Tectonophysics 589 (2013) 77–89

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

New heat flow measurements in Oman and the thermal state of the Arabian Shield and Platform

Frédérique Rolandone [a,*], Francis Lucazeau [b], Sylvie Leroy [a], Jean-Claude Mareschal [c], Rachel Jorand [d], Bruno Goutorbe [e], Hélène Bouquerel [b]

[a] ISTEP, UPMC, Univ. Paris 06, UMR7193, CNRS, F-75005, Paris, France
[b] IPGP/CNRS, UMR7154, 1 rue Jussieu, F-75005, Paris, France
[c] GEOTOP-UQAM-McGill, Montreal, QC, Canada
[d] Applied Geophysics and Geothermal Energy, E.ON Energy Research Center, RWTH Aachen, Germany
[e] Instituto de Geociências, Universidade Federal Fluminense, Niterói, Brazil

ARTICLE INFO

Article history:
Received 5 April 2012
Received in revised form 21 November 2012
Accepted 25 December 2012
Available online 12 January 2013

Keywords:
Heat flow
Arabian plate
Geotherms
Afar plume

ABSTRACT

The present-day thermal regime of the Arabian plate is affected by the dynamics of the Afar plume and the rifting of the Red Sea and the Gulf of Aden. The Arabian plate is a Precambrian Shield and its thermal regime, before the plume and rifting activities, should be similar to that of other Precambrian Shields with a thick lithosphere. This is consistent with low heat-flow values measured in Saudi Arabia (35–44 mWm^{-2}), but not with recent measurements in Jordan that show higher heat flow (56–66 mWm^{-2}). We have conducted measurements in the eastern Arabian plate to obtain 10 new heat-flux values. We also derived 20 heat-flux values from oil exploration wells. Our measurements show that surface heat flux is uniformly low (45 mWm^{-2}) in the eastern Arabian Shield and is consistent with low crustal heat production (0.7 μWm^{-3}). A steady-state geotherm for the Arabian platform that intersects the isentropic temperature profile at a depth of 150 km is consistent with the seismic observations. Differences in heat flow between the eastern (60 mWm^{-2}) and the western (45 mWm^{-2}) parts of Arabia reflect differences in crustal heat production as well as a higher mantle heat flux in the west. Seismic tomography studies of the mantle beneath Arabia show this east–west contrast. The lithospheric thickness for the Arabian plate is 150 km, and the progressive thinning near the Red Sea is caused by the thermal erosion of the plume. The Afar plume mostly affects the base of the Arabian lithosphere along the Red Sea and the western part of the Gulf of Aden by channeling magmas from the asthenosphere through the rift. The continental domain is not affected by rifting in the Gulf of Aden. The main thermal effect of the Arabian plate is probably the channeling of the Afar plume to the North.

1. Introduction

Precambrian Shields are generally low heat flow provinces but detailed studies in the Canadian, South African and Indian shields demonstrate that heat flow differences exist between or within provinces. These differences in heat flow are related to differences of crustal composition and radiogenic heat generation (Jaupart and Mareschal, 1999; Rolandone et al., 2002). The Arabian craton is of particular interest because it was affected by geodynamic processes such as the opening of the Red Sea and the Gulf of Aden, and the Afar plume. The Afar plume is related to large amount of flood basalts that erupted at ~30 Ma during a short time interval (1–2 Ma) in northern Ethiopia (Hofmann et al., 1997) and in Yemen (Baker et al., 1996), more or less coeval with rifting in the Red Sea and the Gulf of Aden. The rifting of the Arabian–African plate during early Oligocene (~34 Ma) resulted in the formation of the Red Sea and the opening of the Gulf of Aden (e.g., Leroy et al., 2012). The formation of new sea floor in the eastern part of the Gulf of Aden started at about 17.6 Ma (Leroy et al., 2004, 2010b) and is now incipient in the Afar and central Red Sea. The margins are volcanic in the southern Red Sea and in the western part of the Gulf of Aden where they are influenced by the Afar hotspot, and non-volcanic east of longitude 46°E (Leroy et al., 2010a, 2012). The Arabian plate to the north plunges beneath Eurasia. Collision occurred between late Eocene and early Miocene, i.e., between ~35–23 Ma (e.g., Agard et al., 2005, 2006). In northern Oman, the ophiolite was emplaced onto the Arabian continental margin during late Cretaceous (Searle and Cox, 1999).

The preexisting thermal state of the lithosphere and asthenosphere is a fundamental parameter for models of continental rifting or subduction, because the thermal regime controls rheology and deformation. It is important to determine the stable thermal state of the Arabian craton on a large spatial scale before lithospheric

* Corresponding author. Tel.: +33 144272308.
E-mail address: frederique.rolandone@upmc.fr (F. Rolandone).

0040-1951/$ – see front matter
http://dx.doi.org/10.1016/j.tecto.2012.12.034

thinning and subsequent thermal perturbations. Surface heat flow data provide the most direct constraint on the thermal structure of the lithosphere.

Very few heat flux measurements are available on the Arabian plate and its thermal structure is poorly constrained. The range of heat flow values reported for the Arabian Shield and its immediate platform (36–88 mWm^{-2}) is broad. Heat flux measurements were conducted in Saudi Arabia (Gettings, 1982) and in Jordan and Syria (Förster et al., 2007; Galanis et al., 1986; Matviyenko et al., 1993) (Fig. 1). In Saudi Arabia, Gettings (1982) measured four sites with heat flow values in the range of 35–44 mWm^{-2}. Heat flow values at two sites near the coast of the Red Sea increase significantly (87 and 111 mWm^{-2}). High heat flow values have been reported in Syria and in Jordan, away from the Red Sea. In Syria, Matviyenko et al. (1993), used temperature measurements for geothermal investigations and obtained heat flux estimates between 50 and 88 mWm^{-2}. For 5 boreholes in Jordan, Galanis et al. (1986) determined heat flow values in the range 42–65 mWm^{-2}. All these estimates of the heat flux must be used with caution because measurements were made in shallow boreholes and/or lack thermal conductivities determinations. Recent measurements made in five deep boreholes in Jordan provide a reliable heat flux value of 60 ± 3 mWm^{-2} (Förster et al., 2007). These measurements provide a higher heat flow value than determined in Saudi Arabia in the central part of the Arabian plate and raise the question of what is the steady state heat flow in the Arabian plate.

In this paper, new data on the surface heat flow in Oman in the eastern part of the Arabian plate are reported (Fig. 1). We use these new measurements and previously published data to constrain the thermal structure and the lithospheric thickness of the Arabian plate. We shall compare the lithospheric thermal structure with recent results from seismic studies that image the lithosphere-asthenosphere boundary (e.g., Hansen et al., 2007) and the shear wave velocity structure of the lithosphere and upper mantle (e.g., Chang and Van der Lee, 2011; Park et al., 2008). Important regional differences in the thermal and seismic structures of the lithosphere show the role of the Arabian craton in channeling the Afar plume beneath the Red Sea and the Gulf of Aden.

2. Geological setting

The Arabian Plate consists of the late Proterozoic Arabian Shield bounded to the east by a Phanerozoic platform (Fig. 1). The Arabian Shield is composed of several terranes, separated by ophiolite-bearing suture zones. Accretion of the terranes to form the Arabian neocraton occurred from 715 to 630 Ma (Stoeser and Camp, 1985). Geochronometric data (Stern and Abdelsalam, 1998) indicate that the terranes accretion began

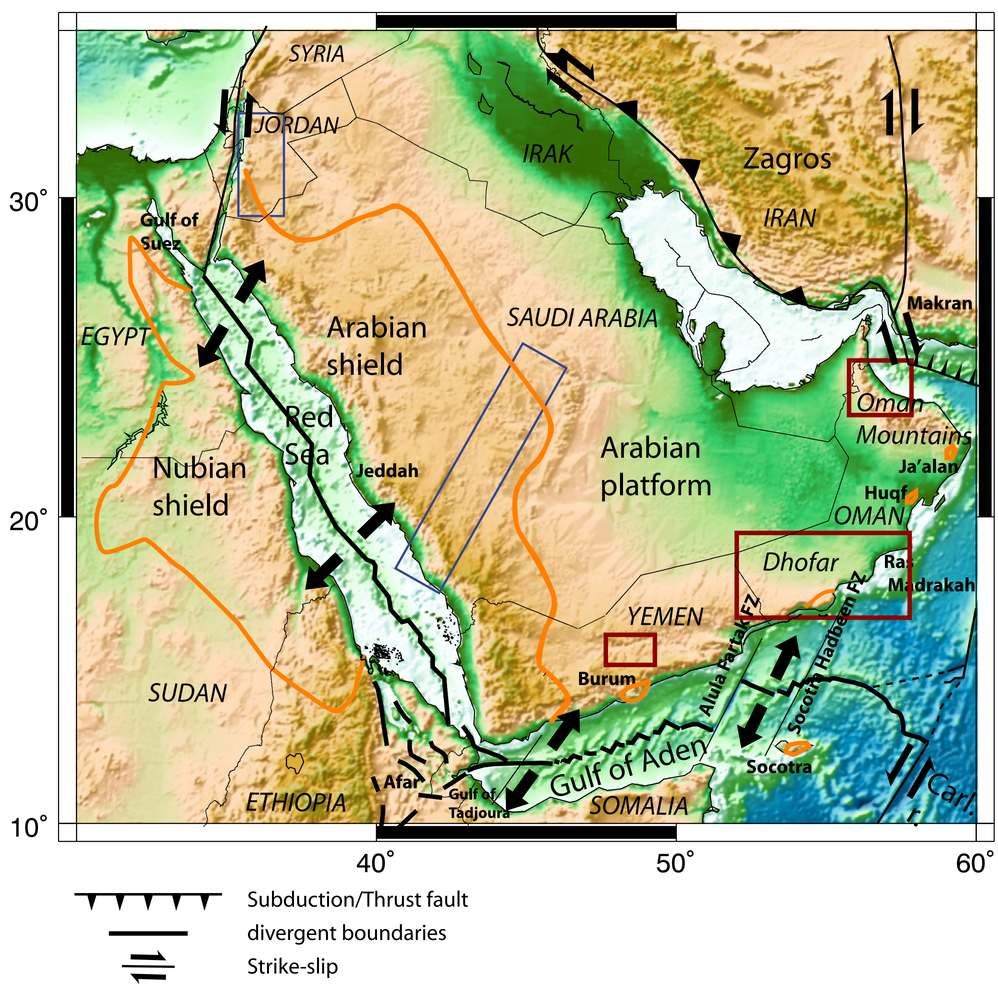

Fig. 1. Topographic and geodynamic map for Arabia showing the Arabian Shield and the Arabian Platform. The Shield is well exposed in the western part of Arabia and locally exposed to the east as in Dhofar or Socotra. The blue boxes indicate heat flow measurements from previous studies (Förster et al., 2007; Galanis et al., 1986; Gettings, 1982). The red boxes indicate heat flow measurements from this study.