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# How Do Oceanic Plateaus Form? Clues From Drilling at Shatsky Rise

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Oceanic plateaus are huge basaltic constructions whose eruptions may briefly outstrip even global mid-ocean ridge magma production. Although they form great undersea mountains, their origins are poorly understood. A widely accepted explanation is that oceanic plateaus are built by massive eruptions from the head of nascent thermal mantle plumes that rise from deep in the mantle to the surface [e.g., *Duncan and Richards,* 1991]. An alternative is that plateaus erupt by decompression melting of fusible patches in the upper mantle at plate edges or zones of extension [*Foulger,* 2007].

Shatsky Rise (Figure 1) is a large Pacific Ocean plateau east of Japan with characteristics fitting both formation models. Magnetic lineations show that it erupted at a triple junction during the late Jurassic and Early Cretaceous (~145–125 million years ago), providing a possible connection to the plate edge hypothesis. This same connection is seen elsewhere through the association of other Pacific plateaus with the paths of triple junctions [*Sager,* 2005]. On the other hand, the volcanic evolution of the rise is consistent with predictions of the plume head hypothesis. Emplacement began with rapid construction of the huge Tamu Massif, which has a volume of nearly 2.5 million cubic kilometers [*Sager,* 2005]. Subsequent constructs (Ori and Shirshov massifs and Papanin Ridge) are smaller and consistent with a transition from voluminous plume head eruptions to smaller-scale plume tail output.

## *Observations From Drill Cores*

During the fall of 2009, scientists and crew of Integrated Ocean Drilling Program Expedition 324 on board the D/V *JOIDES Resolution* cored a total of 923 meters into Shatsky Rise at five sites (U1346–U1350, Figure 1), including 723 meters through igneous basement and volcanic sediments (for details, see *Sager et al.* [2010]). Thick packages of lava flows were encountered at four sites; at the other (U1348), only highly altered volcaniclastic material was recovered. The pattern of igneous activity changes across Shatsky Rise. Massive lava flows (up to ~23 meters thick) dominate at Tamu Massif, whereas pillow lavas prevail at Shirshov Massif. In between, at Ori Massif, a mixture of flow types is found, but pillows dominate on the flank (U1350) and massive flows are thin (Figure 1). Pillows are typical of submarine eruptions at low effusion rates, whereas massive flows, formed by inflation of the flow interior as an elastic skin develops on the upper and lower chilled margins, are characteristic of flood basalt provinces and indicate high effusion rates [e.g., *Jerram and Widdowson,* 2005].

Igneous rocks from sites U1346, U1347, and U1350 are plagioclase-clinopyroxene (micro) phyric basalts with variably evolved tholeiite compositions (Figure 1). In contrast, lavas from Site U1349 are less differentiated olivine-phyric basalts containing chromium spinel, implying greater temperature. Compositional ranges overlap typical mid-ocean ridge basalts (MORB) and Ontong Java Plateau basalts. Overall, Shatsky Rise samples are slightly enriched in incompatible elements compared to normal MORB, showing some resemblance to enriched-type MORB.

Basal sediments at several sites contain indicators of shallow submarine or subaerial conditions. These include neritic–upper bathyal benthic foraminifera (meaning that they grew at water depths less than 500 meters) at Sites U1346 and U1347; cross-bedding indicative of strong currents at Site U1347; shallow-water carbonates, including material from reef-building fauna, at Site U1348; possible wood fragments at Site U1346; and a paleosol (ancient soil layer) close above an oolite layer (round grains of calcium carbonate formed in shallow water) at Site U1349. Volcanic sediments, which were not previously recovered in quantity on Shatsky Rise, make up the entire section at Site U1348 and are common at the basal sedimentary section at most sites (Figure 1).

## *Implications for the Formation of Oceanic Plateaus*

Prior to Expedition 324, scientists knew that Shatsky Rise must be largely basaltic, but the style of volcanism was unknown. Virtually all sediments previously cored from Shatsky Rise were open-ocean carbonates, so there was little information about other sedimentary environments or the role of explosive volcanism. Modestly altered igneous rock samples were available only from Site 1213 (cored during Ocean Drilling Program Leg 198), and they exhibited MORB-like isotope composition [*Mahoney et al.,* 2005]. This composition was not expected if the plateau was created by a plume head, but the significance of this single site was unclear.

Expedition 324 provided samples of igneous basement at four sites, and broadly MORB-like characteristics appear general. Sediments imply that the summits of Shatsky Rise volcanoes were near sea level or emergent, perhaps forming large islands. Lava flows transition from predominantly massive on Tamu Massif to predominantly pillow lavas on Ori and Shirshov massifs, and this is consistent with the effusion rate waning with time. The Site U1347 section, characterized by alternating sections of thick, massive flows and pillow lavas, appears similar to Sites 1185 and 1186 atop the massive Ontong Java Plateau [*Mahoney et al.,* 2001], implying that similar processes formed both plateaus. It is still too early to resolve the question of exactly what caused the formation of Shatsky Rise, but studies of samples recovered on Expedition 324 will provide important data for this debate. Whatever mechanism is called upon, it must explain the fact that initial massive eruptions built an enormous volcanic edifice up to sea level before fading away.

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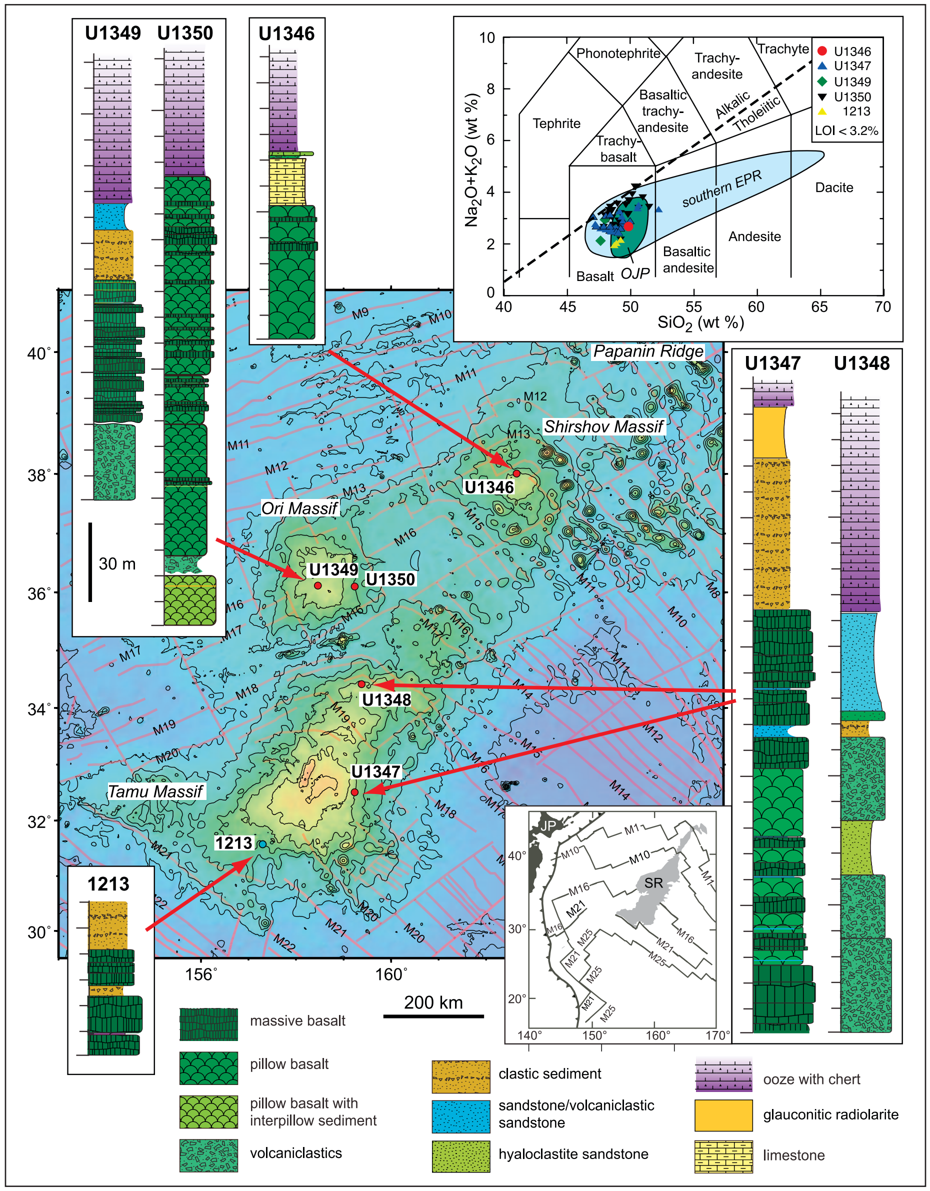


*Fig. 1. Shatsky Rise bathymetry (500-meter contours) with magnetic lineations (orange lines) and Integrated Ocean Drilling Program Expedition 324 drilling results. Expedition 324 drill sites are denoted by red dots, and Ocean Drilling Program (ODP) Site 1213 is denoted by a blue dot. Columns show graphic lithology of drill cores (all at same vertical scale). Inset at top right shows total alkalis versus silica for Site 1213 [*Mahoney et al., *2005] and the least altered Expedition 324 samples, as defined by an LOI (loss on ignition at 1025°C of volatiles) less than 3.2%. Dashed line divides tholeiitic and alkalic lavas. OJP is the Ontong Java Plateau; EPR is the East Pacific Rise. References for the base map and geochemical reference fields are given by* Sager et al. *[2010]. Inset at bottom right shows location of Shatsky Rise (SR) relative to Japan (JP) and nearby trenches (toothed lines).*