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The geothermal resources of the Republic of Djibouti — I: Hydrogeochemistry of the Obock coastal hot springs

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ABSTRACT

This paper examines the hydrochemical features of the waters from the Obock coastal geothermal field. As the submarine waters at the ridge, their chemical and isotope composition shows affinities with sea water–basalt interactions at hydrothermal temperature. Moreover, good linear correlations were obtained between hot springs and of sea water sample points when plotting normalized concentrations of elements to chloride (Mg/Cl, SO_4/Cl, K/Cl, Ca/Cl, SiO_2/Cl) versus concentration of Li/Cl. This would indicate that two end members exist (seawater and reservoir fluid). After extrapolation of the Mg and SO_4 concentrations to zero, the obtained value of SiO_2 corresponding to the reservoir fluid end member was used to estimate the reservoir temperature by quartz geothermometers. The obtained temperature of 187 °C is in good agreement with that obtained from multiple mineral equilibrium approach (180–200 °C), cationic geothermometers (172–191 °C) and by the evaluation of isotopic equilibrium between water and sulfate molecule (207 °C). Summarizing all the employed approaches, a mean temperature of 197 ± 10 °C has been estimated.
The isotopic $\delta^{34}S(SO_4)$ signature of the dissolved sulfates in Obock thermal waters confirms that these waters result from the mixture of a hot seawater-derived fluid (absence of sulfates) with cold seawater. However, water isotope data did not exclude the presence of a small contribution from fresh groundwater.

1. Introduction

The Republic of Djibouti is one of several African countries located on the East African Rift System where geology is also resulting from two other ridges of Red Sea and Gulf of Aden. As in other rifting zones, the activity of the East African Rift System corresponds to large seismic, tectonic and volcanic activities (Barberi et al., 1975; Mlynarski and Zlotnicki, 2001).

In Djibouti, most of the widespread geothermal activity, manifested in the form of numerous hot springs, fumaroles and hydrothermal alteration, is located mainly in the western part of the country and along the Gulf of Tadjourah ridge (Fig. 1A).

The most geologically active area in Djibouti is the Lake Asal area, and the Asal rift is one of two emergent oceanic ridges in the world, the other being Iceland (Mlynarski and Zlotnicki, 2001). Accordingly, numerous geological and geophysical studies were completed in Lake Asal in order to understand the phenomena related to sea floor spreading (Mlynarski and Zlotnicki, 2001; Pinzuti et al., 2010). Moreover, geothermal studies undertaken in the late 1960s and early 1970s allowed selecting the Asal prospect as the most favorable area for carrying out deep drilling exploration (Demange et al., 1971; Lavigne and Lopoukine, 1970). Therefore, six geothermal wells (Asal 1 to 6) with various depths, between 1137 m and 2105 m, were drilled in the Asal prospect during the last decades (Aquater, 1989; BRGM, 1975). However, the high enthalpy Asal geothermal fluids (about 350 °C) have had high salinity (116 g/kg) (D'Amore et al., 1998).

On the other hand, since the main national electricity production sources depend on petroleum products, Djibouti is relatively dependent on diesel fuel and fuel oil imports to meet its energy needs. As a consequence, the electricity cost is exorbitant in the Republic of Djibouti, where in average 1 kWh costs about 0.23 U.S. $ (GBAD, 2011). To mitigate this energy burden, which put a brake on the rate of economic growth in this country, a national program for development of geothermal resources (NPDGR) was implemented in 2010. This program aimed to conduct multidisciplinary studies (geochemical, hydrogeological, geophysical, geological and reservoir engineering) on all areas with geothermal activities in the Republic of Djibouti (CERD, 2011, 2012; Awaleh et al., submitted for publication).

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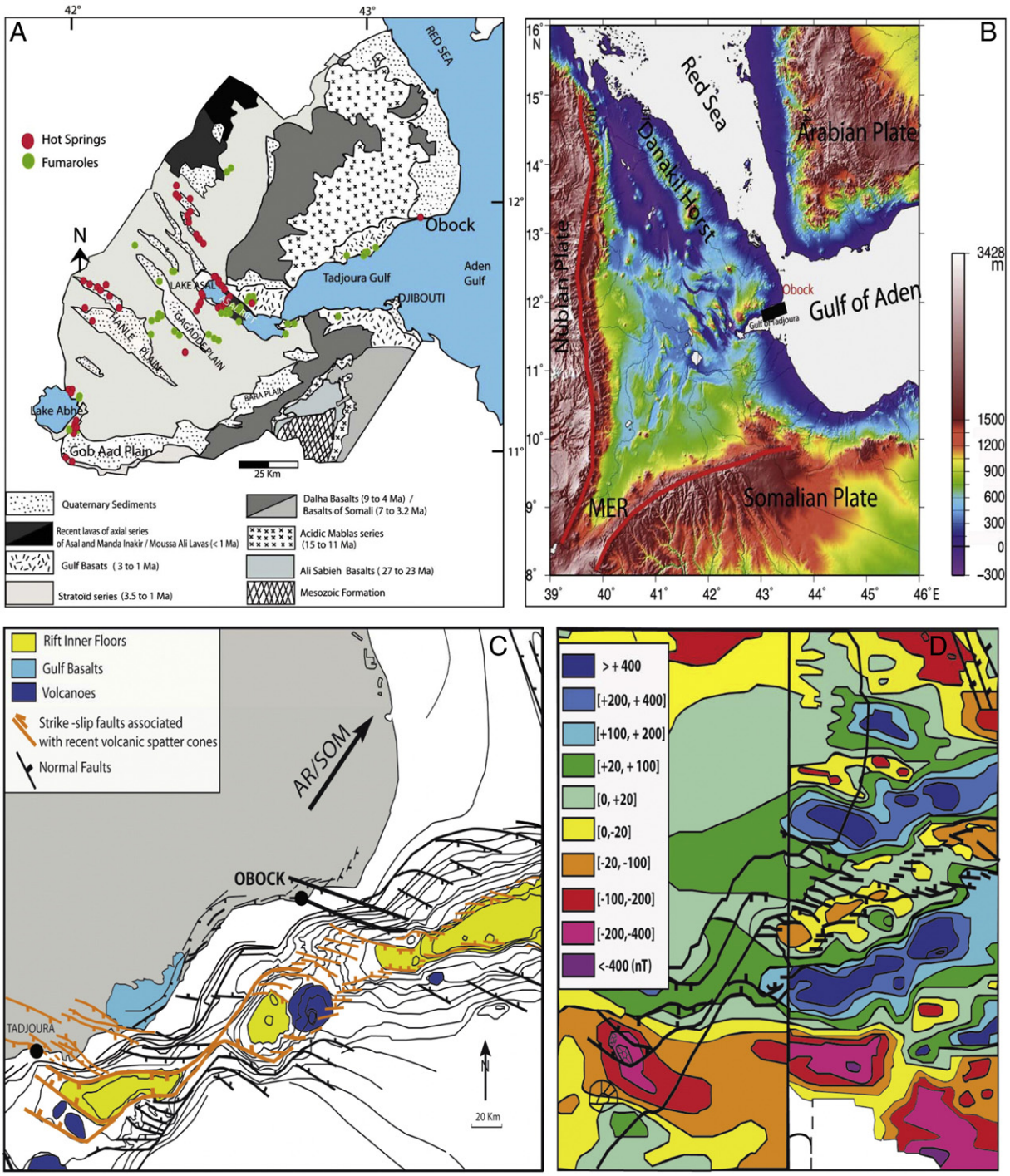

Fig. 1. A: Simplified geological map and hydrothermal activity in the Republic of Djibouti. B: Digital elevation model (DEM) of the Afar Rift system with the location of Obock (Doubre, 2004) (vertical color scale = altitude in meter; the black area = Obock region). C: Tectonic map of the Gulf of Tadjourah. It is noteworthy the extension of the fault lines, from the coast to open ocean (after Manighetti, 1993). D: Magnetic anomaly map of the Gulf of Tadjourah (after Courtillot et *al.*, 1980). In the key, numbers are milliTeslas (mT).

On the basis of new pre-feasibility studies related to the NPDGR, the World Bank granted, in 2012, a loan about 31 M U.S. $ to the Republic of Djibouti to perform four new geothermal wells in the area of Lake Asal (World Bank, 2013). As part of this NPDGR, the hot springs of the Obock beach were also studied in 2013 (CERD, 2013). Previously, 3 samples of Obock hot springs in the intertidal zone were investigated to develop a spa center (Aquater, 1982). Nowadays, the thermal waters of Obock beach are used mainly for hydrotherapy. In the early 1990s, Houssein et al. (1993) studied the geochemistry of four Obock beach thermal springs.

The main purpose of the present study is to characterize the hydrothermal activity from known and newly investigated hydrothermal springs and thus to provide a framework for future studies of the Obock geothermal system, one of the northern active provinces of the Republic of Djibouti. Towards this aim, detailed geochemical investigations have been carried out on the cold groundwaters (well waters and boreholes) and the most representative thermal waters (7 hot springs) from Obock area in order to understand their geochemical evolution and also estimate the reservoir temperature through chemical and isotopic geothermometry as well as mineral equilibrium approach.