Tectonic Evolution of Shatsky Rise: A Plateau Formed by a Plume Head or Not?

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Shatsky Rise is an oceanic plateau located approximately 1600 km east of Japan, in the northwest Pacific Ocean. It is a basaltic mountain range with an area nearly equal to Japan or California, qualifying as one of the globe's larger LIPs. What makes Shatsky Rise unusual among Pacific plateaus is that it formed prior to the Cretaceous Normal Superchron, so that its relationship to spreading ridges can be observed by mapping adjacent magnetic lineations (Fig. 1). Those lineations indicate that Shatsky Rise formed at spreading ridge, similar to Cenozoic-age Iceland. Although much of the existing geologic evidence can be interpreted as supporting the plume-head hypothesis, some data leave room for doubt.

Shatsky Rise consists mainly of three bathymetric highs and a low ridge that sit at the confluence of the Japanese and Hawaiian magnetic lineations from M21 to M10 (Fig. 1; Sager et al., 1988; Nakanishi et al, 1989; Nakanishi el al., 1999). Magnetic lineations can be traced between the highs, implying the basaltic mountains are three large, individual volcanoes separated by lithosphere that has not been greatly altered by volcanism (Sager et al., 1999). Seismic profiles adjacent to the large edifices suggest that much of the low plateau is a sedimentary apron (Sager et al., 1999). The volume of volcanic material appears to decrease northwestward along with volcanic edifice ages. The southern high is largest, with a volume of 2.4×10^6 km^3, whereas the central and northern volcanoes have volumes that are only 0.69 and 0.65×10^6 km^3 (Sager et al., 1999). The ridge, extending from the north end of the rise, is smaller still. All of these larger volcanic edifices display complete isostatic compensation, suggesting they formed at about the same time as the lithosphere. This has been demonstrated for the southern volcanic high, as basement basalts cored on ODP Leg 198 have been dated at 144 Ma (R. A. Duncan, personal communication, 2002), in agreement with the accepted age of the magnetic lineations that surround the edifice (M21-M19, 148-145 Ma in the Gradstein et al., 1994 timescale). Because this date is older than the lithosphere beneath the other edifices farther north, the rise must become younger in that direction. Indirect evidence implies that the largest and oldest volcanic edifice, the southern high, formed very rapidly. The magnetic anomaly of this edifice is consistent with a predominantly reversed magnetic polarity that suggests formation mostly during a single magnetic polarity chron (Sager and Han, 1993). Assuming that the southern high erupted during the longest reversed chron near M19 (Chron M17) gives emplacement rates similar to estimates of flood-basalt eruptions (1.7 km^3/yr; Sager and Han, 1993).

The tectonic evolution of Shatsky Rise, interpreted from the magnetic lineations and bathymetry, can be construed as the result of a plume that "captured" a triple junction (Nakanishi et al., 1999; Sager et al., 1999). Prior to M21 time, the Pacific-Farallon-Izanagi ridge moved NW relative to the Pacific plate, probably in a stable ridge-ridge-ridge configuration (Sager et al., 1988). At M21 time, the triple junction jumped 800 km eastward to the location of the southern volcanic high. Until about M10 time, approximately 16 Myr later, the triple junction moved NE with a speed and direction that cannot be easily be reconciled with spreading rates and ridge geometry (Sager et al., 1988). It appears there were many small ridge jumps that affected the triple junction, with the largest corresponding to the emplacement of the large volcanic highs

(Nakanishi et al., 1999). Apparently successive eruptions from the Shatsky plume caused the triple junction to jump to the plume location, presumably because of the concentrated heat and upwelling. All of these observations seem consistent with a plume-head explanation: the massive initial eruption “captured” a nearby triple junction and kept it pinned at the plume location until the plume strength waned with the transition from plume head to tail.

Despite circumstantial evidence that supports the plume head model for plateau development, some pieces of evidence to not fit as well. Geochemical evidence for a magma source with a deep mantle origin is equivocal. Sr-Nd-Pb isotope ratios from Shatsky Rise basalts are varied, but tend to be more MORB-like than other Pacific plateaus (J. Mahoney, personal communication, 2002). Nb/Zr and Nb/Y ratios give the same result, although data from one dredge are similar to results from the South Pacific Superswell (Tatsumi et al., 1998). However, those dredge samples come not from one of the main volcanic edifices in Shatsky Rise, but a small, undated seamount that is loated between the larger volanoes and whose relationship to the plateau is unclear. Moreover, even if this seamount was formed as a part of Shatsky Rise and has a South Pacific Superswell source, the connections of the Superswell to the deep mantle is currently debated (e.g., Courtillot et al., 2003). Perhaps the most curious observation that does not fit the plume head model well is the remarkable spatial coincidence of Shatsky Rise and other plateaus with spreading ridges at triple junctions. Not only did Shatsky Rise form at a triple junction, but so did the Magellan and Manihiki plateaus. Moreover, other plateaus, whose relationships to ridges are less clear because they formed during the Cretaceous Normal Superchron (Hess Rise and Ontong Java Plateau), are in locations that suggest that they too were formed at triple junctions or spreading ridges. Unless there is some mechanism causes ridges and triple junctions to jump to or migrate rapidly toward plumes (e.g., Mahoney and Spenser, 1991), these coincidences imply that the ridges somehow cause the upwelling.

As our understanding of the mantle processes that form ocean plateaus continues to evolve, Shatsky Rise is a feature that can be used to test plume models. Because it was formed at a time when the Pacific plate was moving rapidly relative to the mantle, the volcanic signature of the plateau eruptions is spread out laterally, unlike some larger plateaus formed during periods of slow plate motion. Furthermore, the sedimentary cover on Shatsky Rise is thin except at the summits of the main volcanic highs and outcrops on the flanks are common. Thus, sampling Shatsky Rise is less challenging than many plateaus with thicker sediment mantles. Unfortunately, the outcrops tend to be weathered and coated with Mn-oxide crusts, so dredging has been ineffective in collecting the samples needed for accurate dating and geochemical analyses. Drilling on ODP Leg 198 showed that relatively shallow coring into basement can yield remarkably well-preserved Jurassic-age igneous samples.

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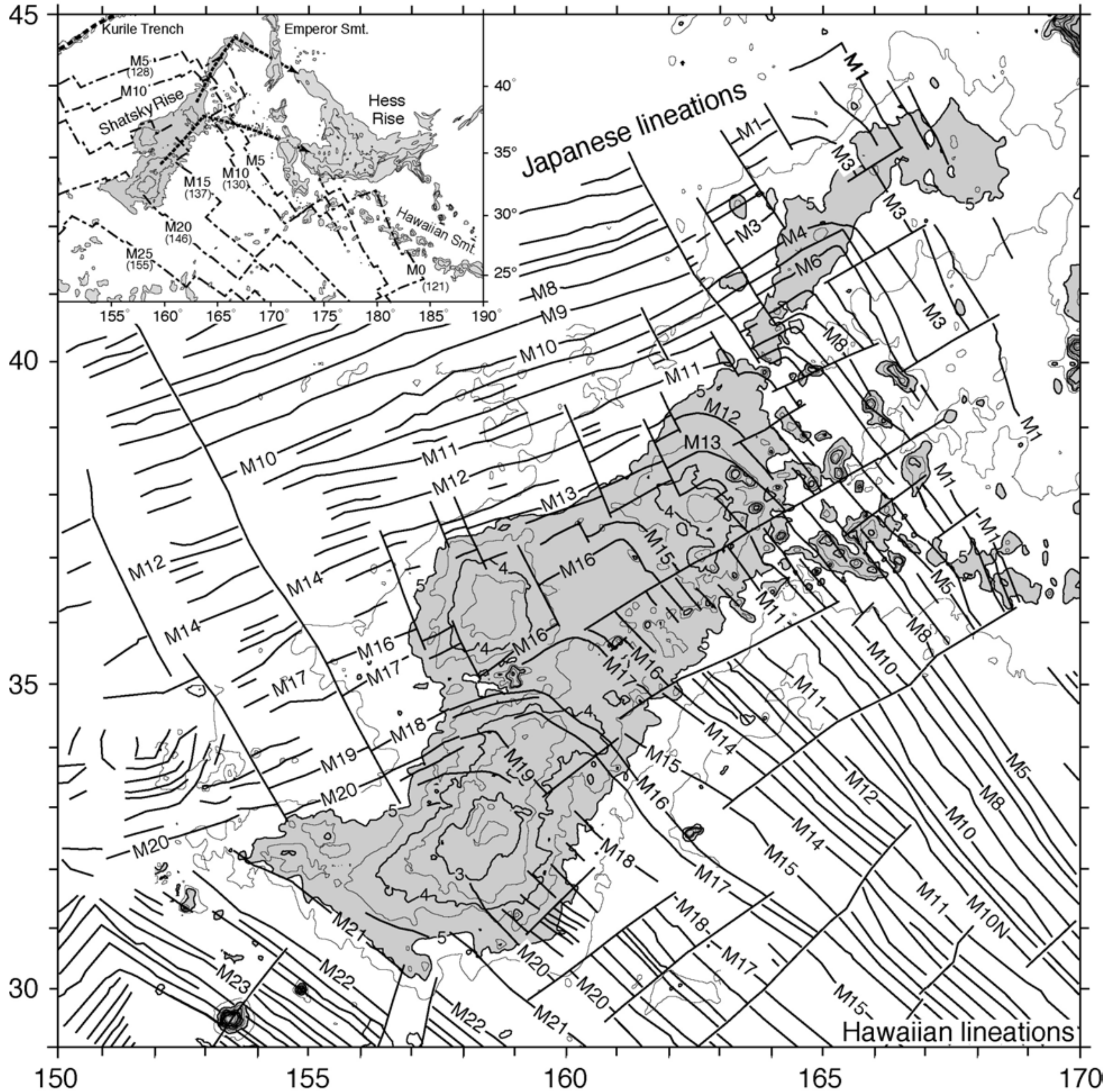

Figure 1. Bathymetry of Shatsky Rise and magnetic lineations. Bathymetry contours are shown at 500-m intervals with heavy contours at 1-km intervals (Sager et al., 1999). Gray area shows the plateau above 5 km depth. Heavy lines denote magnetic lineations and fracture zones (Nakanishi et al., 1999). Inset shows Shatsky Rise region including Hess Rise. Heavy dashed line marks the Kurile Trench, whereas heavy dotted lines represent two seamount trails that connect Shatsky Rise with Hess Rise.