1998).

Figure 9 shows a close correlation between boron contents in various rocks and boron concentrations in leached different rocks. These leaching tests indicate a distinct dependence upon the temperature; besides, the high temperature and buffer effect play an important role.

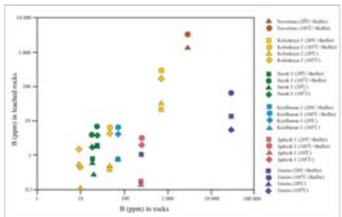

Figure 9. Plot of boron contents in various rocks vs. boron concentrations in leached rocks.

5 DISCUSSION

The stable isotope compositions (δ^{18}O and δ^{2}H) in thermal waters are shown in Figure 10. The groundwater and mixed groundwater-thermal water samples lie along the meteoric water line whereas the high temperature thermal waters deviate from the meteoric water line indicating a fluid-rock interaction under high temperature conditions (Yaman, in prep.).

The solubility of boron from boron-bearing mineral phases may contribute to the increase of boron in the thermal waters in the rift zones of Menderes Massif. Biotite, white micas, tourmaline, feldspars and hornblende are potential boron sources.

The experimental leaching tests of various rocks in Kizildere and its environs show that gneiss and mica schists play an important role as a possible boron sources. In addition, the magmatic input of boron increases these concentrations in the thermal waters, which could be corroborated by the isotope ratios of ^{11}B/^{10}B (Giese 1997, Özgür 1998) and the values of δ^{13}C and δ^{34}S in thermal waters (Özgür 1998, 2001, 2002).

The possible existence of boron deposits at depth, such as those that occur in connection with young volcanism in the northeastern part of Turkey (e.g. the deposits of Bigadic in Balikesir and of Kirka in Eskisehir) should be considered as another potential boron source. Finally, the cause for the high boron concentrations measured in the thermal waters of the rift zones of the Menderes Massif is probably the result of several natural factors.

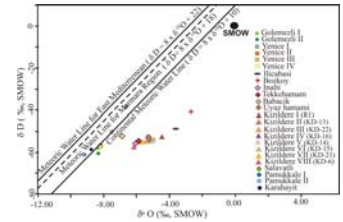

Figure 10. Plot of δD versus δ^{18}O of thermal waters of Kizildere and environs.

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