IODP EXPEDITION 309:
SUPERFAST SPREADING RATE CRUST 2
SITE 1256 SUMMARY

Expedition 309, "Superfast Spreading Rate Crust 2," successfully deepened Hole 1256D (6.736°N, 91.934°W) by 503 m to a total depth of 1255.1 meters below seafloor (mbsf) or 1005.1 meters subbasement. The average rate of core recovery for the expedition was 36%. Much higher rates of recovery were experienced in the lowermost section of the hole (~70% average below 1200 mbsf). At the end of Expedition 309, Hole 1256D penetrated more than 800 m of extrusive lavas and entered a region dominated by intrusive rocks. Hole 1256D is now the fourth deepest hole drilled into oceanic basement since the inception of scientific ocean drilling in 1968 and the second deepest penetration into in situ ocean crust behind DSDP/ODP Hole 504B. At 1255 mbsf, Hole 1256D is tantalizingly close to the predicted minimum depth estimated for the frozen axial magma chambers (1275 mbsf). Following the completion of a comprehensive wireline logging program, the hole was successfully exited and left clear of equipment with only minor unconsolidated fill at the bottom of the hole. Hole 1256D is in excellent condition and ready for further deepening.

Expedition 309 is the second scientific ocean drilling cruise in a multiphase mission to Site 1256 designed to recover, for the first time, a complete section of the upper oceanic crust from extrusive lavas down through the dikes and into the uppermost gabbros. Hole 1256D in the eastern equatorial Pacific was initiated during ODP Leg 206 and is drilled into 15-Ma crust that formed at the East Pacific Rise during a period of superfast spreading (>200 mm/a). This site was chosen to exploit the inverse relationship observed from seismic experiments between spreading rate and the depth to axial low velocity zones, thought to be magma chambers now frozen as gabbros. Hole 1256D is the first basement borehole prepared with the infrastructure desirable for drilling a moderately deep (~1.5–2 km) hole into the oceanic crust.

Description of cores recovered during Expedition 309 coupled with Leg 206 observations have led to a preliminary subdivision of the upper oceanic crust at Site 1256. The uppermost basement consists of a massive ponded lava flow >74 m thick. The lava pond (250–350 mbsf) overlies an interval of massive sheet and pillow flows with flow inflation structures (350– 534 mbsf) that suggest eruption onto a subhorizontal surface. The great thickness of the massive ponded lava required significant topography to pool the lavas, and the distinctive textures of the inflated flows suggest that these two 284 m thick lava groups formed off axis. Sheet and massive flows (534–1004 mbsf) make up the majority of the extrusive sequence in Hole 1256D. Cryptocrystalline to microcrystalline sheet flows, tens of centimeters to <3 m thick, commonly with glassy subhorizontal margins, are the dominant lava morphology. Massive fine-grained lavas become more abundant with depth. The lithologic transition zone (1004–1061 mbsf) is marked by the presence of a cataclastic massive unit with subvertically oriented cryptocrystalline basalt clasts hosted by highly altered, incipiently brecciated fine-grained basalt, crosscut by numerous fine veins and cataclastic stringers. The first subvertical intrusive contact recovered during Expedition 309 occurs at 1018 mbsf. Subvertical fracture sets possibly indicative of diking into the host rocks nearby Hole 1256D are common from ~900 mbsf. Dike chilled margins become more common downhole but extrusive textures and vesicles are still encountered down to 1061 mbsf. Breccias of various styles are common in the transition zone, including a spectacular mineralized volcanic breccia (~1028 mbsf) with hyaloclastite and basaltic clasts cemented by sulfides and subgreenschist facies minerals.

A distinct change from sheet flows to massive basalts at ~1061 mbsf defines the upper boundary to the sheeted intrusives. Extrusive rocks could be present below this level, but evidence for eruption remains ambiguous. The massive basalts are most commonly aphyric and nonvesicular. Fine-grained rocks have holocrystalline or doleritic groundmass textures. Further downhole in Hole 1256D, subvertical intrusive dike contacts are common. Massive basalts are the dominant rock type in the sheeted intrusives but whether they represent dikes or sub-volcanic sills remains unproven. An unambiguous subvertical contact that grades continuously from a glassy chilled margin to microcrystalline then fine-grained massive basalt has so far eluded recovery.

The overall mineralogical and geochemical characteristics of basement drilled during Expedition 309 are similar to the cores from Leg 206 although there are some important differences. Phenocrysts are much less abundant in the Expedition 309 cores than Leg 206 cores with >80% aphyric basalts (Leg 206 = <40%). Olivine was the dominant phenocryst phase in the cores drilled during Leg 206 but plagioclase phenocrysts are more common in the lower 500 m of basement. The basalts show evidence for fractionation and replenishment downhole and trace element concentrations are within one standard deviation of average East Pacific Rise MORB, albeit on the relatively trace element depleted side.

Hole 1256D is the second drill hole to penetrate the transition from low-temperature alteration to high-temperature hydrothermal alteration in a continuous section of oceanic crust. Prior to Expedition 309, this transition had only been described in Hole 504B. Rocks that reacted with seawater at low temperatures are present down to ~965 mbsf. Black, brown, and mixed halos related to veins filled by saponite, celadonite, and iron oxyhydroxides are common in rocks from 752 to 918 mbsf. From 918 to 964 mbsf dark gray background alteration with abundant saponite and pyrite is ubiquitous.

From 964 to 1028 mbsf there is a transition in alteration characterized by the presence of pyrite-rich alteration halos and mixed-layered chlorite/smectite instead of pure saponite. Anhydrite is common from this depth to the bottom of the hole. Below ~1028 mbsf the transition to hydrothermal conditions is complete with the presence of the mineralized volcanic breccia and the first occurrences of actinolite, prehnite, titanite, and epidote. These minerals are indicative of hydrothermal alteration under subgreenschist to greenschist facies conditions. In this part of the crust, green-gray vein halos and patches are common, with 10%–100% chlorite, actinolite, titanite, albite, pyrite (± minor quartz, chalcopyrite, and prehnite) replacing plagioclase and clinopyroxene and filling interstitial spaces.

The rocks at Site 1256D are less altered compared to most other basement sites (e.g., Sites 417 and 418, Holes 504B and 896A). Hole 1256D contains a much smaller proportion of alteration halos within the extrusive lavas, compared to Holes 504B and 896A, and the amount of calcite within Hole 1256D is very low compared to other basement penetrations. Although pyrite is abundant in the Expedition 309 cores, quartz-epidote-chalcopyrite stockwork mineralization present in Hole 504B has not been penetrated in the transition from extrusive to intrusive rocks. Instead, the mineralized volcanic breccia with altered hyaloclastite fragments supported in a sulfide cement is the most sulfide-rich interval (Figure 3a). Anhydrite, which is sparse in Hole 504B, is abundant at Site 1256.

The basalts recovered during Expedition 309 predominantly exhibit brittle structures with rare brittle-ductile structures. Veins, vein networks, cataclastic zones, shear veins, microfaults, and breccia represent the main structural features. In the sheet and massive flows, structures and fracturing are heterogeneously partitioned and are most intensely developed at the top of the massive flows. Vertical sets of veins, cataclastic zones, and shear veins are present in massive units, whereas breccias are more common in sheet flows. Vertical vein sets become more common below ~900 mbsf. Most structures are related to the cooling of lava and are represented by curved, radial, Y-shaped, and irregular veins filled with secondary minerals.

Below ~1004 mbsf, numerous chilled margins were recovered and these contacts are increasingly common with depth. Where such contacts are subvertical, they are interpreted as dike margins. Chilled margins range from lobate and inter-fingered to sharp. Many chilled dike margins are associated with, or highly disrupted by, diffuse veining and brecciation. Multiple dikes and banded dikes also occur. The true dips of the chilled margins range from 50° to 90° with a mode at ~70°–75°. The sheeted intrusives are also characterized by the first occurrence of systematic conjugate veins.

All rocks in Hole 1256D have been subjected to an intense drilling overprint. Rocks from the bottom of Hole 1256D have higher coercivities and there is an apparent increase in the quality of data from 970–1030 mbsf. Because of the equatorial paleolatitude of the site, polarity remains ambiguous until absolute declinations can be obtained. The generally positive inclinations measured are not what are expected for the low paleolatitude. The most likely explanation is that a significant portion of the drilling overprint remains on nearly all of the samples. Magnetic intensities show a recurrent concave pattern with relatively high intensities at the upper and lower boundaries of igneous cooling units and lower intensities in the unit interiors suggesting an average thickness of ~1.0 ± 0.5 m for most cooling units.

P-wave velocities of Expedition 309 basalts range from 4.8 to 6.1 km/s, with an average of 5.5 ± 0.3 km/s, similar to velocities estimated from regional seismic reflection data. Below 752 mbsf, the average VP increases ~0.05 km/s for each 50 m downhole to ~6.1 km/s at 1240 mbsf. Average VP is slightly higher below 1061 mbsf (5.8 ± 0.1 km/s) than above (5.4 ± 0.3 km/s). Porosities range from 2% to 14% (average = 4%). Porosity in the massive units decreases from 4% ± 1% above 1061 mbsf to 2% ± 1% below this level. The average thermal conductivity in the sheet and massive flows is 1.8 ± 0.2 W/(m·K), but there is a significant increase in thermal conductivity starting in the transition zone and a distinct step-like increase to 2.1 ± 0.1 W/(m·K) at the top of the sheeted intrusives.

Following the completion of drilling in Hole 1256D, a complete suite of geophysical wireline logs was collected. Caliper readings from both the triple combo and FMS-sonic tool strings show generally good borehole conditions with a diameter typically between 11 and 14 inches. Comparison of the pre- and post drilling hole caliper measurements in the upper 500 m of basement shows an enlargement of Hole 1256D due to drilling, with a number of quite strongly eroded intervals. The borehole deviation measured at 1200 mbsf is 4.3°. Preliminary analyses of downhole geophysical measurements and images show a high degree of variation, reflecting different basement lithologies. A number of petrophysical intervals can be distinguished that closely match the subdivisions developed from core observations. Preliminary interpretation of FMS and UBI images indicate that subvertical dike margins in the sheeted intrusives have true dips towards the northeast, consistent with slight tilting of the lavas toward the paleoridge axis.

Expedition 309 (July–August 2005) will be followed closely by IODP Expedition 312 (November–December 2005). Despite our grueling pace of advance (15 m/day), progress with deepening Hole 1256D has been steady. Optimistically anticipating the same benign drilling conditions, good fortune, and assured of highly astute rig floor operations, Expedition 312, with more than 30 days of drilling operations, is set to deepen Hole 1256D by a further 500 m, well beyond the depths where geophysical interpretations predict gabbros to occur.