Origin of the South Australian Heat Flow Anomaly

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Introduction

The Flinders Range is one of the seismically most active area of the Australian continent, however it is relatively far from recent, active plate boundaries. The question arises as what could be the driving force for the recent tectonic activity. Apart from the active plate boundaries, either rifting due to delamination or mantle-plume could account for striking tectonic activity in within-plate geodynamic setting. Since neither of these processes has been recognized by seismic measurements, another driving force is needed to be considered.

Possible Sources

Obviously, the South Australian Heat Flow Anomaly (SAHFA) is a suitable candidate, namely elevated heat flow could dramatically soften the crust giving way to extensive deformation. The SAHFA overlaps a region of mild neotectonic activity which has resulted in the formation of the Flinders Ranges. It is broadly coincident with, and represents a reactivation of the Adelaide Fold Belt, which contrasts the adjacent Gawler Craton and Stuart Shelf, where there is no evidence of significant fault-related displacement since the Mesoproterozoic. The age of the initial uplift of the modern Flinders Ranges is still debated and may be as old as Eocene, or as recent as late Pliocene. The coincidence of the uplands with a belt of active low-level, seismicity supports the notion that tectonism is ongoing, as do widespread Pleistocene fanglomerate aprons in the footwall to steep reverse faults that typically bound the uplands. In the following paragraphs the possible reasons for this particular heat flow anomaly and some of its consequences will be highlighted.

The zone of elevated heat flow, which we term the South Australian heat flow anomaly (SAHFA), overlaps the boundary between the eastern Gawler Craton and the Adelaide Fold Belt, including the Stuart Shelf. The extent of the SAHFA is not precisely constrained from the available data. It clearly extends from Adelaide in the south some 600 km north to the Mount Painter Province. North of Mount Painter it appears to merge with a broad heat flow anomaly extending almost all the way across the continent. The most westerly record within the SAHFA is at Iron Knob, although the anomaly may well extend as far westwards as 136°E, which represents the approximate longitude of the boundary between the eastern and western Gawler Craton. Although the eastern boundary is relatively poorly defined, the anomaly extends as far eastwards as the Mount Painter Province at 140°E giving a minimum width of 250 km.

One apparent explanation of the elevated heat flow is the sub-recent volcanic activity, which is present in South-eastern Australia as volcanic province that includes the very south-east corner of South Australia. While this magmatic province is also associated with elevated heat flow (e.g. Mount Gambier) the province is more than 400 km from the nearest measurement used to define the SAHFA and up to 1000 km from its north-westerly limit. This magmatism can therefore be dismissed as a significant contributor to the SAHFA.

Another plausible explanation is that the heat source is located in the crust itself. The SAHFA forms part of a province that hosts several significant uranium deposits, the most notable being the giant Olympic Dam deposit. Such occurrences suggest that the province may be unusually enriched in heat-producing elements, and it is therefore pertinent to explore the possibility that elevated crustal heat production provides the additional heat flow within the SAHFA. The surface heat production distribution of approx. 2650 samples as a function of longitude clearly indicates that the SAHFA is characterized by elevated concentrations of heat-producing elements. Although U and Th concentrations within these granites are extreme, corresponding Th/U values are dominantly 3-5, suggesting that this enrichment is a primary magmatic signature. The heat production compilation highlights the fact that the region of high heat flow in South Australia coincides with the occurrence of Proterozoic granites and volcanics which contain anomalously high U, Th and K concentrations. This suggests that Proterozoic felsic magmatic events have been important in shaping the vertical distribution of radiogenic elements in the crust. Furthermore, such a high crustal radiogenic component implies that U, Th and K concentrations in the SAHFA are significantly higher than in typical crustal profiles, posing the question of how such elevated concentrations of heat-producing elements become localised in this crustal zone.

There is a distinct rise in median heat production from ~3 μWm^{-3} in the western Gawler Craton to ~5 μWm^{-3} for the eastern Gawler Craton. Surface heat production reaches a maximum within the Mount Painter Province where the range is extreme (1-65 $\mu W\ m^{-3}$), the average is ~11 μWm^{-3} and median is ~6 μWm^{-3}. To the east, heat production decreases to a median value of V2.5 μWm^{-3} in the eastern Willyama Inliers. in the Mount Painter Province allows for the construction of relatively well constrained heat production maps. Using both airborne radiometric data and whole rock geochemistry, were able to show that the area-integrated surface heat production for the province is 9.9 μWm^{-3}. Calculated heat production values for metasedimentary units within this transect are consistent with accepted lithological means and show little variation across provinces, suggesting that they do not contribute to the SAHFA. In contrast, granitic and volcanic lithologies display a large range in heat production, with many units within the eastern Gawler Craton and especially the Mount Painter Province containing extremely elevated values.

The Mount Painter Province is also a type locality of high geothermal gradient metamorphism (HGGM), however the event can not be simply explained by the most favored transient advective process,such as magma ascent, or abnormally high heat flows from the mantle. Because the generation of magmas in the deep crust and upper mantle is associated with anomalously steep thermal gradients, it is clear that HGGM metamorphism in the shallower parts of the lithosphere may be produced by a combination of advective processes associated with the segregation and ascent of magmas within the lithosphere and enhanced heat flow from the mantle. Indeed, the spatial correlation between metamorphism and magmatism in many high temperature metamorphic belts has been used to support hypothesis. While this notion of transient advection remains the principal paradigm for HGGM, several recent thermochronologic studies have raised the possibility that other less transient mechanisms may play a significant or even dominant role. For example, evidence for extended periods of HGGM, with the elevated geothermal regimes apparently lasting many 10s of millions of years.

Sandiford et al. (1998) have shown that heat production distributions consistent with modern heat flows and measured surface heat production in a number of Australian Proterozoic HGGM terranes, can generate the conditions required for HGGM in the mid-upper crust without necessarily generating significant quantities of melt in the deep crust (provided mantle heat flows are low). Sandiford et al. (1998) approach was essentially parametric in as much as they did not address the geological setting in which such conditions are likely to prevail, also they develop a coupled thermal-isostatic model to show that such conditions will naturally develop as a consequence of burial of a radioactive sequence (such as a granitic basement complex) during thermal subsidence following rifting. The motivation for this analysis is provided by the geological evolution of the Mount Painter province in the northern Flinders Ranges, South Australia. Lithospheric thicknesses estimates of the order of 200–300 km throughout this region suggest low contemporary mantle heat fluxes (10–15 mWm^{-2}) implying crustal heat sources contribute in excess of 70 mWm^{-2} to the average measured heat flow.

Across much of this region near surface temperature gradients determined from drill hole measurements are in excess of 35ºC/km leading further support to the notion that substantial heat production is concentrated in the crust. Granitic gneisses, which commonly comprise more than 50% of the basement terrains in these Proterozoic belts are unusually good heat producers, and frequently have heat production rates in the range 5–10 mW m^{-3}. During metamorphism in the Proterozoic and Phanerozoic, these basement sequences were buried to depths of 10–20 km, thus providing an ideal mid-crustal radioactive sequence of the type alluded to here.

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