History of a long-lived mantle plume in the Southern Indian Ocean

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The formation of Large Igneous Provinces (LIPs) on the ocean floor may reflect fundamental changes in convective processes within Earth's interior. In turn, the eruption of large magma volumes during a brief time interval has major effects on the terrestrial atmosphere and hydrosphere. A hypothesis for the formation of LIPs, such as the once contiguous Kerguelen Plateau and Broken Ridge in the SE Indian Ocean (Figure 1), is that they result from the initial impact of a mantle plume on the lithosphere (a mantle plume is a localized and typically long-lived buoyant upwelling in the mantle). The long-term manifestation of a plume is a linear chain of volcanoes (hotspot track) formed as a migrating lithospheric plate moves over the plume location. The Hawaiian-Emperor Ridge in the north Pacific Ocean is the best known example, but the ~5000 km north-south trending Ninetyeast Ridge in the eastern Indian Ocean is an equally good example (Figure 1).

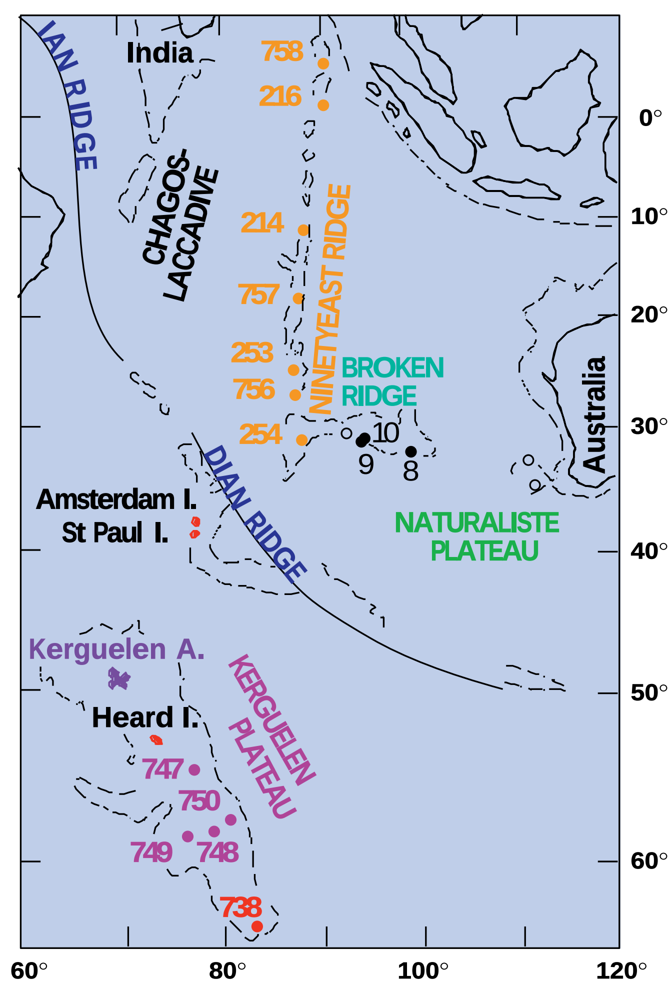

Figure 1: Numbers indicate ODP, DSDP, and dredge sampling sites of basaltic basement on the Kerguelen Plateau, Broken Ridge, and Ninetyeast Ridge.

The geochemical characteristics of the magmas that form a LIP and subsequent volcanic chain differ significantly from the lavas erupted at spreading and converging plate boundaries; consequently, plume volcanism provides "new" information about the earth's interior. The Kerguelen Plateau-Broken Ridge LIP, the Ninetyeast Ridge hotspot track and the recently active Kerguelen and Heard Islands (Figure 1) provide the best long-lived, ~115 my, record of plume volcanism [*Weis et al.,* 1992]. Following up on DSDP drilling, basaltic basement was recovered from the Kerguelen Plateau (Sites 738, 747, 749, and 750 on ODP Legs 119 and 120) and the Ninetyeast Ridge (Sites 756, 757 and 758 on ODP Leg 121) (Figure1). Studies of the basaltic basement cores established that: (1) these lavas are geochemically very different from lavas erupted at spreading ridge axes [*Frey et al.,* 1991; *Saunders et al.,* 1991; *Weis and Frey,* 1991; *Storey et al.,* 1992]; (2) the Kerguelen Plateau was formed from ~113 to 85 my [*Storey et al.,* 1996]; and (3) the basaltic basement of the Ninetyeast Ridge increases in age from south (~38 Ma) to north (~82 Ma) [*Duncan,* 1991]. These results combined with ongoing studies of the ~40 my to recent lavas erupted in the Kerguelen and Heard Islands (e.g., Yang et al., [1996]) provide answers to several important questions. (1) Are the ages and geochemical characteristics of these lavas consistent with derivation from a single fixed plume? The answer is — yes. The age progression of volcanism along the Ninetyeast Ridge is consistent with rapid northwards movement of the Indian Plate over the Kerguelen Plume located at ~50°S, but the associated LIP (Kerguelen Plateau-Broken Ridge) did not form in a single magmatic pulse.

As shown in Figure 2 the isotopic ratios of lavas erupted over the ~115 my are consistent with a common but isotopically heterogeneous source; however, lavas from Site 738 on the southern Kerguelen Plateau contain an isotopically distinctive continental component, perhaps incorporated into the oceanic mantle during breakup of Gondwana. (2) Do the source components of plume magmas change systematically with time? Currently, there is debate as to how much of the isotopic variation in Figure 2 is intrinsic to the plume and how much is contributed by other components as the plume encountered diverse tectonic settings ranging from centered at a spreading ridge to intraplate. Regardless, it is clear that the Kerguelen Plume is quite different from the Hawaiian Plume [*Weis and Frey,* 1996]. Thus the Kerguelen Plume has generated large volumes of geochemically distinctive magmas for at least 115 my; this knowledge could not have been obtained without DSDP and ODP. (3) The most important volcanological and societal question is — What was the flux of magma; i.e., how much magma entered the crust per year? The age range, ~115 to 85 my, for lavas from the Kerguelen Plateau has major implications for addressing this question. Present sampling of the volcanic record of the Kerguelen Plume is, however, too sparse for reliable constraints on magma flux. Sampling of the basement over a wider area and to a greater depth is required. ODP is now planning another drilling leg (austral summer of 1998-99) on the Kerguelen Plateau. A major objective of this additional drilling is to determine the temporal and spatial variations in magma volume supplied by this plume.

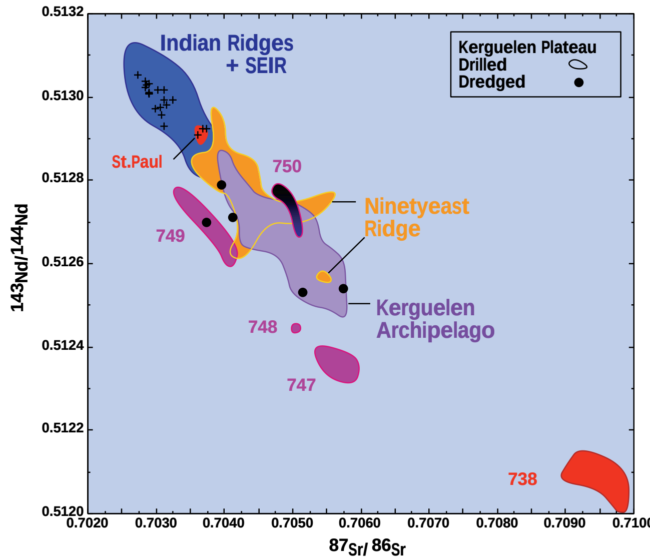

Figure 2: Sr-Nd isotopic diagram (measured data) for basaltic basement samples from the Kerguelen Plateau, Broken Ridge, and Ninetyeast Ridge. Comparison with Indian ridges and Kerguelen Archipelago.

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