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Insights on the Formation and Evolution of the Upper Oceanic Crust from Deep Drilling at ODP/IODP Hole 1256D

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Deep drilling of Hole 1256D on ODP Leg 206 and IODP Expeditions 309/312 provides the first complete section of intact upper oceanic crust down to gabbros. Site 1256 is located on ocean crust of the Cocos Plate that formed at the East Pacific Rise (EPR) 15 million years ago during an episode of superfast rate ocean spreading in excess of 200 mm/yr. Past deep drilling of intact ocean crust has been fraught with difficulties due to the highly fractured nature of oceanic lavas. Site 1256 was specifically chosen because the observed relationship between spreading rate and the depth to axial seismic low velocity zones at modern mid-ocean ridges (thought to be magma chambers), suggests that gabbroic rocks should occur at the shallowest levels in ocean crust formed at the highest spreading rates. In line with pre-drilling predictions, gabbroic rocks were first encountered 1157 m into the basement. Hole 1256D penetrates 754 m of lavas, a 57-m thick transition zone and a thin (346 m) sheeted dike complex. The lower ~60 m of the sheeted dikes are contact metamorphosed to granoblastic textures. After encountering gabbros the hole was deepened a further 100 m before the cessation of drilling operations and the plutonic section comprises two gabbroic sills, 52 and 24 m-thick, intruded into a 24 m screen of granoblastic dikes. The gabbro sills have chilled margins and compositions similar to the overlying lavas and dikes, precluding formation of the cumulate lower oceanic crust from the melt lenses so far penetrated by Hole 1256D.
A vertical seismic experiment conducted in Hole 1256D indicates that the bottom of the Hole is still within seismic layer 2 despite gabbroic rocks having been recovered. These data together with 1-D and imaging wire-line logs, have been used to construct a continuous volcano-stratigraphy for Site 1256. Comparison of this data with the recovered cores and the styles of eruption occurring at the modern EPR indicate that ~50% of lava sequences were formed within a few kilometres of the ridge axis, with a further 200 m of lavas that display inflation textures deposited at the base of the axial slope. The great thickness (>75 m) of the ponded lava that makes up the uppermost crust at Site 1256, and an absence of vertical fracturing within those rocks, supports the shipboard interpretation that this unit crystallized a significant distance (~5-10 km) off axis.
Geochemical analyses of the Hole 1256D cores have been undertaken to evaluate the melting processes and mantle source heterogeneity under the superfast spreading ancient EPR. Hole 1256D cores have significantly lower incompatible element concentrations than present-day EPR lavas, a signature typically interpreted in terms of greater extents of mantle melting. However, similar crustal thicknesses between Site 1256 (5.5 km) and the EPR (5-7 km) challenge that view. This observation coupled with preliminary radiogenic isotope signatures indicate that the depleted mantle source variation might be caused by upwelling previously depleted Galapagos plume mantle at the paleo-Site 1256. Whole rock and mineral trace element analyses indicate that the gabbros sampled to date cannot be the cumulate rocks remaining after melt extraction. Instead, most of the gabbros represent slowly cooled equivalents of the overlying basaltic rocks. However, some patches of gabbro are magmatically highly evolved, and record late stage melts squeezed out from the crystallizing mush within the melt lens.
Secondary mineralogy plus oxygen isotope analyses of vein minerals document the thermal structure of the fossil hydrothermal system penetrated by Hole 1256D, and record a complex history of repeated episodes of magmatism and hydrothermal alteration. The ~800 m volcanic section is partly altered to saponite and celadonite, typical of altered submarine basalts but with little oxidation. There is a stepwise increase in alteration grade across the lava-dike transition and the dikes are variably altered to chlorite and other greenschist minerals (250-350 deg C). The lower 60 m of granoblastic dikes were contact metamorphosed at 850 to 950 deg C. Thermal modelling indicates that this metamorphic aureole can not be formed by the gabbro sills alone unless there was melt replenishment or significant topography on the dike-gabbro boundary. The gabbros are moderately to

highly altered to amphibole, plagioclase, epidote, chlorite, prehnite and laumontite, with maximum alteration temperatures of 400 to 800 deg C. Strontium isotope analyses indicate only limited seawater-basalt strontium exchange within the lavas but extensive exchange within the narrow sheeted dike complex. The gabbros are less altered but the boundaries between the gabbro sills and the dikes and the lava-dike transition are zones of extensive fluid flow, fluid-mixing and Sr-isotopic exchange.