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HEAT FLOW INCREASE FOLLOWING THE RISE OF MANTLE ISOTHERMS AND CRUSTAL THINNING; Jean-Claude Mareschal and George Bergantz, School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia 30332

Heat flow measurements in the western United States define a zone of high heat flow which coincides with the Basin and Range Province where extension has taken place recently. In this region, the average reduced heat flow is ∿30 mW/m^2 higher than in stable continental provinces; locally (e.g., Battle Mountain High), the heat flow anomaly can be more than 100 mW/m^2 above average [1]. Estimates of the amount of extension range between 30% and 100% for the past 30 Ma [2]. In the Colorado Plateau, which has been uplifted without major tectonic deformation, the heat flow is only slightly above average [3].

Several hypotheses have been proposed that would account for the anomalous thermal flux and relate it to the mechanism of extension. Essentially, the models fall into three categories: thinning of the lithosphere by various processes [e.g., 4, 5], distributed injection of basic magmas [6], and increase in heat flow and/or temperature at the lithosphere-asthenosphere boundary.

One of the simplest models accounting for the higher heat flow requires a stepwise increase in heat flux or temperature at the base of a thermal boundary layer. Analytical calculations show that an abrupt change in heat flow at the base of the lithosphere 30 Ma ago would not affect the surface significantly. Uplift would proceed at a slow rate [e.g., 7]. A thermal perturbation at the base of a 40 km thick crust, however, would reach the surface faster and, after 30 Ma, the increase in surface heat flow would be about 75% of the amplitude of the heat flow anomaly. The calculations show that a 500°C increase in temperature at -30 Ma could account for at most 15 mW/m^2 increase in surface heat flow.

The amount of volcanic rocks in the Basin and Range suggests that magma intrusions may provide an effective heat transfer mechanism [6]. It can be shown [8] that if the source of the intrusions is at the base of the lithosphere, the response time will be much longer than 30 Ma, and most of the heat transferred from the asthenosphere will be absorbed in the lithosphere. Also, the amount of magma required to increase in steady state the heat flow by 30 mW/m^2 is equivalent to 100% of the volume of the lithosphere in 30 Ma; an extension of 100% is required to accommodate such an intrusion rate. Local increases in heat flow of the order of 100 mW/m^2 could never be accounted for by such models.

Crustal thinning could also increase the surface heat flow by steepening the geothermal gradient. The calculations show that, for long wavelength perturbations, the fractional increase in heat flow is equal to the ratio of crustal thickness after to thickness before thinning. If the mantle component of the heat flow was 30 mW/m^2 at -30 Ma, the crustal thickness must have been reduced to half its original value, i.e., the original crustal thickness would have been 60 km and the average elevation required by isostatic consideration would have been 3 to 4 km above the present. Geological data seem to rule out such an initial state for the western United States.

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In view of these results, it seems that no mechanism is totally adequate to explain the increased surface heat flow and that a combination of effects is needed. The suggested evolution is the following:

The rapid rise of isotherms in the lithospheric mantle with an increase in temperature of the order of 500°C at the base of the crust. The only mechanism for a rapid increase is the mechanical replacement of the lower lithosphere by hotter asthenosphere. This could be the result of diapiric uprise or delamination. Numerical models investigated show that the replacement could occur in a short time (1 to 10 Ma) provided that the effective viscosity of the lithospheric mantle is low enough (10^{20}-10^{21} Pas). The numerical models also show that the rising diapirs spread out at the base of the crust and that the temperature could rise more or less uniformly by 500°C in a short time. Isostatic uplift and lithospheric extension will follow. As the lower crust is heated from below, it becomes more ductile and crustal extension proceeds by flow in the lower crust and fracturing of the upper brittle part of the crust.

The combined effect of the increased temperature at the base of the crust and crustal thinning by extension account for the average increased heat flow. The local high anomalies are not accounted for; they are probably transient effects that follow the intrusion of very large volumes of magma near the surface.

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