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ODP-IODP SITE 1256 (EAST PACIFIC RISE): AN IN-SITU SECTION OF UPPER OCEAN CRUST FORMED AT A SUPERFAST SPREADING RATE

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ABSTRACT

The igneous rocks cored in Holes 1256C and 1256D during Ocean Drilling Program (ODP) Leg 206 and Integrated Ocean Drilling Project (IODP) Expedition 309 are dominated by thin (10's of cm to 3 m) basaltic sheet flows separated by chilled margins, with several massive flows (> 3 m thick), minor pillow basalt and hyaloclastites, and rare small dikes. In Hole 1256D, the percentage of massive flows decreases downhole. One notable feature of both holes cored is the presence of a very thick massive lava (~35 m thick in Hole 1256C and ~75 m thick in Hole 1256D) near the top of each hole. The structural aspect of this thick massive unit are here described. It has been interpreted as a lava pond emplaced in a topographic depression. Although the ocean crust drilled at Hole 1256C and Hole 1256D partly fits the "Penrose" model for showing the superposition of volcanics on sheeted dikes and intrusives, the relative thickness of the lava-dike sequence could reflect a combination of two or more of the following processes: local (spatial) heterogeneity along ridge-axis, (temporal) variability, essentially linked to a more or less intense activity of the magma chamber, and off-axis eruptions.

INTRODUCTION AND GEOLOGICAL SETTING

Over 60% of the Earth is covered by ocean crust formed at mid-ocean ridges, all of which formed within the last 200 Ma. The accretion of ocean crust at mid-ocean ridges is the dominant process of thermal and chemical transfer from the Earth's interior to the crust, overlying oceans, and atmosphere. Observations from ophiolites, Oman in particular (e.g., Nicolas and Boudier, 1991; Nicolas et al., 1994), which represent tectonic sheets of fossil oceanic lithosphere, provided the first constraints for testing the results of seismic surveys in the oceans and for modeling and interpreting the formation of the ocean crust (e.g., Bergman and Solomon, 1984; Purdy, 1982). In the last decades, seafloor geology and marine geophysics, supported by sampling, greatly improved our understanding of the fundamental processes involved in the formation and evolution of the ocean crust (e.g., Barth and Mutter, 1996; Karson, 1998; Perfit and Chadwick, 1998; Toomey and Hooft, 2004, and refs. therein). Despite the central role that the ocean crust plays in the evolution of our planet, sampling of intact *in situ* ocean crust is inadequate. Namely, the nature and variability of the composition and structure of the ocean crust away from transform faults and other tectonic windows are still poorly known. Drilling a complete crustal section has always been a major goal of scientific ocean drilling (Bascom, 1961; Shor, 1985), but achievement of this goal has been mainly impeded by technical difficulties.

The distribution of drill holes in ocean crust of different ages and formed at different spreading rates is sparse (Fig. 1; see Wilson et al., 2003a and refs. therein). Hole 504B, drilled during the Deep Sea Drilling Project and ODP into 5.9 Ma crust on the southern flank of the intermediate-spreading Costa Rica Rift, was previously the only hole to penetrate a complete sequence of extrusive lavas and partially through the underlying sheeted dike complex (Alt et al., 1993). At that site, the dike - gabbro transition had never been drilled in Hole 504B, and the nature of the plutonic rocks directly subjacent to the sheeted dike complex is not known in present-day ocean crust.

At the end of 2002, a multicruise program was launched by ODP with the main goal of drilling, for the first time, a complete intact *in situ* section of the upper ocean crust from extrusive lavas, through the dikes, and into the underlying gabbros. The area selected to drill was ODP Site 1256 (6°44.2 N, 91°56.1 W) on 15 Ma old crust that formed at the East Pacific Rise (EPR) with a superfast full spreading rate of >200 mm/y (Fig. 2) (Wilson, 1996). Site 1256 is located ~1150 km east of the present crest of the EPR and ~530 km north of the Cocos Ridge; it formed on a ridge segment at least 400 km in length, ~100 km north of the triple junction between the Cocos, Pacific, and Nazca plates. The sediment thickness in the region is relatively thin (up to a few hundred meters) and is 250 m at Site 1256. Calculated sedimentation rates vary from ~6 to 36 m/m.y., being faster in older (Middle Miocene) than in younger sediments.

Site 1256 has a typical seismic structure for Pacific off-axis seafloor. Upper Layer 2 velocities are 4.5-5 km/s and the Layer 2-3 transition is between ~1200 and 1500 meters below the top of basement (msb). The total crustal thickness is estimated at ~5-5.5 km.

During ODP Leg 206, four holes were drilled at Site 1256 (Wilson et al., 2003a). Among the deepest, Hole 1256C was cored down to 88.5 m into basement, and Hole 1256D was cored down to 502 m into basement. Average recovery in basement was 61.3% for Hole 1256C, and 47.8% for Hole 1256D. The upper section of the igneous basement is dominated by thin (< 3 m) basaltic sheet flows separated by chilled margins. The second most common rock type is represented by massive basaltic flows (> 3m). This includes the ponded lava flow that occurs near the top of the basement in each hole. Minor intervals of pillow lavas (20 m) and hyaloclastite (a few meters) were recovered in Hole 1256D.

During the subsequent IODP Expedition 309 (Expedition 309 Scientists, 2005), Hole 1256D was deepened by ~503 m

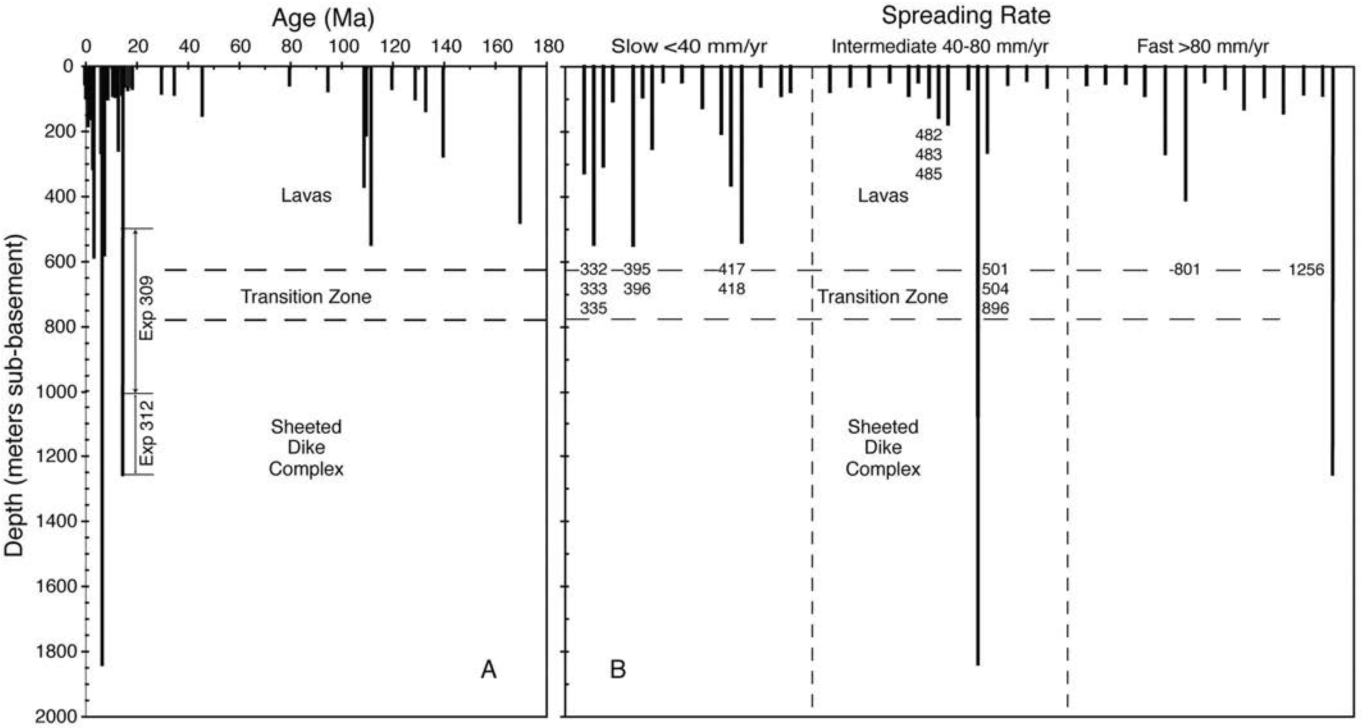

Fig. 1 - Distribution of DSDP and ODP/IODP drill holes in the oceanic crust a) Basement age versus depth of basement penetration for scientific drill holes deeper than 50 m drilled into in situ ocean crust formed at the mid-ocean ridges. b) Depth of penetration of drill holes into in situ basement from slow (< 40 mm/y), moderate (< 80 mm/y) and fast (> 80 mm/y) ridges. Holes 1256C and 1256D drilled into basement during Leg 206, Expedition 309, and Expedition 312 (Expedition 309 and 312 Scientists, 2006). VCD records (after Expedition 309 Scientists, 2005).

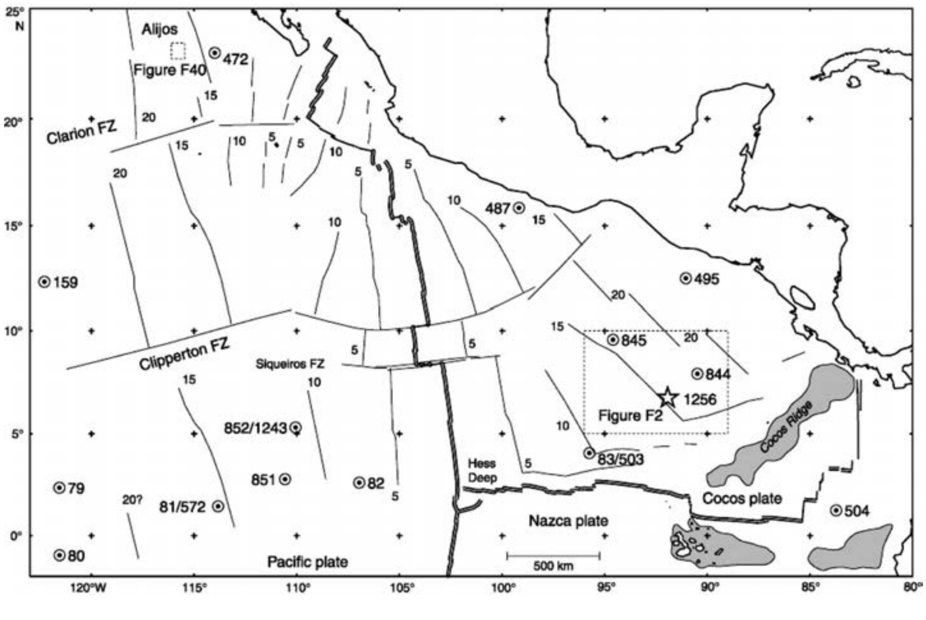

Fig. 2 - Location of Site 1256 (star) and distribution ages of the Cocos Plate and corresponding regions of the Pacific Plate (after Wilson et al., 2003b). Isochrons at 5-m.y. intervals have been converted from magnetic anomaly identifications according to the timescale of Cande and Kent (1995). Selected DSDP and ODP sites that reached basement are indicated by circles. The wide spacing of 10- to 20-Ma isochrons to the south reflects the extremely fast (200-220 mm/yr) full spreading rate.

to 1255.1 meters beneath seafloor (mbsf), and extrusive rocks and underlying sheeted dike complex were sampled (Fig. 3). The more recent IODP Expedition 312 (Expedition 309 and 312 Scientists, 2006) successfully continued the coring of upper ocean crust, and reached the first gabbros at 1406.6 mbsf. This depth is close to that which was predicted based upon a correlation of spreading rate with decreasing depth to the axial low-velocity zone (i.e., 1100-1300 meters below the top of basement at Site 1256; e.g., Purdy et al., 1992), interpreted as a melt lens now crystallized to gabbro at Site 1256. At 1257.1 meters below the top of basement (or 1507.1 mbsf), Hole 1256D is now the fourth deepest hole drilled into ocean basement since the launch of scientific ocean drilling in 1968 and the second deepest penetration into in situ ocean crust behind Hole 504B. The continuous section of in situ ocean crust generated at a superfast spreading rate in the eastern Pacific provides the first sampling of a complete section of upper ocean crust from extrusive rock, dikes and gabbros. By representing one end-member style of mid-ocean-ridge accretion, such crustal section allows a test of whether ocean crust formed at a superfast spreading rate conforms to the “Penrose” ophiolite stratigraphic model (Penrose Conference Participants, 1972).

This paper focuses on results obtained during ODP Leg 206 and on structural aspects of the upper ocean crust drilled at Site 1256. Thick massive microcrystalline basalts

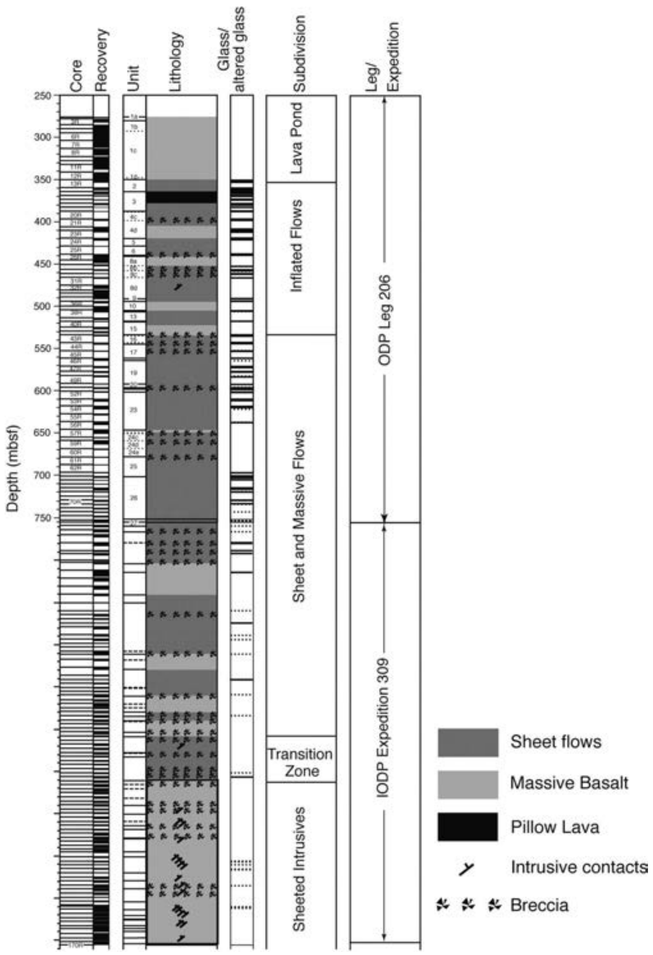

Fig. 3 - Summary of basement stratigraphy in Hole 1256D, cored during ODP Leg 206 and IODP Expedition 309, showing (from left) a depth scale, core numbers, recovered intervals, unit and subunit boundaries, igneous lithology, locations of glass and altered glass (solid/stippled line). The Leg 206 stratigraphy is slightly revised according to the Leg 206 VCD records (after expedition 309 scientists, 2005).

from both Hole 1256C and 1256D record the best examples of structures. Ductile to brittle-ductile structures from massive units in 1256C-Unit 18 and 1256D-Unit 1 at the top of igneous basement provide information on the emplacement mechanism of lava flows (see also Crispini et al., 2006, this volume), and constraints for determining the relation between tectonics and crustal accretion.

CRUSTAL STRATIGRAPHY AND COMPOSITION AT SITE 1256

Beneath a sedimentary overburden ca. 250 m-thick, the upper ocean crust at Site 1256 is preliminarily subdivided into a *Lava pond* (250-350 mbsf), *"Inflated flows"* (350.3-533.9 mbsf), *Sheet and Massive Flows* (533.9-1004.2 mbsf), *Transition Zone* (1004.2-1060.9 mbsf) and *Sheeted Intrusives* (>1060 mbsf) (Fig. 3). The crustal stratigraphy is mainly based on the stratigraphic log of Hole 1256D (Expedition 309 and 312 Scientists, 2006).

Lava Pond

The Lava Pond is the uppermost massive basalts unit both in Hole 1256C and Hole 1256D. The massive ponded flow *sensu stricto* (lithological units 1256C-18 and 1256D-1 in Holes 1256C and 1256D, respectively) is defined at its top by a ~75 cm rind of glassy to cryptocrystalline aphyric basalt that overlies ~30 and ~74 m of fine-grained basalt in Holes 1256C and 1256D, respectively. Some differences have been highlighted in the massive units from the two holes. For example, in Hole 1256C, the massive ponded flow lies between sheet flows interlayered with some sediments, whereas in Hole 1256D, it caps sheet flows and pillow lavas (Fig. 3). In Hole 1256C, the uppermost 0.7 m is composed of aphanitic lava with folded glassy chilled margins and volcanic rubble including glassy clasts; this top part is interpreted as the folded and brecciated surface crust of a lava flow (see also Crispini et al., this volume). The top of basement in Hole 1256D has not been cored because it was reduced to rubbles during the casing deployment procedure. In this hole, fine-grained massive basalt of Unit 1256D-1 was drilled in the first core at 276.1 mbsf, i.e. about 4 m above the top of Unit 1256C-18 of Hole 1256C. Unit 1256D-1 continues downhole to 350 mbsf.

The basal 1.6 m of the Ponded Lava in Hole 1256C consists of an aphyric cryptocrystalline basalt cut by late magmatic veins. Basalt exhibits an unusual groundmass texture of equigranular clinopyroxene and magnetite with sparse plagioclase laths that reflects recrystallization at near-magmatic temperatures. Similar structures have not been observed in Hole 1256D. The lower contacts of the Lava Pond in the two holes have not been recovered. In spite of such differences, Unit 1 in Hole 1256D has been lithologically correlated to the thick massive lava Unit 1256C-18 in Hole 1256C, although Unit 1 is much thicker (>70 m thick) and it lacks the quenched upper surface and the basal recrystallized basalt lava.

Although the massive flow is much thicker in Hole 1256D than in 1256C, which is only 30 m away, it is interpreted as a single lava body whose interior was liquid at the same time in both locations, thus representing a clear marker unit for correlation between holes (Wilson et al., 2003a).

"Inflated flows"

This portion occurs in Hole 1256D and consists of a sequence of massive flows, pillow lavas, and sheet flows grouped together as the "inflated flows". The term "inflated" refers to the occurrence of subvertical elongate fractures filled with quenched glass and hyaloclastite at the top of the lava flows indicating flow-lobe inflation that requires eruption onto a subhorizontal surface at less than a few degrees (Umino et al., 2000; 2002).

Sheet and massive flows

This 470 m thick sequence occurs in Hole 1256D and consists of sheet flows tens of centimeters to ~3 m thick with subordinate massive flows >3 to 16 m thick and various breccias (Fig. 4). It represents the bulk of the extrusive lavas at Hole 1256D.

Transition zone

This zone is present in Hole 1256D. Most of the rocks within the transition zone are aphyric, cryptocrystalline sheet flows. The top of the transition zone is marked by a cataclastic unit. Deeper Core 309-1256D-120R (~1018 mbsf) includes the first sign of a subvertical intrusive contact. Dike chilled margins become more common downhole, although extrusive textures and vesicles are still encountered. The boundaries of the transition zone are not well defined because they are characterized by the occurrence of differ-

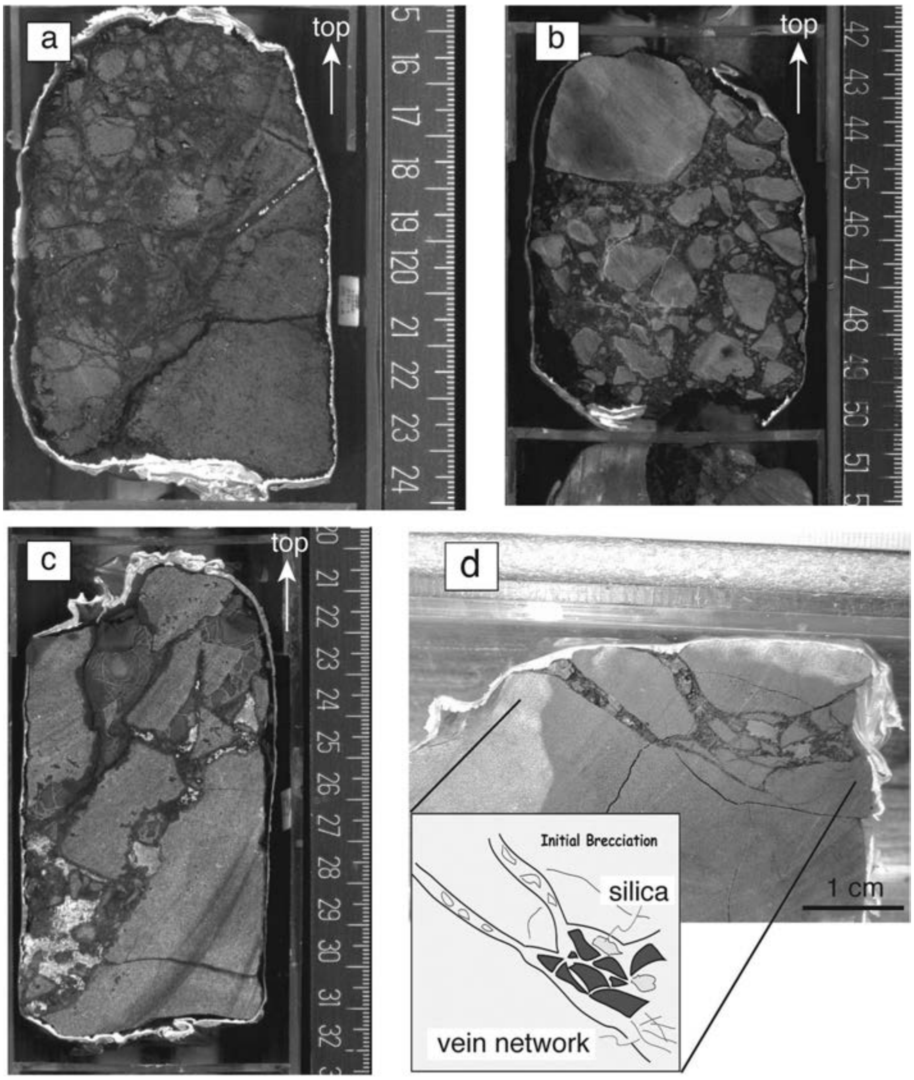

Fig. 4 - Examples of breccia recovered during ODP Leg 206. a) Close-up photograph of pieces of hyaloclastite consisting of rounded glassy blocks with chilled margins and angular clasts of glass embedded in altered glass (Sample 206-1256D-21R-1, Piece 20). b) Close-up photograph of volcaniclastic rock composed of angular and sub-rounded fragments of cryptocrystalline basalt embedded in a matrix of glassy fragments cemented by altered glass and phyllosilicate (Sample 206-1256D-20R-1, Piece 7). c) Close-up photograph of breccia composed of clasts of crystalline basalt intruded by fingers of black glassy basalt and cemented by a hydrothermal assemblage of amphibole, chlorite, and chalcedonic quartz (white) (Sample 206-1256D-26R-2, Piece 4). d) Incipient breccia starting from vein network (Sample 206-1256D-29R-1, Piece 23).

ent rock types rather than by the first appearance of a specific feature. Further structural, petrographic and geochemical investigations will help refine the boundaries of this zone.

Sheeted dikes

This interval was encountered in Hole 1256D during IODP Expedition 309 at ca. 1060 mbsf. The upper boundary is defined by a change from sheet flows to massive basalts. Below that level, subvertical intrusive contacts are common. Several types of contacts have been observed, including planar or irregular direct contacts and brecciated contacts. All contacts have developed chilled margin.

Geochemical features

All lavas from Site 1256 are N-MORB although a general trend of decreasing chemical fractionation with depth has been detected (Wilson et al., 2003a). However, exceptions exist and some basalts show a more evolved composition. In general, rocks from the Lava Pond of the two holes represent the majority of the evolved basalt distinguishable for their Zr and TiO_2 contents. In Hole 1256D, basalts from the Lava Pond have lower Mg# (Mg# $\leq$ 50) and higher concentrations of incompatible elements with respect to basalts from deeper parts. In addition, some samples from the Lava Pond in Hole 1256C (from 294 to 306 mbsf) have very high K_2O contents which coincides with an increase in NGR measurements.

STRUCTURES OF THE LAVA POND AT SITE 1256

The Lava Pond drilled in Hole 1256C and 1256D is characterized by structures related to both primary magmatic and postmagmatic processes. Primary igneous features include magmatic fabrics, lamination, flattened vesicles, folds, shear-related structures, and late magmatic veins. Postmagmatic structures include joints, veins, shear veins, and microfaults. Magmatic, ductile, and brittle-ductile structures are mostly concentrated in Hole 1256C (lithologic Unit 1256C-18) near the top and bottom parts of the Lava Pond. Detailed descriptions of these structures and related microstructures are reported in a companion paper (Crispini et al., 2006, this volume) and interpreted as being related to flow kinematics (see also Wilson et al., 2003a).

Downhole distribution of brittle structure in the Lava Pond

The downhole distribution of structures in the Lava Pond is illustrated in Fig. 5. Veins are the most prominent structures. They consist of brittle failures of the rock filled with a variety of minerals, such as saponite, celadonite, Fe-oxyhydroxides and minor carbonate which precipitated by rock-seawater and low-temperature rock-hydrothermal fluid interaction. Veins are characterized by planar and slightly curved morphology, or branch into a number of diverging

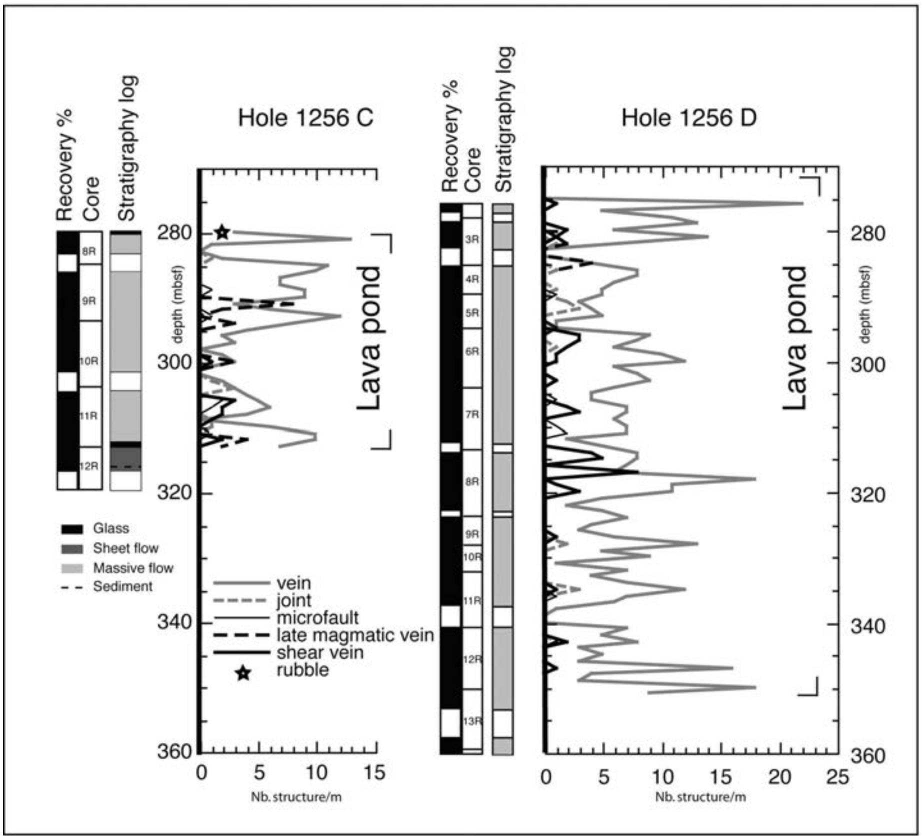

Fig. 5 - Downhole distribution of structures in lava pond from Holes 1256C (left) and 1256D (right).

splays. Veins may be arranged in conjugate sets which are mostly concentrated in two zones of Hole 1256D, at 296-303 mbsf, within fine-grained basalt, and at 347-351 mbsf, within sparsely phyric microcrystalline basalt. On the whole, vein frequency does not seem to be concentrated at the same depths in the two holes, except in the top part of the Lava Pond where spikes occur around 281 and 285 mbsf in both holes. Joints (i.e. failure of the rock with no infillings) are uncommon but widespread in the Lava Pond within both holes. Microfaults are not very abundant in the two holes: in Hole 1256C faulted rock occurs at ca. 306 mbsf (Section 206-1256C-11R-3: fine-grained basalt) where the highest frequency of shear veins is also recorded (Fig. 5). In Hole 1256D, faulted rocks are also scarce and they are more concentrated at ca. 311 mbsf (Section 206-1256D-7R-6: fine-grained basalt). By contrast, shear veins in Hole 1256D are much more abundant than in Hole 1256C, and they are mostly concentrated between ca. 296 and 300 mbsf (core 206-1256D-6R), and between ca. 314 and 320 mbsf (core 206-1256D-8R). Many of these veins show a reverse sense of shear (Fig. 6).

Breccias are almost absent in the Lava Pond from the two holes. Only one occurrence is recorded near the top part of the Lava Pond in Hole 1256C. Breccias are more common out near the tops or bottoms of sheet flows from the two holes (Wilson et al., 2003a; Tartarotti and Crispini, 2003).

One of the most striking features of the Lava Pond is the occurrence of late magmatic features. These include felsic veins (usually > 0.5 mm wide) and glassy veins (< 0.5mm wide). Felsic veins are characterized by quartz + plagioclase symplectites showing a granophyric texture ± clinopyroxene ± magnetite ± apatite (Fig. 7a, 7b, 7c; see also Laverne et al., submitted). Glassy veins are almost totally replaced by saponite. Late magmatic veins are either planar features, or form sigmoidal pull-aparts or fill tension gashes (Fig. 6d). These are much more frequent in Hole 1256C in which they are mostly concentrated in the top and bottom part of the Lava Pond (see also Crispini et al., 2006, this volume). The highest frequency of late magmatic veins was observed at 291-292 mbsf and near the bottom part of Lava Pond in Hole 1256C, and at 285 mbsf in Hole 1256D.

Structural measurements carried out on cores from the two holes suggest that all planar structures (dip directions are not determined because cores are free to rotate and thus are not oriented with respect to geographic coordinates) are mostly gently dipping (Fig. 8). In Hole 1256C, most structures from the Lava Pond have dip angles of ~15° ± 5°. In Hole 1256D, gently dipping structures predominate, although a second maximum around 60-80° is present. Comparison of various types of structures from the two holes (Fig. 9) shows that (hydrothermal) veins and late magmatic veins are mostly gently dipping; shear veins are moderately to steeply dipping in both Hole 1256C and 1256D, showing the highest frequency at 50° and 80°. Joints are subhorizontal in the two holes; faults dip values are scattered, although in Hole 1256D they have a maximum in frequency between 40° and 60°.

DISCUSSION

Lava Pond structure in Hole 1256C and Hole 1256D

The igneous rocks cored in Holes 1256C and 1256D during ODP Leg 206 are dominated by basaltic sheet flows, massive flows, minor pillow basalt and hyaloclastites, and rare small dikes. One notable feature of both holes cored is the presence of a very thick massive lava (~35 m thick in Hole 1256C and ~75 m thick in Hole 1256D) near the top of each hole. Such a thick lava flow could potentially have

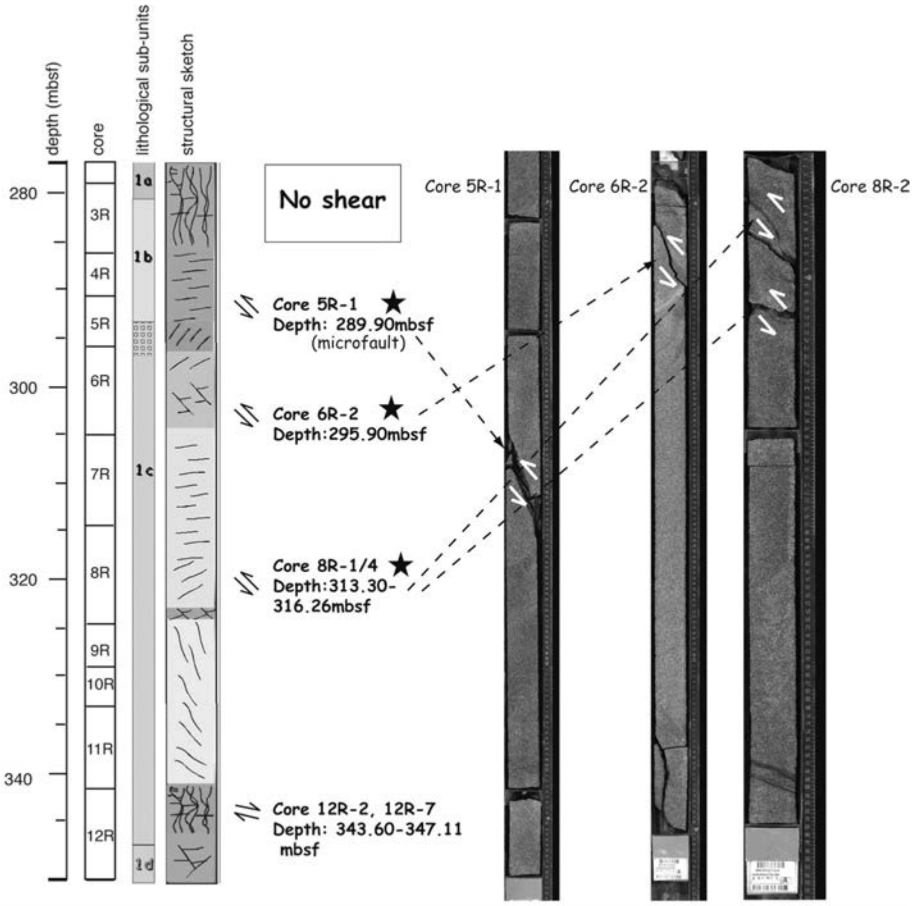

Fig. 6 - Deformation pattern and shear vein concentration in lava pond from Hole 1256D. Lithologic sub-units (1a - 1d) of Unit 1256D-1 as defined in Wilson et al. (2003a). Third column from the left is a simplified representation of average attitude of planar structures (black lines). Arrows indicate the sense of shear in shear veins and microfault. Columns on the rights: pictures of core sections.

formed as a lava pond (and such term is adopted in the present paper), where delivered lava accumulates in a depression, or alternatively as an inflated sheet flow, with delivered lava confined by its own chilled margin. These massive basaltic units have been interpreted by Wilson et al. (2003a) to be a thick ponded lava and not an inflated sheet flow on the following grounds: 1) the absence of inflation-related structures on the upper surface of and within the massive lava, 2) the absence of fine-grained coalesced flow lobe contacts, 3) the largest groundmass grain size and incompatible element concentration in the upper part of the massive lava body suggests the presence of a more differentiated, late solidified melt horizon in the upper one third of the lava body, 4) the scarcity of subhorizontal vesicle-rich layers and segregated melt lenses that are commonly observed within inflated sheet flows elsewhere in the Hole 1256D.

Cores recovered from the Lava Pond in Hole 1256C and in Hole 1256D may not be representative of whole lava flow, due to the small size of core diameter, which is centimetric, and to the fact that the top and bottom contacts of the Lava Pond with the surrounding rocks were not recovered during ODP Leg 206. Consequently, it is difficult to univocally interpret the nature and origin of Unit 1256C-18 and Unit 1256D-1. However, taking into account structural results and other data from the ODP and IODP cruises (Wilson et al., 2003a; Expedition 309 Scientific Party, 2005), a possible interpretation for the origin of the Lava Pond is discussed.

Structural constraints from the Lava Pond may be summarized as follows:

– Inflation-related structures were not sampled either in the upper surface or in the internal parts of the Lava Pond: this supports the hypothesis that massive Unit 18 and Unit 1 do not correspond to an inflated sheet flow.
– Ductile structures developed in aphyric cryptocrystalline basalt near the top and bottom parts of the Lava Pond in Hole 1256C provide evidence for shear stress that probably accommodated the emplacement of the ponded lava flow. Unusual textural features related to the flow kinematics were recognized mainly in the top and in the bottom parts of the Lava Pond (see Crispini et al., this volume). These textures are interpreted to be deformed coalesced spatter clasts erupted during the first stages of the Lava Pond emplacement or, alternatively, to have formed during the draining-back of lava in the final emplacement stages. The occurrence of late magmatic felsic material filling brittle and ductile-brittle structures calls for migration of late-stage differentiated melts when the Lava Pond was not yet completely crystallized.
– Brittle deformation affected the thick Lava Pond after cooling of lava as attested by veins, shear veins, joints and microfaults. Dip values of such brittle planar structures do not seem to change systematically downhole; different types of structures show different dip angles. However, (hydrothermal) veins and late magmatic veins are mostly gently dipping, whilst shear veins and microfaults are mostly steeply dipping in both holes. Steeply dipping structures may be the result of thermal contraction during cooling of lava, but could as well be partly related to the regional stress field. Further investigations, including re-orientation of structures with respect to the geographic North (Tartarotti et al., in press; Tartarotti et al., in prep.), would help to discriminate structures linked to the regional stress field.

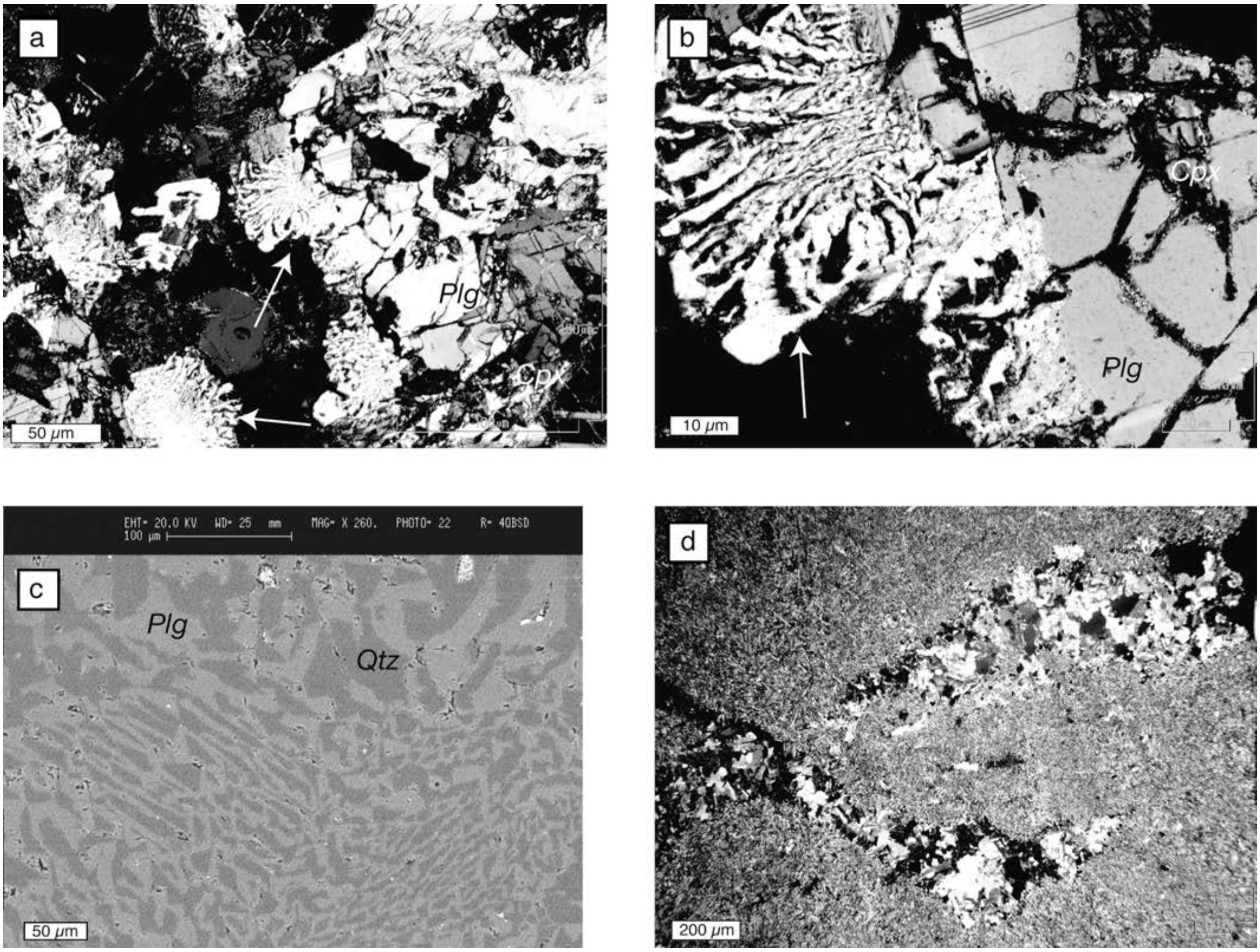

Fig. 7 - Photomicrographs showing late magmatic material (arrows) in lava pond from Hole 1256C. a) Late magmatic veinlets cutting fine-grained basalt (Sample 206-1256C- 9R-5, Piece 2c). Veinlets run from lower right to upper left. Plg- plagioclase; cpx- clinopyroxene. Crossed nicols. b) Detail of picture a). Micrographic texture consisting of plagioclase + quartz symplectites in late magmatic vein. Crossed nicols. c) SEM backscattered image illustrating a detail of plagioclase + quartz symplectites (same sample of picture a). d) Hook-shaped tension gashes in fine-grained basalt. Gashes are filled with late magmatic felsic material (Sample 206-1256C-11R-7, Piece 1c). Crossed nicols.

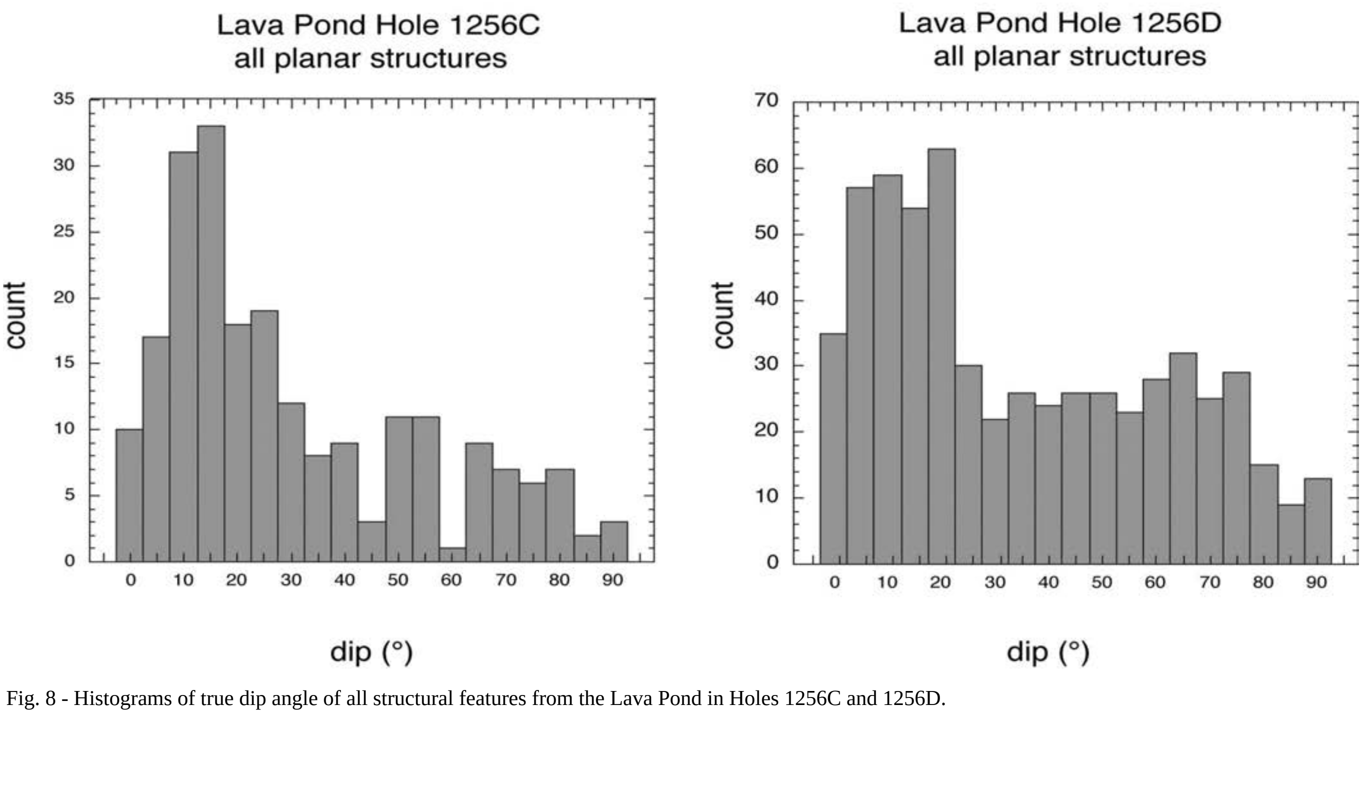

Fig. 8 - Histograms of true dip angle of all structural features from the Lava Pond in Holes 1256C and 1256D.

– No breccias were recovered in the Lava Pond, but this can be due either to the position of the two holes with respect to the Lava Pond geometry, or because brecciated intervals were lost during drilling.
– In spite of the good correlation of the Lava Pond between the two holes, ductile and brittle-ductile structures, such as tension gashes and sigmoidal pull-aparts, are much more abundant in Hole 1256C than in Hole 1256D; shear veins and microfaults are more frequent in Hole 1256D.

Structural and microstructural features observed in the Lava Pond suggest that such a massive lava flow likely had filled a topographic low (graben?) and that was deformed by brittle and brittle-ductile deformation during and after its emplacement.

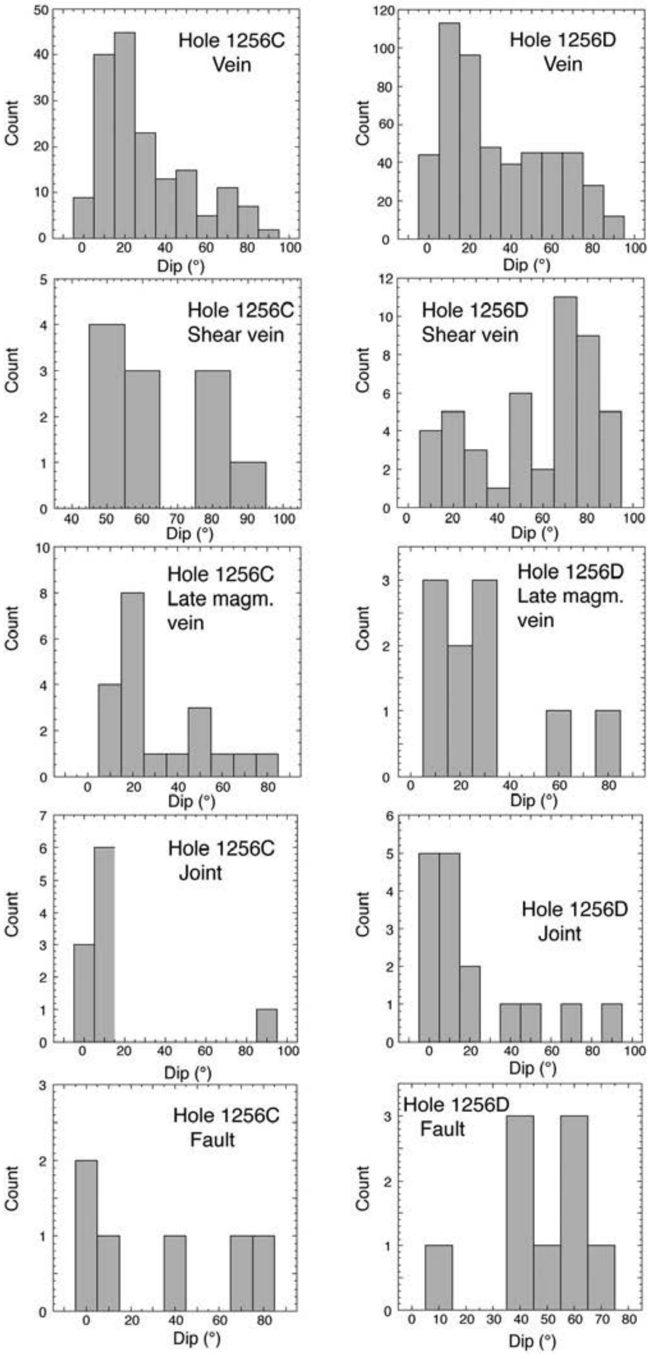

Fig. 9 - Histograms of true dip angles from various types of planar structures (as defined in the text) occurring in the Lava Pond from Hole 1256C (left column) and Hole 1256D (right column).

Massive lava flows have been documented by side-scan sonar images along the East Pacific Rise (EPR). For instance, at 8°S latitude, MacDonald et al. (1989) recognized a 220 km^2 lava field inferred to be erupted at the axial part of the median ridge and then flowed to a distance of about 18 km from the axial part of the ridge segment. At 9°-10°N latitude, channelized lava flows have been mapped by high-resolution side-scan sonar (Soule et al., 2005). Channels extend up to 3 km from the axial summit trough of the ridge segment. Whether the Lava Pond was a summit or off-axis eruption is difficult to infer, until results from ODP and IODP cruises are integrated with further studies. The ponding of a lava flow thicker than 75 m requires a significant basement topography near the axis to pool the magma. The Lava Pond could have been flooded during a period of relatively intense magmatism, corresponding to the drain of the inflated melt lens, and filling the axial submit trough. However, neovolcanic zones are nearly free of faults and fissures, which instead are more commonly observed at 2-4 km off-axis (Soule et al., 2005). Small basement faults with throws of about 100 m are apparent in the site survey seismic sections of the region surrounding Site 1256, and faults of such magnitude are commonly observed 5-10 km from the axis of the East Pacific Rise (Macdonald et al, 1989; 1996).

Geochemical data from ODP Leg 206 (Wilson et al., 2003a) show that bulk rock composition of Lava Pond basalt differs from the average chemical composition of basalts from the deeper parts of the holes. Noteworthy, Mg# ≤ 50 in the Lava Pond basalts from Hole 1256D. These values have been suggested to be compatible with off-axis eruptions rather than basalt flowed from the axial valley (Soule et al., 2005).

Stratigraphy of ocean crust at Site 1256

The stratigraphy of the upper ocean crust drilled at Site 1256 is characterized by the relative abundance of sheet and massive flows and by the paucity of pillow lavas, which seems to be a distinctive feature for a superfast-spreading ridge. In fact, at fast-spreading mid-ocean ridges, the upper oceanic crust is commonly made of tens to hundreds meters-thick extrusive lavas (e.g., Christeson et al., 1992). This layer is constructed by interfingering and overlapping of lava flows erupting either from the axial summit trough or at off-axis eruptive vents and fissures, or from both (e.g., Perfit et al., 1994; Perfit and Chadwick, 1998; Fornari et al., 2004). MacDonald et al. (1989) hypothesized that a significant part of the present ocean crust created at the East Pacific Rise may owe its origin to such extensive flow. According to these authors, this might also explain the complex pattern of magnetic lineations found in some areas of the fast spreading Pacific crust where magnetic anomalies are usually well defined.

In conclusion, the occurrence of a few tens of meters-thick massive lava flow in the upper parts of ocean crust at Site 1256 is well compatible with the observations made at some areas of the EPR, where similar volcanic bodies have been detected either on axial summit trough of the ridge or in off-axis portions.

If we compare the stratigraphy of the ocean crust at Site 1256 with that drilled in Hole 504B (Alt et al., 1993 and refs. therein), and particularly the relative thicknesses of pillowed lavas, massive flows, and sheeted dikes, some differences may be highlighted: most of all, at Site 1256 the sheeted intrusives are much thinner (see Expedition 309 and 312 Scientists, 2006). Predictions based on marine seismic reflection studies indicate that the combined thickness of the lava - dike sequences should decrease with spreading rate but this has not been tested, and whether it is the dikes or lavas that are thinned is still unknown.

We argue that, although the ocean crust drilled at Hole 1256C and Hole 1256D partially fits the "Penrose" model, at least for showing the superposition of volcanics on sheeted dikes and intrusives, the relative thicknesses of the lava-dike sequence could reflect a combination of local (spatial) heterogeneity along ridge-axis, or (temporal) variability, essentially linked to a more or less intense activity of the magma chamber, or off-axis eruptions.

CONCLUDING REMARKS

We have conducted a structural analysis on a peculiar submarine massive lava flow drilled during ODP Leg 206 and IODP Expeditions 309 and 312 at Site 1256 (6°44.2 N, 91°56.1 W), located at ca. 1150 km east of the present crest of the East Pacific Rise and at ca. 530 km north of Cocos Ridge. This lava flow occurs at the upper parts of Hole 1256C, where it is ~30 m thick, and in Hole 1256D (> 70m thick), which is only 30 m apart; the lava flow has been interpreted by Wilson et al. (2003a) as a single lava pond whose interior was liquid at the same time in both locations.

Structural and microstructural descriptions provided by this paper and by Crispini et al. (this volume) suggest that the lava pond likely had filled a topographic low (graben?) and that was deformed by brittle and brittle-ductile deformation during and after its emplacement.

The geochemical signature of the lava pond basalts and the ocean floor topography necessary for the lava pond to be emplaced suggest that it could represent an eruption occurred at least 2-5 km off the axial summit of the East Pacific Rise. However, an "axial" origin, as suggested for the channelized lava flows and lava lakes mapped near the EPR at 9°-10°N and at 8°S cannot be ruled out until further integrated geological studies are carried out.

The superposition of a several tens of meters-thick lava flow upon extrusive volcanics, sheeted dike and the upper part of intrusive gabbroic rocks at Site 1256 fits the general "Penrose" model of the ocean crust structure. The relative thicknesses of extrusive lavas and dikes likely reflect local heterogeneities of the crustal accretion processes, mainly linked to minor or major exhalations of the axial magma chamber.

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