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Serpentinization pulse in the actively deforming Central Indian Basin

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ABSTRACT

Heat flow in the actively deforming Central Indian Basin is on average 30 mW/m^2 higher than the theoretical 55 mW/m^2 heat flow expected from plate cooling of a Cretaceous oceanic lithosphere. Strong spatial correlation between the anomaly and the active thrust fault network at local (faults) and regional scales suggests two potential tectonically driven mechanisms activated at the time of initiation of deformation: friction-to-heat conversion or exothermic serpentinization. We quantitatively examine both processes using an updated geometry of the thrust fault network and simple thermal models. Friction generated heat is limited in all cases: at shallow levels, shear stresses remain small, while heat generated at deeper levels does not contribute significantly to the surface heat flow since permanent regime is not reached. In the exothermic serpentinization model, a maximum anomaly of 20 to 30 mW/m^2 is reached 2 to 6 Myr after the onset of widespread serpentinization, depending on the efficiency of the water circulation. The amount and timing of heat release can fully explain the present-day surface heat flow of the Central Indian Basin, provided vigorous hydrothermal circulation closely followed the onset of deformation. Based on a reprocessed multichannel seismic line, we suggest that faults cutting through the entire crust and across the Moho discontinuity drive water at mantle levels and trigger the exothermic serpentinization reaction. We interpret sub-Moho reflectors imaged at depths of 8 to 15 km below the top of the crust – and coinciding with the location of the maximum reaction rate coefficient of serpentinization – as serpentinization fronts. We discuss the significance of this pulse of serpentinization in terms of timing of deformation, weakening and transient rheology of the oceanic lithosphere.

1. Introduction

Anomalously high heat-flow measurements have been acquired in the northeastern Indian Ocean for decades (Pollack et al., 1993) and were promptly related to the abnormal level of intraplate seismicity recorded between the India and Australia tectonic plates (Weissel et al., 1980; Wiens et al., 1986; Stein et al., 1988). The heat-flow anomaly was shown to coincide with an area of widespread intraplate deformation that started in the late Miocene (Cochran et al., 1989). Seismic profiles (Bull and Scrutton, 1992; Chamot-Rooke et al., 1993; VanOrman et al., 1995) further imaged the highly faulted sediments, crust and mantle of the Central Indian Ocean, confirming the spatial correlation between high heat-flow and active deformation. The thermal anomaly was thus seen as a consequence of friction-to-heat conversion along deeply rooted reverse faults (Weissel et al., 1980; Geller et al., 1983; Stein et al., 1988; Gordon et al., 1990). An alternative view was immediately raised: deformation may have concentrated in areas of high thermal state and weaker rheology, the high heat flow being a cause rather than a consequence of the localization of deformation. Stein and Weissel (1990) ruled out large-scale reheating at the base of the lithosphere showing that there was no associated bathymetric swell. They further inferred that the source of additional heat had necessarily to be shallow (Geller et al., 1983; Stein et al., 1988) in order to satisfy simultaneously the present-day depth to basement, the deep seismicity (Okal, 1983) (suggesting low temperatures at depth of 30–40 km) and the high surface heat flow. The topic remained closed and rather unsolved until Verzhbitsky and Lobkovsky (1993) proposed that the required shallow heat source may relate to the exothermic serpentinization of mantle peridotites, as first mentioned in Fyfe (1974). They provided a crude estimate of the produced heat and concluded that serpentinization may be as efficient as other mechanisms to increase significantly the surface heat flow in this part of the Indian Ocean.

Substantially more data are available today: (1) Using deep seismic refraction, Louden (1995) detected a low velocity zone that he attributed to partially serpentinized clasts of peridotites in the gabbros layer at the base of the oceanic crust; (2) At the scale of the thrusts network, one

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detailed heat-flow profile across two major active faults was obtained during a pre-site survey of the ODP Leg 116 drilling in an area close to the Afanasy–Nikitin Seamount Chain (Cochran et al., 1989). Distribution of the observed heat flow along this profile was modeled by Ormond et al. (1995) as vigorous fluid circulation through the Bengal fan sediments, redistributing an already anomalous basal heat flow. No heat source origin is proposed to explain the ~30 mW/m^2 anomaly, but these data do confirm the link with the faults; (3) Numerous seismic reflectors have been imaged in the mantle, including deep penetrating faults. Acquired in 1991, Phèdre multichannel seismic profiles (Chamot-Rooke et al., 1993) imaged the deep geometry of the thrust faults along a 2100 km-long profile across the area. Below the ODP Leg 116 site, two fault reflectors cut across discontinuous Moho phases and reach deep into the mantle, suggesting that fluid paths do exist at sub-Moho depth. Deep

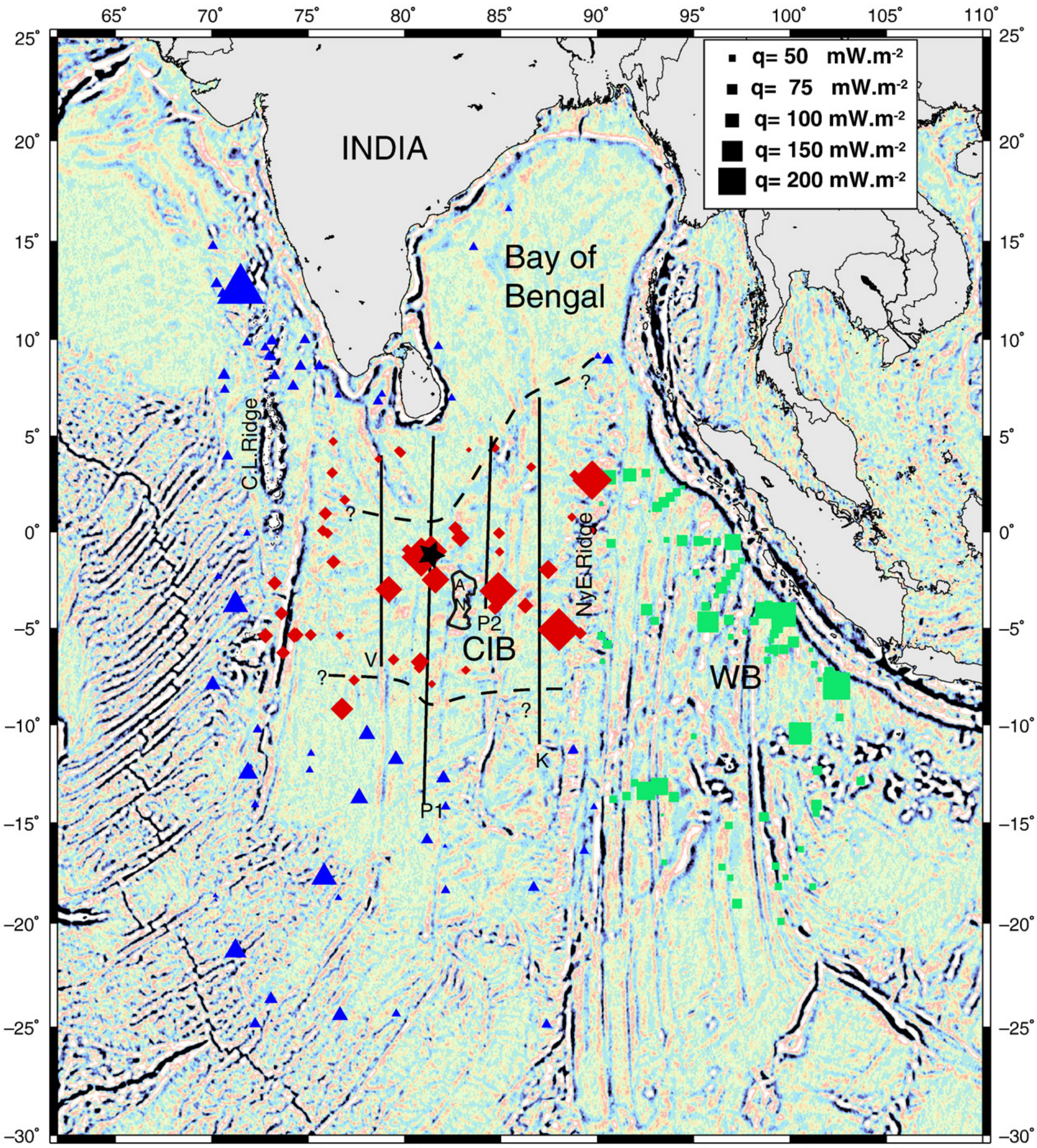

Fig. 1. Location of surface heat-flow measurements in the Indian Ocean and some of the seismic tracks where E–W thrust faults have been imaged. V: Conrad monotrace profile (VanOrman et al., 1995); P1: Phèdre Leg1 wide angle profile; P2: Phèdre Leg2 wide angle profile (Chamot-Rooke et al., 1993); K: Eastern CIB seismic profile (Krishna et al., 2001). Red symbols cover the Central Indian Basin, green symbols the Wharton Basin, blue symbols the remaining areas. The size of the symbol is proportional to the heat-flow value. Background is a filtered Sandwell 15.1 satellite (Sandwell and Smith, 1997) gravity field showing contrasting structural trends on both sides of NinetyEast Ridge. Contour of the Afanasy Nikitin Seamount is also shown. The ODP Leg 116 site is represented by a star. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)