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The thermal regime of South African continental margins

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Abstract

We present thermal data from 100 oil exploration boreholes on the continental margins of South Africa. Near surface temperature profiles are constrained with temperatures acquired during reservoir tests, corrected bottom-hole temperatures and seafloor temperatures. The thermal conductivity profiles are estimated from geophysical well logs using a neural network method. Available data allow us to determine 41 new heat flow values computed from depth ranges greater than 1000 m, located on the western and southern continental margins of South Africa. We believe that the variations in surface heat flow are not controlled by the contribution of the sediments or the basement, but rather by the mantle heat flow. An upper bound of ~30 mW m^{-2} for the mantle heat flow on the interior of the continent can be inferred from the lowest available estimates, located near the coastline on the southern continental margin. On both continental margins, heat flow values reach a maximum of about 60 mW m^{-2}, 100 km away from the shore, and consistently decrease further away towards values typically encountered in old oceanic domains (~50 mW m^{-2}). This indicates that (1) the mantle heat flow increases over a short distance at the edge of the continent, which is consistent with studies on the effect of continents on mantle convection, and (2) it may increase to a value greater than heat flow on the adjacent ocean, as a possible consequence of the effect of the transition between thin oceanic lithosphere and thick and cold continental lithosphere on mantle convection.

Keywords: heat flow; thermal regime; South Africa; continental margins; oil exploration data

1. Introduction

Southern Africa is made up of a well defined Archean nucleus surrounded by younger Proterozoic belts. Heat flow was extensively studied in this region (Bullard, 1939; Carte, 1954; Gough, 1963; Carte and van Rooyen, 1969; Ballard et al., 1987; Jones, 1987, 1988, 1992; Nyblade et al., 1990; Martinelli et al., 1995), and shows an increasing trend from the craton towards the mobile belts, that was interpreted either as a lateral variation of crustal heat production or as a lateral variation of mantle heat flow (Jones, 1988; Ballard and Pollack, 1987; Jaupart and Mareschal, 1999; King, 2005). In contrast, the thermal regime of the continental margins remains poorly known, because conventional marine measurements cannot be performed in shallow waters. Yet, this is an interesting problem, as continental margins are often interpreted as the result of a rifting phase followed by passive thermal cooling (McKenzie, 1978). They might, on the other hand, have a much more active role, especially on the border of a thick continental shield, by driving small-scale convection due to a step change of lithospheric thickness (King and Anderson, 1998). By using South African oil exploration data, we had the opportunity to extend the knowledge of the heat flow pattern to the offshore continental plateaus surrounding southern Africa on the southern and western continental margins of South Africa. The tectonic setting and existing heat flow measurements of the region will be briefly presented before we describe data processing and interpretation of the results.

1.1. Tectonic setting

The Kaapvaal craton (Early–Middle Archean) and the Zimbabwe craton–Limpopo belt (Late Archean) form the

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Archean nucleus of the southern African Precambrian shield (Fig. 1). They are surrounded by various Proterozoic belts, grouped under the Kgalagadi province (Eburnean episode–Early Proterozoic), the Namaqua province (Kibaran episode–Middle Proterozoic) and the Damara province (Pan-African episode–Late Proterozoic) (Hartnady and Joubert, 1985). The tectonic framework of the region was completely in place by the Early Paleozoic. A large part of southern Africa is covered by the main Karoo basin, which is a retroarc foreland system formed during the Late Paleozoic–Early Mesozoic as a consequence of the subduction of the paleo-Pacific plate beneath the Gondwana plate (Catuneanu et al., 2005). Then, the geodynamic evolution of southern Africa was principally controlled by extensional tectonism related to the Mesozoic break-up of the Gondwana supercontinent. Rifting occurred mainly along Pan-African sutures during the Late Jurassic–Early Cretaceous (Bumby and Guiraud, 2005) and led to the opening of the South Atlantic ocean (~130 Ma), from which the western and southern margins of South Africa originated. The former is a classic volcanic rifted margin associated with a thick and dense underplated crust that originated about 100 km away from the coastline and extends over 200 km width (Bauer et al., 2000; Séranne and Anka, 2005). This margin is overlain by the Orange basin (Fig. 1), whose sedimentation process began during the rifting phase and was subsequently controlled by the subsidence history of the margin. The southern margin is a non-volcanic sheared margin bordering the Agulhas–Falkland shear zone which formed during the Early Cretaceous (Scrutton and Dingle, 1976). The overlying Outeniqua basin has four major depocentres separated by basement highs, the Bredasdorp, Pletmos, Gamtoos and Algoa basins (Fig. 1) (Thomson, 1998).

1.2. Heat flow in southern Africa

Existing measurements of heat flow in southern Africa and bordering oceans are shown in Fig. 1. It is not always straightforward to decide to which tectonic element a given data belongs because the boundaries are not always well established, particularly in areas where the Karoo sedimentary rocks cover the basement rocks (see previous section). Keeping that in mind, we describe below the general trends of heat flow.

In the Kaapvaal craton, heat flow varies from 33±2 mW m^{-2} (7 values) in the granitic terranes to 51±6 mW m^{-2} (81 values) in the Witwatersrand basin (Jones, 1992). The high values encountered in the latter area are due to high heat production in the Witwatersrand sediments. After removing the radiogenic contribution of sediments and of the Archean basement complex, Jones (1988) estimated a value of 17 mW m^{-2} for the mantle heat flow.

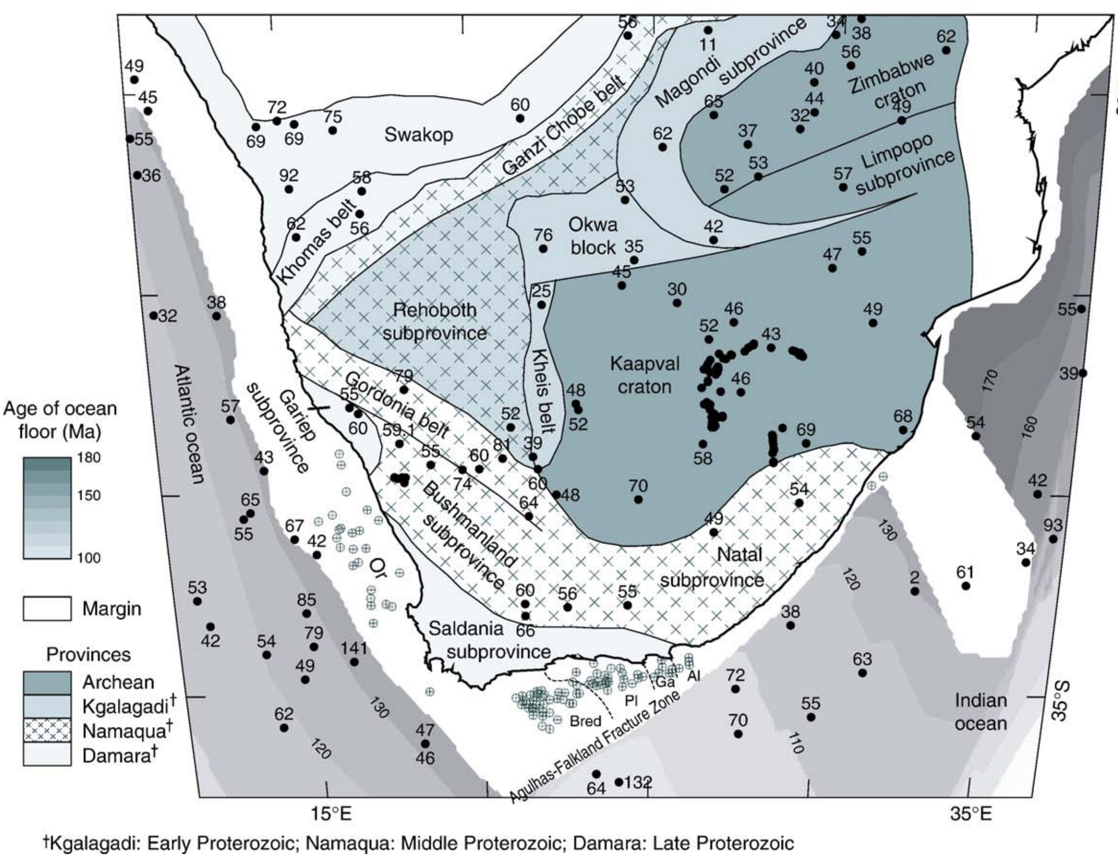

Fig. 1. Black dots: previously published continental heat flow values in southern Africa (Bullard, 1939; Carte, 1954; Gough, 1963; Carte and van Rooyen, 1969; Ballard et al., 1987; Jones, 1987, 1988, 1992; Nyblade et al., 1990) and in the surrounding oceans (Vacquier and von Herzen, 1964; Von Herzen and Langseth, 1965; Langseth et al., 1966, 1971; Bookman et al., 1972; Marshall and Erickson, 1974; Anderson et al., 1977; Herman et al., 1977; Lee and von Herzen, 1977; Pribnow et al., 2000). Grey crossed circles: oil exploration wells used in this study. Tectonic elements from Hartnady and Joubert (1985). Age of ocean floor from Müller et al. (1997). Or: Orange basin; Bred: Bredasdorp basin; Pl: Pletmos basin; Ga: Gaamtos basin; Al: Algoa basin.