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1. Leg 179 Summary[1]

Shipboard Scientific Party[2]

ABSTRACT

Ocean Drilling Program (ODP) Leg 179 set out with two primary objectives. These objectives were (1) testing the recently developed hammer drill-in casing system on the Atlantis Bank, Southwest Indian Ridge (SWIR), and (2) drilling a cased reentry hole into basaltic basement on the Ninetyeast Ridge to allow future installation of an ocean floor geophysical observatory, the Ninetyeast Ridge Observatory (NERO). Both of these objectives were accomplished during Leg 179. Because of contingencies developed during the leg, certain ancillary objectives were not accomplished, but one contingency drilling site was cored on the Atlantis Bank, SWIR.

Hammer drill testing was completed on the Atlantis Bank at Sites 1104 and 1106 (virtually coincident locations but positioned from different beacons after a hiatus in testing while waiting for resupply). These tests provide a wealth of information regarding the viability of the system as a new tool for investigating the solid Earth. Although the testing was not completed as planned during Leg 179, design changes as a result of tests that were completed are already under way. We are confident, based on the results of the first sea trial of the hammer drill-in casing system, that continued development will soon allow us to sample the deep ocean crust in hard-rock environments where, with rare exceptions, we have historically been unable to operate.

Hole 1105A penetrated to a depth of 158 m on the Atlantis Bank. Coring of an interval measuring 143 m started 15 meters below seafloor (mbsf). We recovered 118.43 m of gabbroic rock representing 82.8% of the cored section. Gabbro, olivine gabbro, oxide gabbro, and felsic rocks were recovered. Together with logging results that included Formation MicroScanner images of the borehole, this recovery provides a rather complete coverage of the rock types and a comprehensive view of pseudostratigraphy in the gabbroic section that appears related to

[1]Examples of how to reference the whole or part of this volume.
[2]Shipboard Scientific Party addresses.

nearby Hole 735B, 1.2 km away. This is the first example of two offset holes (Holes 735B and 1105A) in an oceanic gabbroic section in which shipboard results indicate a high probability that specific units, structures, and/or geophysical characteristics may indeed be correlated.

Our second primary objective specifically included drilling a single hole as deep as possible into basement, and installing a reentry cone and casing beyond basement to prepare the Ninetyeast Ridge site as an ocean-bottom observatory. The observatory will be installed at a later date and will be part of the future network of seafloor observatories proposed in the International Ocean Network program. Drilling reached a depth of 493.8 mbsf, which was sufficient to create an acceptable borehole below casing for the downhole seismometer installation. The total penetration into basement was 122 m, and total penetration below casing reached 79.4 m. This significant depth of penetration below the casing, as well as the firm attachment of casing to the basement, should isolate the instrument from noise reported from other ocean-bottom seismometer installations.

INTRODUCTION

Leg 179 represents an endeavor aimed at two long-standing gaps in our understanding of the nature of the solid earth. First, we set out to test a new drilling technology that might enable deeper drilling and eventually higher core recovery than ever before possible from the deep ocean crust. Our second goal was to prepare a site where researchers can establish a long-term geophysical ocean-bottom observatory (GOBO) as part of the International Ocean Network (ION) program. Both of these primary objectives were accomplished. Initial tests of the hammer drill-in casing system yielded data that will allow future development and implementation of this technology on a regular basis. A nearly 500-m-deep borehole—cased and cemented into the hard-rock basement, and left with a reentry cone—was established at the Ninetyeast Ridge. Installation of a downhole observatory at this location will fill one of the six major gaps in global seismic monitoring coverage. Given potential delays in port because of repairs to the drillship, the advisory structure of ODP prioritized the supplementary objectives for Leg 179. The highest priority for these objectives was given to the two-ship offset seismic experiment in coordination with the *Sonne*. Unfortunately, time constraints prevented completion of this supplementary objective.

Hammer Drilling System (HDS) Engineering

Drilling the igneous foundation of the ocean crust has always been a challenging undertaking. Since the inception of the Deep Sea Drilling Project and its successor, the Ocean Drilling Program (ODP), one of the principal objectives of the science community has been to penetrate an entire section of the ocean crust and to reach the boundary between the Earth's crust and mantle. Attempts at accomplishing this objective have been limited by drilling technology that was originally designed for recovering sediments by the oil industry but adapted by ODP for sampling igneous basement. There have been spectacular successes in this endeavor, witness Holes 504B and 735B, but challenges confronted in establishing, maintaining, and reentering boreholes in fractured, hard rock have been more common.

In response to these challenges, ODP has embarked on the development of a new technology, the hammer drill-in casing system, which will allow us to initiate a hole, then simultaneously deepen that hole and stabilize its walls with casing. This system is an adaptation of pneumatically driven drilling systems that have successfully drilled in environments not unlike those that present our greatest challenge. Owing to the water depths in which we operate, however, pneumatic power is not an option. This innovative design employs a hydraulically actuated hammer, which drives a drill bit into the ocean floor. Following the bit is a string of casing to stabilize the borehole walls and improve our ability to clean drill cuttings from the hole. The bit design allows it to be withdrawn through the casing system, after deployment of a reentry funnel, such that most of the documented problems associated with drilling hard rock in the ocean's basin are alleviated. This new technology not only solves the technological problems, but it also reduces our dependency on site specific surveys, because the hammer can initiate a hole without regard to local topographic variability, thin sediment cover, debris, or rubble lying on the surface.

HDS testing was undertaken adjacent to the Atlantis II Fracture Zone along the Southwest Indian Ridge (SWIR) on an uplifted platform where two other ODP legs had successfully cored in hard rock using conventional drilling technology (see Robinson, Von Herzen, et al., 1989; Dick, Natland, Miller, et al., 1999). We hoped that the shallow but variable water depth and locally flat but regionally rugged topography would both adequately emulate other environments where the HDS might be employed and test the limits of the system. By choosing this location, we also had a proven record of our best performance in hard-rock penetration rate and recovery for comparison.

Ninetyeast Ridge Observatory (NERO)

Geophysical observatories currently operating worldwide share a common attribute and shortcoming in that these stations are only emplaced on continents or islands. Inasmuch as the world's oceans cover more than two-thirds of the planet's surface, the sporadic coverage allowed by observatories on oceanic islands is woefully incomplete. There are six major gaps in global seismic coverage, defined by vast expanses of sea without a land surface on which to establish an observatory. During Leg 179, ODP engaged in preparation of the first deep ocean global seismic observatory in one of these gaps, along the Ninetyeast Ridge in the east Indian Ocean.

Over the past decade, our understanding of deep Earth processes has improved owing to the development of new generations of global monitoring networks. Although the quantity and quality of data have radically increased, these new data have revealed large departures from lateral homogeneity at every level within the Earth from surface to core. Additionally, absolute plate motions cannot be accurately determined without precise geodetic measurements that are conventionally monitored on land. Extrapolating the Earth's magnetic field to the core/mantle boundary is challenged by gaps in coverage, particularly in the Indian and Pacific Oceans. Images of the velocity heterogeneity of the interior of the Earth, related to thermal and chemical convection, are aliased by the lack of control in observation sites. As the technology to deploy observatories to monitor these types of phenomena is under development, a borehole cased and firmly attached to basement at the Ninetyeast Ridge will provide an ideal deployment structure.

LEG OBJECTIVES

There were two primary and several ancillary objectives outlined in the scientific prospectus for Leg 179. The two primary objectives can be summarized as (1) engineering tests of the hammer drill-in casing system, and (2) establishing a borehole, cased and cemented to basement and deepened as far as possible for future deployment of an ocean-bottom observatory.

Supplementary objectives included deepening a hole through a hammered-in casing, a proof-of-concept test for acquiring seismic data while drilling, and a conventional vertical seismic profile (VSP) to complement an offset seismic profile experiment in conjunction with the *Sonne*. We had also hoped to attempt deployment of a test borehole strainmeter in preparation for Leg 186.

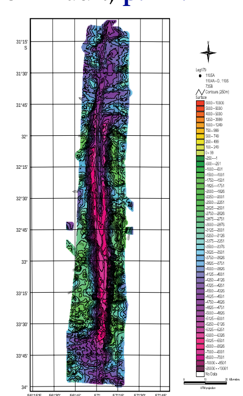
As a result of an extended delay in port because of ship repairs and loss of equipment in shipment, 17 of the 26 operational days scheduled for primary and ancillary objectives were lost. Although 2 additional days were added early in the leg to ensure completion of as many primary and ancillary objectives as possible, both of these days were lost to longer than expected transits. Consequently, in terms of primary objectives, the hammer test was incomplete as envisioned in the scientific prospectus, but still a success in that a detailed evaluation of the tests completed will result in modifications to various components of the system. As with most engineering endeavors, our test of the hammer drill-in casing system was a proof-of-concept experiment, and based on the results of these tests we remain confident in the viability of the system. In contrast, despite the abbreviated operations schedule, our second primary objective, establishing a borehole for the ION program, was wholly a success.

One consequence of the reduction in drilling time was less success in achieving supplementary objectives. We were, however, able to collect seismic-while-drilling (SWD) data at both the hammer drill test site and at NERO without use of any additional ship time. These data await shore-based processing to develop a plan for future deployments of this technology. Regrettably, we were unable to complete the conventional VSP experiment, the two-ship offset seismic experiment, logging and coring of the NERO hole, or the test deployment on the borehole seismometer. An unanticipated but overwhelmingly successful additional contingency program resulted from the delay we suffered waiting on a ship-to-ship transfer of hammer drilling supplies. We chose to invest this time in bare rock drilling at the hammer drill test site. What resulted was superb recovery from 158 m penetration in the gabbroic massif at the Atlantis II platform at a distance far enough from previous drilling to potentially allow correlation on a scale yet unfathomed in marine research. Additionally, a full suite of downhole logs was collected, which will surely aid in that endeavor.

HAMMER DRILL-IN CASING TEST RESULTS

Hammer drill testing was carried out on the Atlantis II Bank, located east of the Atlantis II Fracture Zone which offsets the SWIR between 31°50′S and 33°40′S at 57°E (Fig. F1). The platform is a flat-topped bench, ~9 km long and 4 km wide. This massif was successfully cored during Legs 118 and 176 to a depth in excess of 1500 meters below seafloor (mbsf). This location was chosen primarily as an area of opportu-

F1. Bathymetry of the Atlantis II transform fault, p. 14.

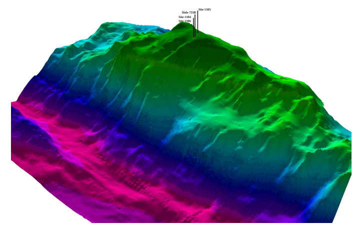


nity, to coincide with a point in the hammer drill development when sea trials were in order. As an additional benefit, the shallow water (~700 m) was envisioned to facilitate efficiency in our early operations. The flanks of the massif offered additional targets at greater depth and with topographic slopes, should the engineering tests advance beyond the initial objectives.

Site 1104

Site 1104 is located at a water depth of 731 m on the east rim of the Atlantis II Fracture Zone, ~200 m northwest of Hole 735B (32°43.32′S, 57°15.85′E; Fig. F2). This site was selected based on a video survey beginning at Hole 735B, by which we sought to find a reasonably flat, large outcrop to initiate the first spud tests of the hammer drill. During the transit from Cape Town, the water hammer was successfully deck-tested. The initial assembly of the drill string including just the SDS hammer and a concentric arm bit to test the spudding capability of the system. A frequency analyzer for monitoring hammer operations was built and installed during the transit.

F2. Three-dimensional shaded-relief image of the Atlantis Bank along the wall of the Atlantis II Transform fault, p. 15.



After a 4-hr video survey starting at the Hole 735B guide base, we selected a location with extensive, relatively flat-appearing outcrop and set the bit down on the outcrop to see how the hammer functioned without rotation. Several spud tests indicated the hammer was performing as expected, so we decided to recover the subsea camera and begin hammer drilling Hole 1104A. After ~45 min, it appeared from rig floor observation that we had made ~1.5 m of penetration, so we deployed the camera to inspect the hole. We had also noted excessive vibration of the stand pipe and derrick during hammer operations. A clean, circular hole was apparent on the video image, so we recovered the camera and initiated a second test hole (Hole 1104B). After ~2 hr rotation, we had made ~2 m of penetration but also noted increasing torque and slower rate of penetration (ROP). Another camera trip revealed a second clean, circular hole, but some apparent obliquity indicated the hole had been initiated on a small local slope. We recovered the camera and attempted to spud a third hole, but the hammer would not fire, so it was pulled to the surface.

Inspection of the concentric arm bit indicated that the reaming arms were damaged and that a valve had cracked in the hammer. The hammer was rebuilt, a new concentric arm bit installed, and we ran the assembly back to the seafloor. After a short video survey to inspect the site, we recovered the camera and spudded Hole 1104C. In <2 hr, although we noted ~2 m of penetration, there was also indication of high erratic torque and ROP effectively ceased. We attempted to initiate another hole (Hole 1104D) but made no advancement and experienced high and erratic torque, so this hammer test was terminated and we pulled the drill string. During the pipe trip, we deployed the two United States Geological Survey (USGS) ocean-bottom seismometers (OBS), 100 and 300 m, respectively, from our drill site to monitor the noise transmitted through the outcrop which was generated by the hammer.

When inspection of the second concentric arm bit indicated once again that the underreamer arms had experienced excessive wear, a bit was modified by trimming the concentric arms to match the outside diameter of the pilot bit. After this modification, however, the bit did not appear robust enough to cut through the hard rock so this modification was abandoned. A second modification removed the concentric arms, cut the bit shank, and welded the interval where the arms had been closed. We had hoped to test the drilling capability of the bit without the added challenge of attempting to ream out the hole. Unfortunately, during the modification of the bit, a crack developed and the bit was set aside. We then modified a third bit by welding the concentric arms closed. This bit was tripped to the seafloor and we initiated Hole 1104E. After ~1 hr, we had made ~1.5 m of penetration, but the bit stuck in the hole. We were able to free the bit with left-hand rotation, indicating that the arms had broken free and were causing the bit to stick. Having exhausted all the bits we had on board for hammer testing, and with the promise of delivery of a different bit design in a few days from a supply vessel, we chose to commit to conventional rotary coring while we waited for the equipment transfer. The OBS and positioning beacons were recovered, thus ending operations at Site 1104.

Site 1106

Because of continued deterioration of sea state, only the new bits were transferred from the supply vessel. After delivery of the new bits, we returned to the location of Site 1104 in anticipation of continued hammer testing. Despite the same coordinates as Site 1104 (32°43.32′S, 57°15.85′E; Fig. F2), because a new beacon was deployed and we wanted the record to indicate the next phase of hammer testing, this location was assigned as Site 1106. The hammer was tested on the deck in preparation for deployment.

The hammer was deployed, and after a brief seafloor survey, Hole 1106A was initiated. After ~2 m of penetration, the hammer ceased activity, and we tripped it back to the surface. Once again a valve had broken in the hammer, potentially because of excessive heave during the continuing poor sea state. Hole 1106B was initiated on the ensuing pipe trip, which included the second of the three bits that we acquired on the transfer (coincidentally the last bit capable of drilling an overgauge hole) because the first bit was worn after Hole 1106A. Only ~½ m of penetration was realized before the hammer ceased activity again, necessitating another pipe trip. Again the bit was worn, so it was replaced with the last of the bit configurations we had available, a flat-faced drilling bit. Our decision to run this bit was based on the assumption that if we could demonstrate the ability to make a hole, we could use this information in future bit design.

Hole 1106C was spudded and we drilled ~1 m in <1 hr before the hammer stalled again. On the ensuing pipe trip, the piston in the hammer was replaced and the flat-faced bit was run back to the seafloor. Hole 1106D was attempted, but the hammer would not start, so it was pulled and rebuilt once again. Hole 1106E was initiated, and the hammer drill system performed admirably, cutting an 8-m-deep hole in <2 hr. The pressure transducer on the stand pipe gave way at this time, so the pumps had to be shut down for repairs. Once the repair was completed, the driller noted no pressure buildup and was able to slowly lower the drill string to the total depth of the hole + 4 m, indicating that we had lost some of the bottom-hole assembly. The subsequent camera trip indicated that the bit and hammer were indeed missing, and because we could not see them on the seafloor, we assume they are still in Hole 1106E. Weather conditions had still not improved, and we did not have a clear idea which of the several holes within a few meters radius was Hole 1106E, so a fishing attempt was unrealistic. Given that we had exhausted all the bits and hammer spare parts, we declared the hammer test for Leg 179 complete, and got under way for Ninetyeast Ridge.

In summary, although a detailed summation of all the data relevant to the hammer testing awaits postcruise development, we do have some preliminary impressions. We are encouraged by the performance of the hammer and will be able to use this series of tests for optimal design improvements. Despite the less than desired performance of the bits, again we are optimistic, particularly based on the last test where we made 8 m of penetration in <2 hr, that bit design improvements will yield improved performance in the future. Finally, as with all our operations, sea state appears to be a primary control if not on the success of an operation, at least on its duration and ease of completion.

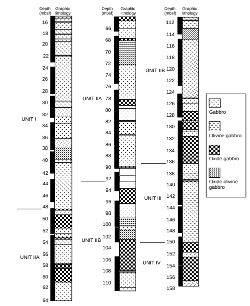
Site 1105

Because of delays in the resupply ship that inhibited resumption of hammer tests near Hole 735B, Hole 1105A was drilled during Leg 179 for a period of 6 days. The hole was located ~1.3 km east-northeast of Site 735 on the Atlantis platform along the eastern transverse ridge of the Atlantis II Transform (32°43.13′S, 57°16.65′E; Fig. F2). The site is along a near-ridge axial trend with respect to Hole 735B, but more distal from the north-south trending Atlantis II Transform that lies to the west. The site was chosen to avoid a duplication of Hole 735B efforts that might occur by drilling at proximal Site 1104. At the same time, we wanted to utilize Hole 735B as a reference section to attempt lateral correlation of large-scale igneous units, structural features, and geophysical characteristics over the broader distance represented by the offset in holes in the direction approximately parallel to the former ridge axis. In addition, the site was chosen to help constrain the overall structure of the massif exposed on the platform. If successful, the correlation experiment could yield a minimum measure of the dimensions of subaxial magma chambers and continuity of structure and processes along strike of the ridge axis at a very slow-spreading center. If correlations are unsuccessful we can limit the dimensions of igneous units, former magma chambers, or structures to be smaller than the scale of the experiment. Correlation will be attempted on the basis of detailed and integrated data sets including core descriptions and subsequent shore-based laboratory analyses to establish cryptic chemical and mineralogical variations, and the alteration and structural framework of the core. A full and highly successful logging program that was completed after the cessation of drilling will aid in the correlation attempts.

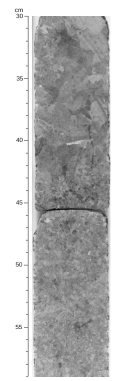
The hole penetrated to a depth of 158 m, and the cored interval measured 143 m, starting 15 mbsf. Core recovery included 118.43 m of gabbroic rock for a total recovery of 82.8%. Together with logging results, this recovery provides nearly complete coverage of the rock types and a comprehensive view of pseudostratigraphy in the gabbroic section cored (Fig. F3). Shipboard results now indicate a high probability that specific units, structures, and/or geophysical characteristics from Holes 735B and 1105A may indeed be correlated.

The cores recovered record a wide variety of rock types ranging from gabbro (Fig. F4), oxide gabbro with up to 20–25 modal% Fe-Ti oxides (Fig. F5), and olivine gabbro (Fig. F6) to scarcer troctolitic gabbro, gabbronorite, and felsic rocks such as trondhjemite. One hundred forty-one rock intervals have been described within the core and defined on the basis of distinct changes in mode, modal proportions, grain size, and/or texture. Well-defined igneous layer contacts or structural bound-

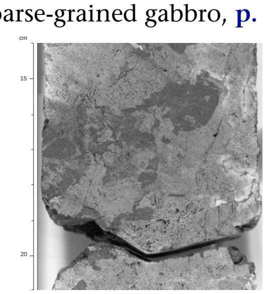
F3. Summary of visually defined lithologic intervals and syntheses units of Hole 1105A, **p. 16.**



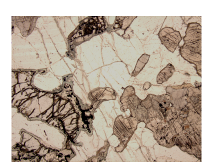
F4. A planar interface between layers of massive medium-grained gabbro and massive coarse-grained gabbro, **p. 17.**



F5. A regular layer with high concentration of Fe-Ti oxide minerals in coarse-grained gabbro, **p. 18.**



F6. Medium-grained olivine gabbro with adcumulate texture, **p. 19.**



aries to these intervals are preserved in many sections of the core (Fig. F7). The highly layered nature of the gabbroic rocks documented within the core is supported by high-quality continuous Formation MicroScanner (FMS) logs of the borehole (Fig. F8), as well as other logs and whole-core magnetic susceptibility measurements (Fig. F9). The scale of the layering in the core varies from a few centimeters to meters. On a broader scale, the intervals define four basic units from top to bottom consisting of (1) a gabbroic unit characterized by more primitive rock types, a scarcity or lack of oxide gabbro, and a low (828 SI) average magnetic susceptibility, (2) a gabbroic unit characterized by a high abundance of interlayered oxide gabbro and oxide-bearing gabbro, and a high (3208 SI) average magnetic susceptibility, (3) a gabbroic unit characterized by more primitive rock types and a lack of oxide gabbro with low (780 SI) average magnetic susceptibility, and finally (4) another unit rich in oxide gabbro and oxide-bearing gabbro with high (3472 SI) average magnetic susceptibility. Rocks of all four units are crosscut by millimeter- to decimeter-sized veins of leucocratic gabbro, quartz diorite, trondhjemite, and irregular pegmatitic gabbro intrusions. Irregular veins and bands of oxide minerals have also been observed.

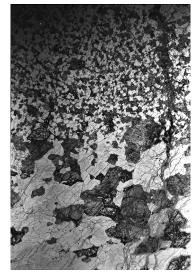
Thin sections indicate typical cumulate textures in the majority of samples that range from adcumulate to orthocumulate and show variable amounts of core-to-rim zoning in plagioclase. Poikilitic textures are also common with pyroxene as the oikocryst phase and plagioclase as the chadocryst phase (Fig. F10). Igneous laminations were observed in several samples but are generally scarce or may be overprinted by crystal-plastic fabrics in deformed parts of the core. Preliminary bulk rock geochemical results show a wide range in the chemistry of gabbroic rocks with Mg# varying from ~0.80–0.23, Fe_2O_3 from ~3.5–24.0 wt%, P_2O_5 from ~0.01–4.1 wt%, Y from 7–192 ppm, Nb from 1–10 ppm, and Cr from 1–1066 ppm.

Alteration of the primary igneous mineralogy in the core is generally low, but varies on the scale of a thin section to meters. Alteration of olivine to chlorite, tremolite-actinolite, and talc is the most common manifestation of alteration, whereas plagioclase and clinopyroxene tend to be less altered. It is common for clinopyroxene, where altered, to be partially replaced by patchy brown amphibole, but such alteration generally does not exceed 1%–2%. A portion of this brown amphibole is likely to be of magmatic origin. Where alteration is extensive, clinopyroxene is replaced by assemblages of actinolite and chlorite. Plagioclase is generally not strongly affected by alteration.

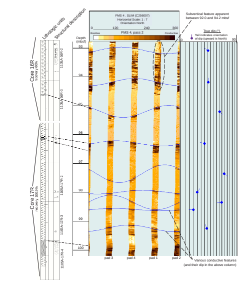
Actinolite and chlorite are also the most common vein assemblages. Scarce high-temperature brown amphibole and low-temperature smectite and carbonate veins have also been observed.

The structure of the core is complex, and structural styles range from brittle to ductile. Most of the gabbroic samples cored possess igneous textures, but there are several parts of the core that display crystal-plastic fabrics. Mylonitic zones characterized by high oxide-mineral content were observed at ~53 and 71 mbsf (Fig. F11). Coarser grained centimeter- to decimeter-thick zones of ductile shear are present in the upper 90 m of core, whereas thicker zones of ductile deformation with weak to strong crystal-plastic fabrics become more prevalent at depths in excess of 90 mbsf. Intervals of penetrative ductile deformation in the lower portion of the core locally exceed 2 m in thickness. Zones of ductile deformation are commonly oxide rich, as are the contact regions between undeformed and ductilely deformed rocks. Oxide gabbro-rich

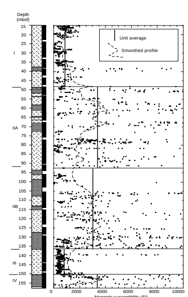
F7. Contact between fine-grained olivine gabbro with granular texture and a medium-grained olivine gabbro, p. 20.



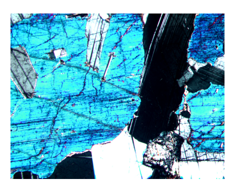
F8. FMS image over the depth interval 93–100 mbsf in Hole 1105A, p. 21.



F9. Filtered whole-core magnetic susceptibility measurements, p. 22.

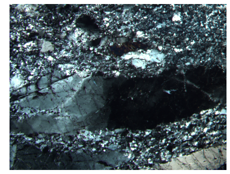


F10. Poikilitic clinopyroxene enclosing anhedral plagioclase grains in medium-grained olivine gabbro, p. 23.



zones appear to be strain localizers because many, although not all, of the crystal-plastic shear zones are rich in oxide minerals. Inclination of the ductile foliations on the core face vary from ~18° to 75° in the cored intervals and averages ~30°–35°. Thin sections show a range of textures from strictly igneous to slightly deformed igneous to dynamically recrystallized metamorphic textures with crystal-plastic fabrics. As deformation intensity increases, the effect can be most easily observed in plagioclase, where a progression from strain-free plagioclase to plagioclase with deformation twins, undulose extinction, kink bands, and dynamic recrystallization to neoblasts along grain margins progresses to porphyroclastic textures with small neoblasts of plagioclase and highly strained and kinked plagioclase, pyroxene, or olivine porphyroclasts. Olivine appears to have fully recrystallized to neoblast grain sizes prior to pyroxene, which tends to be preserved as the dominant large porphyroclastic phase unless the intensity of deformation is very severe. Brittle fractures are generally filled with vein material such as actinolite and chlorite, but no large faults zones were recovered in the core. There were several regions of low recovery that could correspond to fault zones based on temperature, sonic, resistivity, and porosity logs. These regions of poor recovery generally sampled little intact core, although gabbroic rocks that were recovered were altered to smectite and contained carbonate veins.

F11. Highly strained ribbon grains of plagioclase in mylonitic fine-grained matrix, **p. 24.**



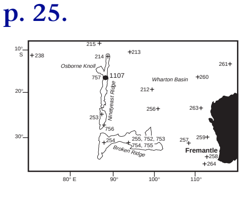
Preliminary analysis of the downhole geophysical measurements from core and logging data yields a wide variety of information. Magnetic data indicate that the core possesses a single coherent magnetic direction with an average inclination of ~67°. This is compared with an inclination of –52° expected for the site. As in Hole 735B, these results indicate a consistently reversed polarity for the section and may indicate a significant block rotation of the massif similar in magnitude to rotations interpreted from Hole 735B (15°–20°). The consistency of the magnetic inclination downhole suggests that any relative rotations along ductile shear zone in the section must have occurred before cooling below the blocking temperature and are necessarily high temperature in nature. Magnetic susceptibility measurements clearly define zones of oxide gabbro and oxide-bearing gabbro documented in the core. Likewise, it provides a direct downhole comparison for the FMS logs, which measure resistivity. Oxide-rich zones are conductive whereas oxide-free zones have high resistivity. Magnetic intensity on split cores ranges from ~0.2–5 A/m and provides a significant signal range.

Lastly, an SWD experiment was conducted at Hole 1105A using two USGS OBS. These data, together with accelerometer data from the drill rig, will be employed to test the feasibility of SWD during drilling operations of the *JOIDES Resolution*.

NERO SITE

After an 8-day transit, we arrived at Site 1107. The specific NERO site was selected based on seismic data collected in support of Leg 121, investigating the geology and paleoclimatic history of Ninetyeast Ridge. We selected Site 757 as our target, because, while meeting the criteria for emplacement of a borehole observatory in the Indian Ocean, it was also in our most direct line of transit between the hammer drill test site and our end of cruise port call in Darwin, Australia. Hole 1107A is located in 1650 m of water at 17°1.42′S, 88°10.85′E (Fig. **F12**). There was

F12. Site map in the eastern Indian Ocean showing the location of Ninetyeast Ridge and NERO Site 1107, **p. 25.**



an ambitious program outlined in our prospectus, including establishing a borehole for future installation of a subseafloor observatory, conventional logging and VSP experiments, deployment of a test installation of the strainmeter module in preparation for Leg 186, and the NERO offset seismic experiment (NOSE) in conjunction with a concurrent German expedition called Seismic Investigations at the Ninetyeast Ridge Observatory Using *Sonne* and the *JOIDES Resolution* (SINUS) during Leg 179. We had originally scheduled 11 days to complete these objectives. However, our extended port call, lost shipment, and extended transit times all worked to shorten our operational schedule, paring away 17 of our original 26 days of total operational time devoted to the hammer tests and NERO and reducing our time on location at NERO from 11 days to less than 6 days. Our optimistic estimate indicated that even given this radical reduction, if all went extraordinarily well we could still complete the borehole (although to significantly less depth of penetration than our original target of 100–200 m into basement) and have some time remaining for the two-ship experiment. Our restricted schedule, however, required that we allocate no time for the many other operations we had hoped to complete at NERO.

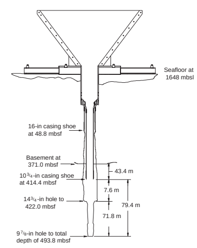
After we arrived on site, we deployed a beacon and ran to seafloor with 48.82 m of 16-in casing fixed to a reentry cone. This assembly was washed in, and subsequently we reentered the hole with a 14¾-in tricone bit to drill a large borehole to allow deployment of 10¾-in casing some 30–40 m into basement. We also deployed the OBS and installed the Lamont-Doherty Earth Observatory sensor assembly on the drill string to conduct our second SWD experiment. Based on Leg 121 statistics, we had hoped to drill to basement in ~12 hr, and to drill at least 30–40 m into basement over the next 10 hr. Drilling the sediment column took longer than we expected, probably because of the size of the hole we were drilling and resistive layers of volcanic breccia and tuff overlying basement previously reported in the Leg 121 *Initial Reports* volume (Pierce, Weissel, et al., 1989). Basement drilling also proceeded somewhat slower then we expected, although penetration rates were quite variable in the subaerially emplaced lava flows. At ~410 mbsf, we encountered a relatively hard layer, and ROP slowed to <2 m/hr. In light of the fact the drilling in basement had up to this point proceeded reasonably quickly, we envisioned this hard layer as an ideal position to anchor the bottom of the casing with cement. After drilling to 422 mbsf to ensure that any material wiped off the walls of the borehole during emplacement of the casing would have a place to go and would not impede casing operations, we terminated deepening Hole 1107A because we had reached our target depth for casing of ~40 m into basement.

In our optimistic schedule developed after recognizing that we only had 5.5 days of operational time, we had hoped to set aside ~48 hr of ship time for the two-ship experiment. This time included pipe trips, set up and rig down time, and preparation to get under way (as this was to be our last operation), which resulted in an estimated 29 hr of shooting time for the two-ship experiment. Any additional time was to be allocated to deepening the hole. At this point in our operations, however, individually minor but collectively significant delays because of handling pipe in heavy seas, slowed ROP, and mechanical difficulties had pared >25 hr from our already drastically reduced timetable.

By the time our last casing operation was completed (10¾-in casing set to 414 mbsf), we recognized there would not be sufficient time to clean out the cement shoe in the bottom of the casing, drill through the cement, clean out the rathole underneath, make 10 m of new hole below the casing string, and still have time remaining for a two-ship experiment. A 10-m penetration below the casing string was the absolute minimum envisioned as necessary for establishing a borehole for the observatory emplacement. In our estimation, completing the borehole and allowing time for even a short two-ship experiment would have resulted in a 24-hr delay in our arrival at Darwin. This was not possible given the program's tight operational schedule and that the leg had already been extended 2 days beyond the original schedule.

Even with the disappointment we all felt regarding cancellation of the two-ship experiment, we recognized that although we did not have sufficient time to prepare for and rig down after a two-ship experiment (at least 20–24 hr), because we already had a drilling bit in the bottom of the hole, we did have enough operational time to deepen the borehole. We had elected to use a tricone bit rather than a coring bit to ensure that we could penetrate through the casing shoe without delay. This bit, although not allowing coring of the material drilled, did allow rapid penetration through the formation in the hours we had remaining. We continued drilling to a depth of 493.8 mbsf, which is just over 120 m into basement and almost 80 m below the casing shoe (Fig. F13). We hope this depth will allow a successful installation of NERO. During drilling through the sediment column and into basement, we again collected SWD data via OBS and the shipboard accelerometer. Postcruise processing is required to interpret these data; however, our initial inspection of the data indicates this will be possible.

F13. Schematic illustration of cased borehole configuration at Hole 1107A, p. 26.



SUMMARY

The two primary objectives, which consisted of (1) testing the hammer-in casing system recently developed by ODP on the Atlantis Bank, SWIR, and (2) drilling a cased reentry hole into basaltic basement on the Ninetyeast Ridge to allow future installation of an ocean floor geophysical observatory, NERO, were accomplished during Leg 179. Because of delays during the leg caused by a late departure from Cape Town resulting from a lengthy repair to the ship's guide horn, slower than expected transits, and an errant shipment of hammer drill supplies requiring a resupply effort at sea, certain ancillary objectives could not be accomplished and one unexpected contingency drilling site was cored on the Atlantis Bank, SWIR.

The hammer testing at Sites 1104 and 1106 on the Atlantis Bank supplied the engineers with enough data to suggest that the hammer is viable for the purpose of initiating hard-rock holes on gentle or steep bare rock slopes. At the same time, modification to the bit design, in particular the underreaming arms originally developed for use on land, will be required to accommodate the significant heave conditions the ship experiences during drilling. A conventional simplified hammer bit design without underreaming capabilities was also tested and performed admirably with the hammer penetrating 8 m in 2 hr with the same strong heave conditions. This indicated that the underreaming bit design and its response to significant heave is the most serious problem and not the hammer's basic ability to spud and rapidly penetrate hard rock on the seafloor. In general, sea states were uncooperative during the entire hammer testing, and this inhibited completion of the tests and shortened their duration. A new generation of the active heave compensator may also help to improve bit operational tolerances. The

ODP engineers are now quite convinced that the hammer system with a modified or alternate bit design will be the answer to the significant problem of spudding and maintaining stable holes in a range of bare rock environments and will be one of the most significant engineering developments for future hard-rock drilling by ODP.

Contingency drilling at Site 1105 was highly successful and drilling penetrated 158 mbsf over a 6-day period. This resulted in 118 m of core from a large gabbroic massif exposed along the transverse ridge of the Atlantis II Transform. The site was ~1.3 km from the highly successful Hole 735B, which was cored to 1508 mbsf. The core included gabbro, olivine gabbro, and abundant oxide gabbro, and preliminary investigations indicate that part of the pseudostratigraphy may be similar to that recovered in Hole 735B. We also acquired an extensive suite of logging data including high-quality FMS borehole image data. Because the core and logging data provide a comprehensive data set, cross-hole correlations between two high recovery offset holes (Holes 1105A and 735B) drilled into the plutonic foundations of the oceanic crust will be possible for the first time. The data will also allow us to conduct high-resolution structural and igneous studies and gain understanding into the geometry of igneous layering and ductile shear zones in the cumulate sequences sampled. The drilling of Hole 1105A demonstrated the versatility of the *JOIDES Resolution* in a hard-rock environment in the face of unplanned contingencies and the general ability to easily establish quality holes with good recovery on the Atlantis platform.

The primary objective of the NERO portion of Leg 179 was to prepare a seafloor borehole for future establishment of a GOBO. This objective specifically included drilling a single hole as deep as possible into basement, as well as installing a reentry cone and casing beyond the sediment/basement interface to prepare this site for an ocean-bottom observatory. The GOBO will be installed at a later time by submersible or surface ship and will be part of the future network of seafloor observatories proposed in the ION program. Hole 1107A was drilled in a water depth of 1648 m on the Ninetyeast Ridge. The sediment cover above the basaltic basement was drilled to ~372 mbsf; however, the drilling rates suggested that firm basement was not reached until 404 mbsf. Drilling reached a depth of 493.8 mbsf which was sufficient to create a 97/8-in borehole below casing for the downhole seismometer installation. The acceptable region of the borehole in basement for emplacement of a seismometer is the lower 71.8 m. The total penetration into basement was 122 m, and total penetration below casing reached 79.4 m. The hole is regarded as a success for a number of reasons. These include the excellent stability of the hole, the fact that the hole was cased to 43.4 m into basement as planned, and because a significant depth of the borehole below the casing was achieved, which otherwise have might been a source of potential noise as experienced at other ocean-bottom seismometer installations.

Lastly, Leg 179 accomplished basic testing of the SWD concept at Sites 1104, 1105, and 1107 that should allow the feasibility of the concept to be evaluated. Other supplementary objectives of the leg, including coring and logging of the NERO hole, the offset seismic experiment, a VSP, and a strainmeter test could not be achieved because of the unfortunate and considerable amount of operational time lost.

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Pierce, J., Weissel, J., et al., 1989. *Proc. ODP, Init. Repts.,* 121: College Station, TX (Ocean Drilling Program).

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Figure F1. Bathymetry of the Atlantis II Transform Fault (data from Dick et al., 1991) displaying the transform valley, transverse ridges, median tectonic ridge and the northern and southern ridge-transform intersection. Solid circle marks the position of Hole 735B atop the Atlantis Bank.

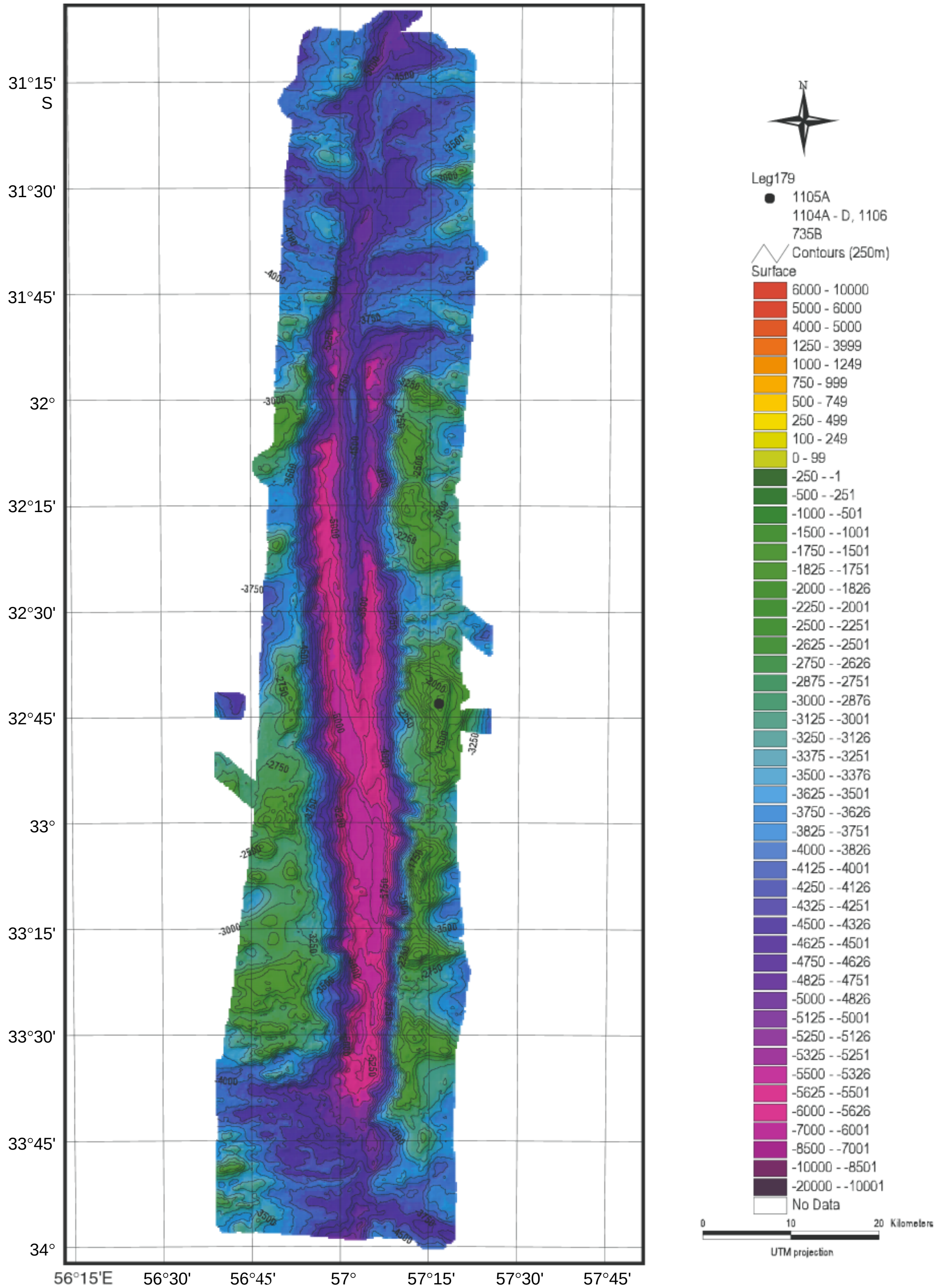

Figure F2. Three-dimensional shaded-relief image of the Atlantis Bank (looking northeast) along the wall of the Atlantis II Transform Fault (data from Dick et al., 1991). The image shows Sites 1104, 1105, and 1106 drilled during Leg 179 and Hole 735B drilled during Legs 118 and 176. The image shows the transform valley, transverse ridges with the Atlantis Bank (highest region), and the termination of the median tectonic ridge in the axis of the transform valley.

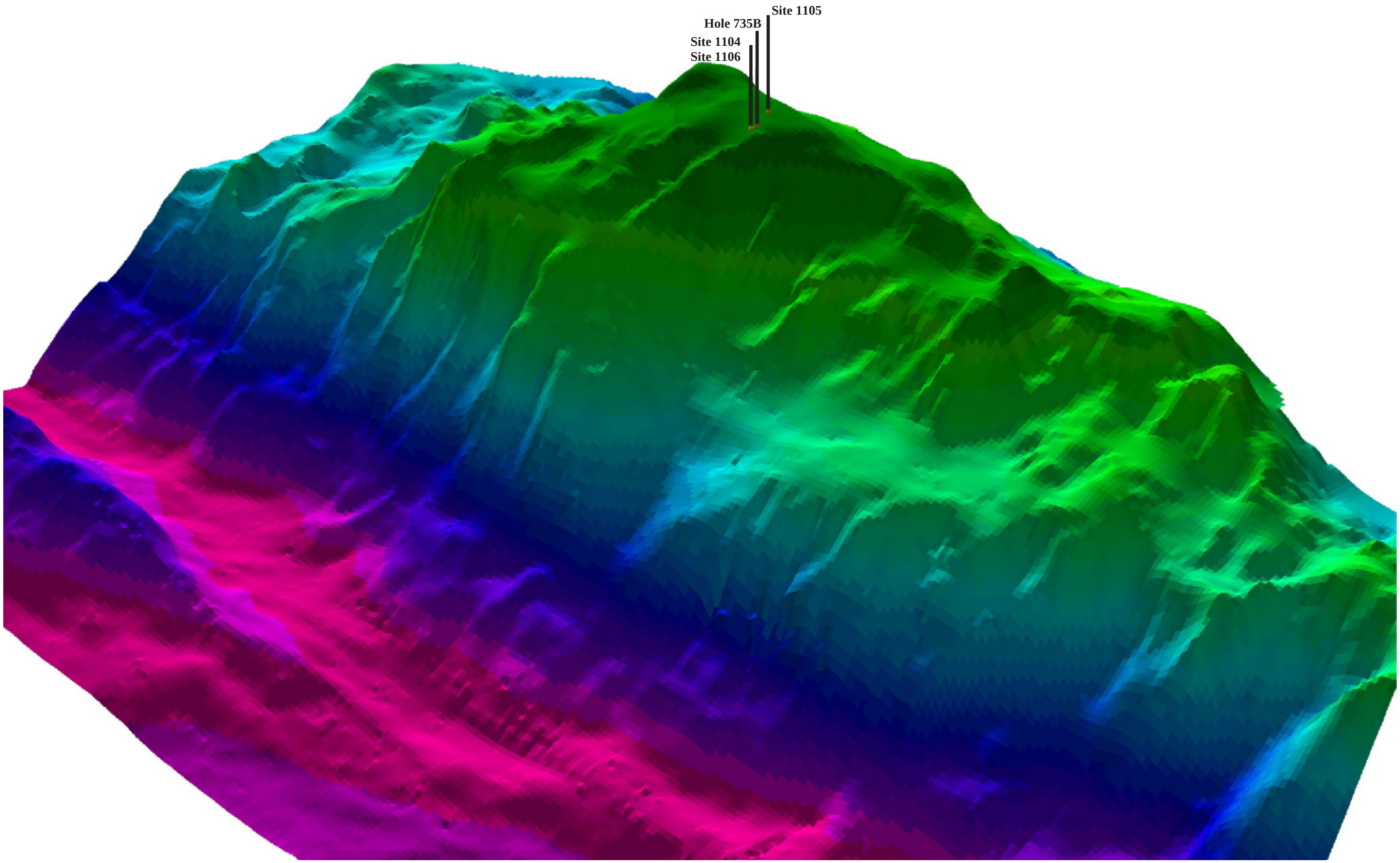

Figure F3. Summary of visually defined lithologic intervals and syntheses units of Hole 1105A. Only the main lithologic rock types are illustrated.

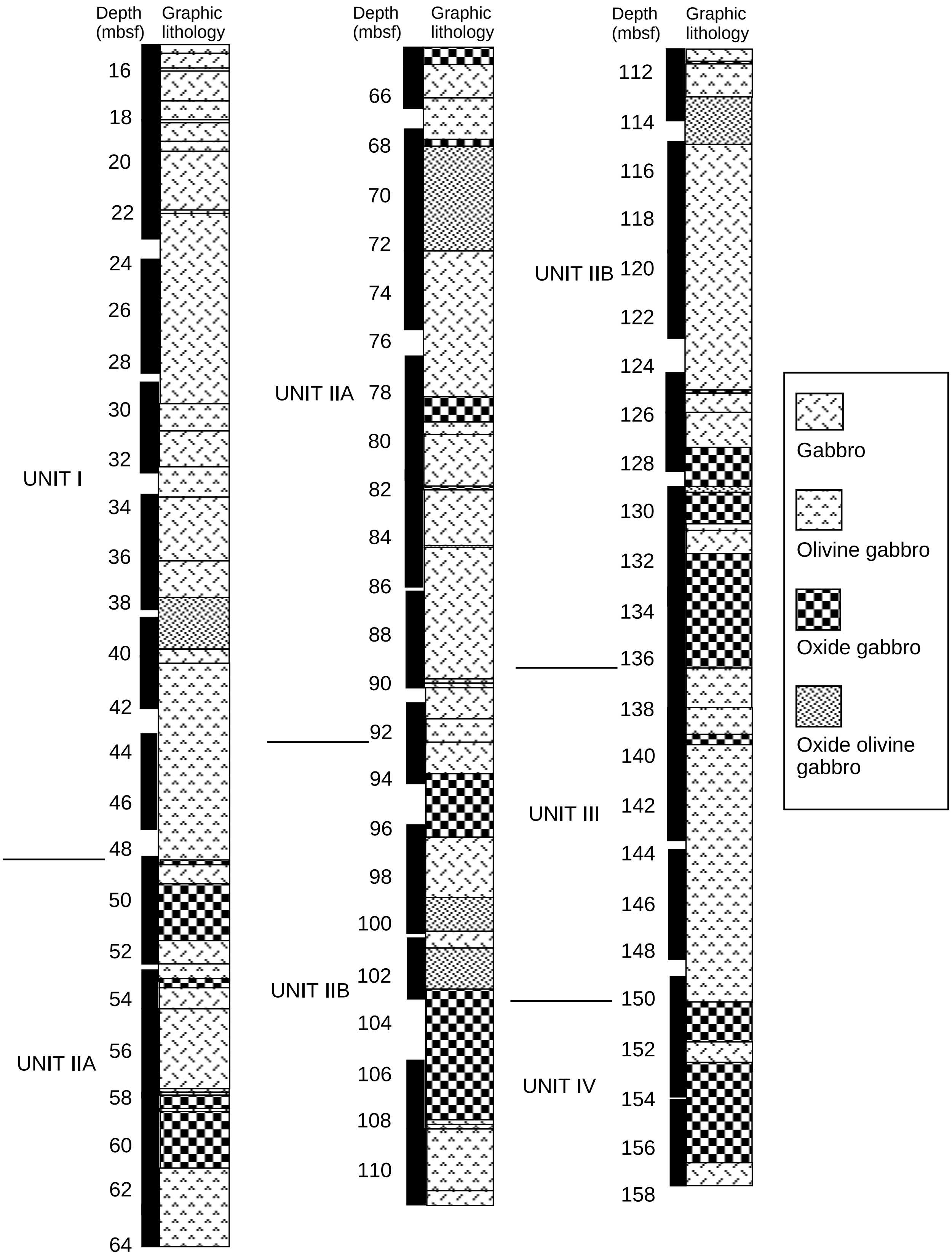

Figure F4. Close-up core photograph showing a planar interface between layers of massive medium-grained gabbro and massive coarse-grained gabbro (interval 179-1105A-13R-4, 30–59 cm).

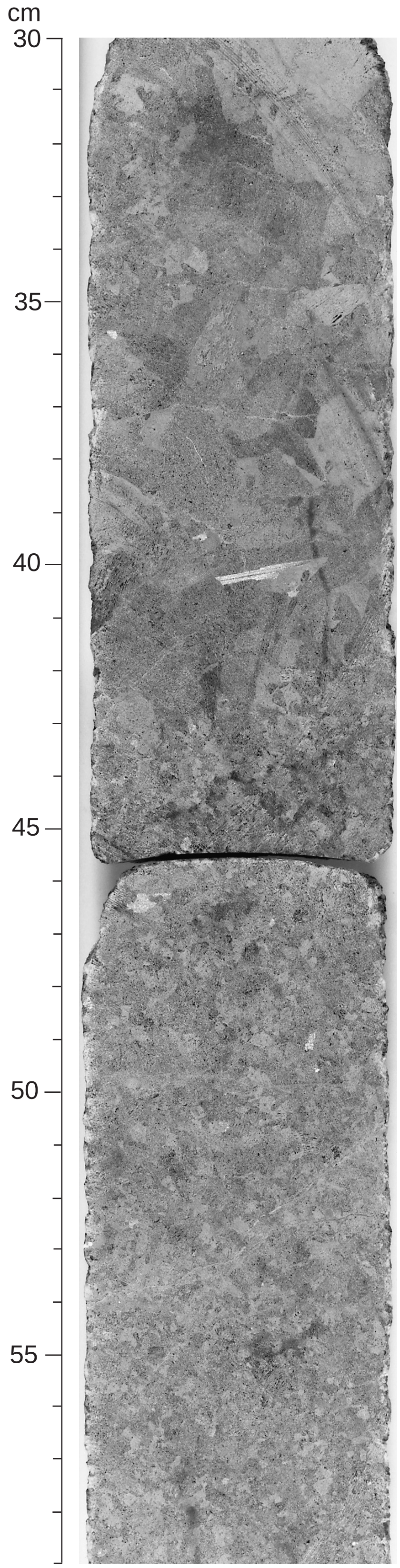

Figure F5. Close-up core photograph showing a regular layer with high concentration of Fe-Ti oxide minerals in coarse-grained gabbro (interval 179-1105A-15R-1, 14–21 cm).

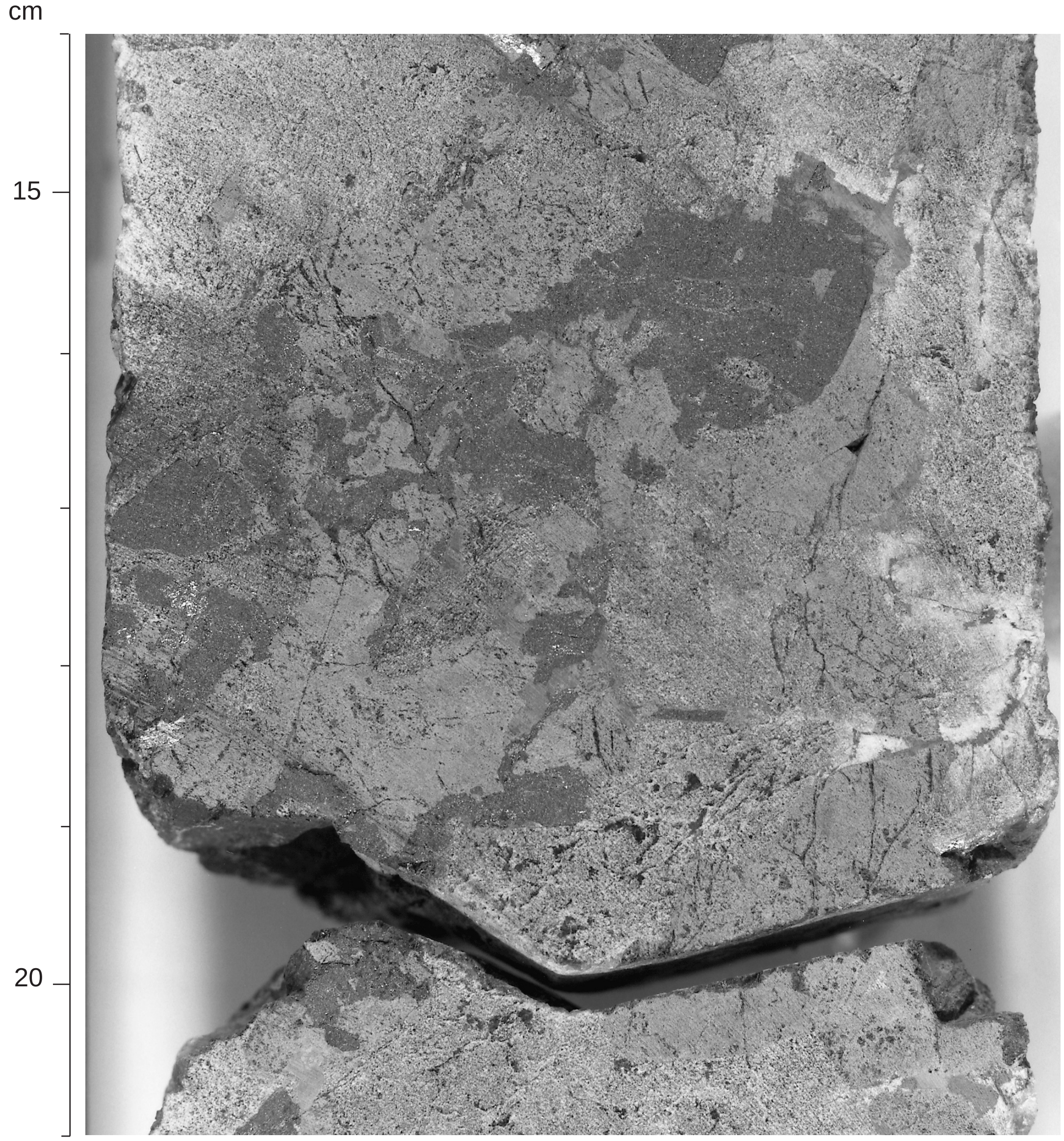

Figure F6. Digital photomicrograph of medium-grained olivine gabbro with adcumulate texture. Field of view = 2.75 mm (plane-polarized light; Sample 179-1105A-1R-2, 88–91 cm).

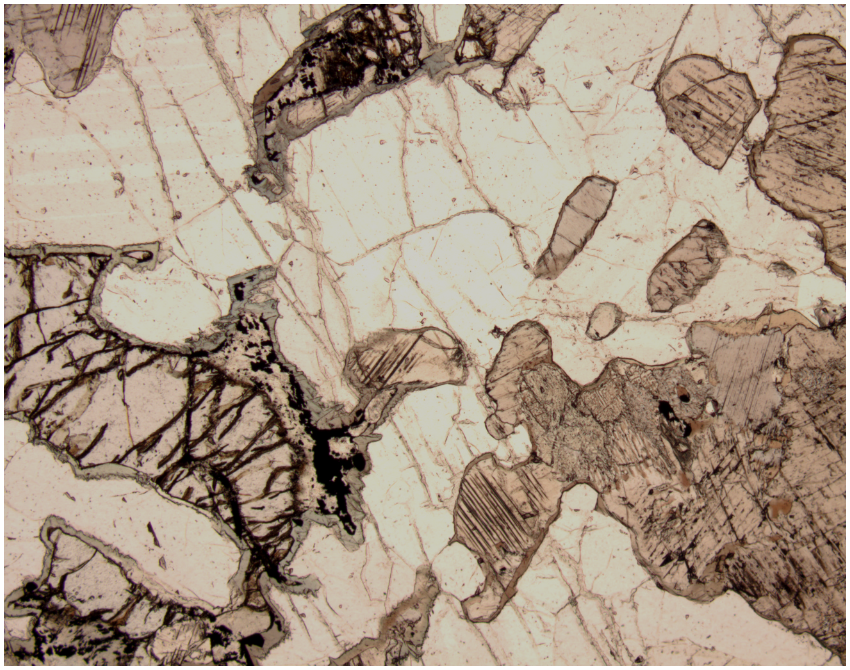

Figure F7. Photomicrograph of contact between fine-grained olivine gabbro with granular texture and a medium-grained olivine gabbro. Field of view = 23 mm (plane-polarized light; Sample 179-1105A-13R-3, 24–26 cm).

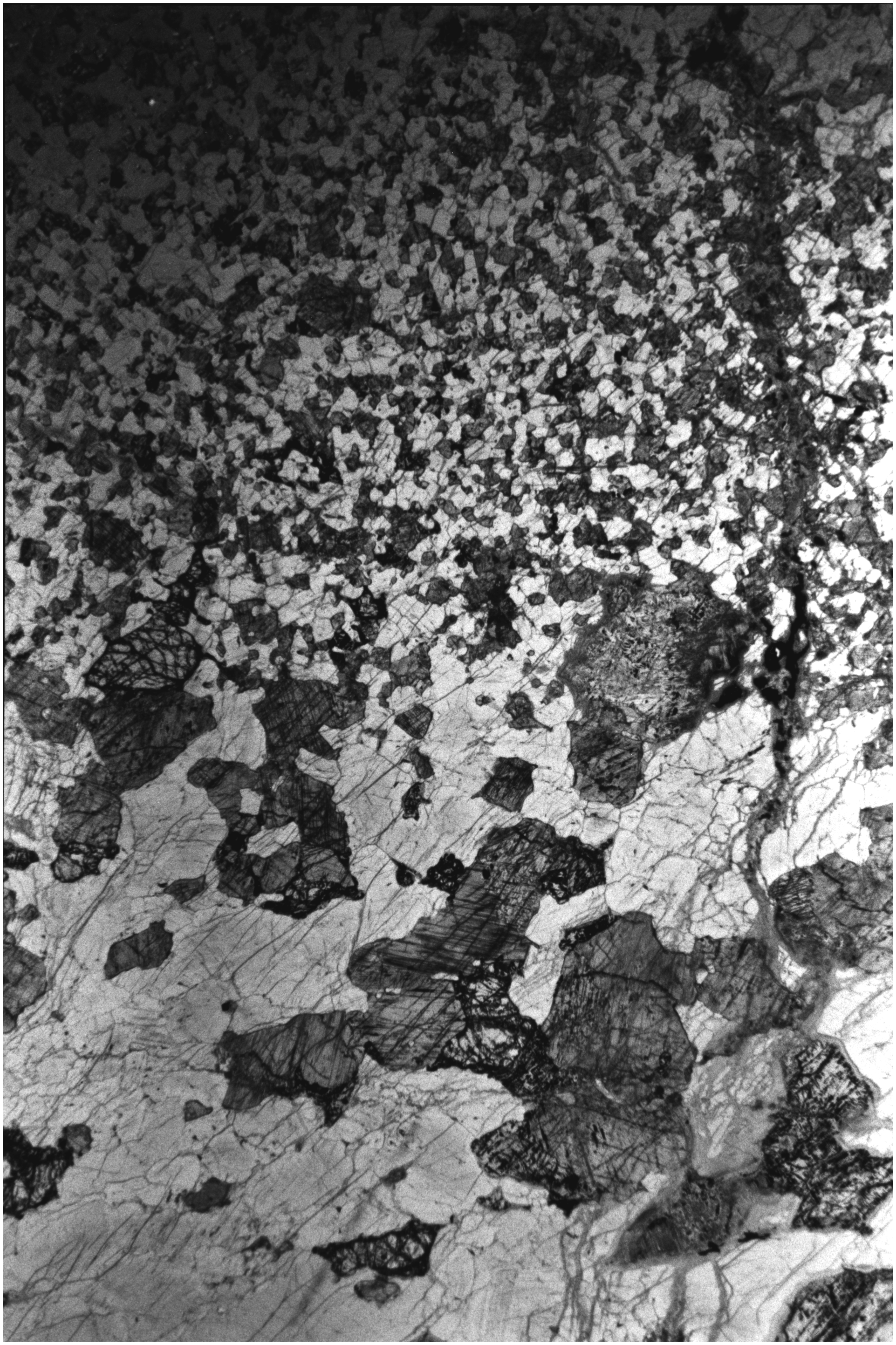

Figure F8. FMS image over the depth interval 93–100 mbsf in Hole 1105A with correlated lithologic units and oriented dips. Conductive areas appear in dark shades, whereas light shades are attributed to resistive zones.

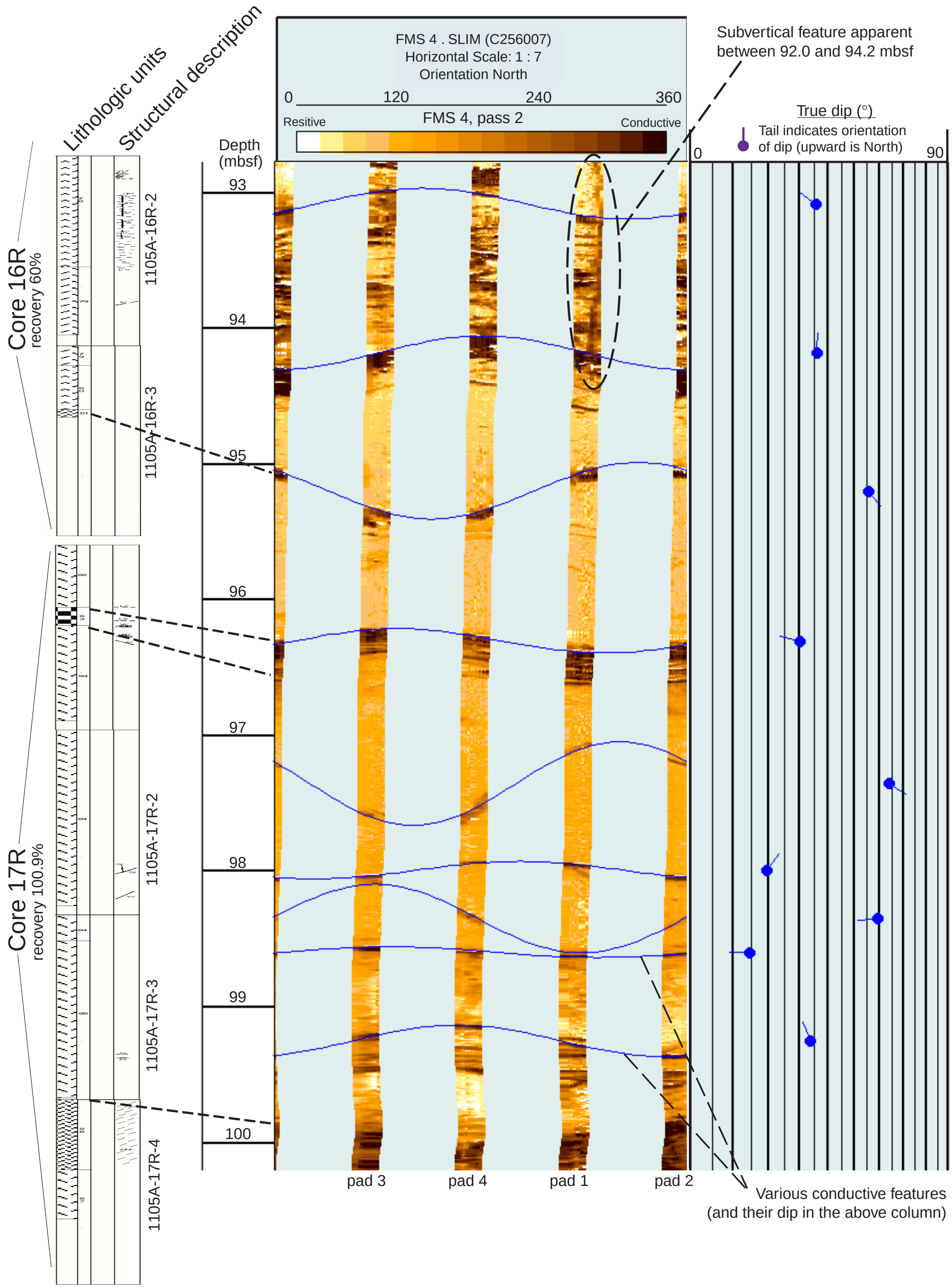

Figure F9. Filtered whole-core magnetic susceptibility measurements. All measurements of pieces smaller than the sensing interval of the susceptibility loop, as well as all measurements within 5 cm of the end of a piece have been removed. A simplified graphic lithology column, highlighting only those intervals where Fe-Ti oxide have been reported, is plotted to the left. Lithologic unit boundaries are also shown adjacent to the graphic lithology plot and embedded in the magnetic susceptibility plot. The dashed line represents a weighted moving average through the magnetic susceptibility data. Lithologic unit average magnetic susceptibilities are Unit I, 828 SI; Unit IIA, 3406 SI; Unit IIB, 3010 SI; Unit III, 780 SI; Unit IV, 3472 SI.

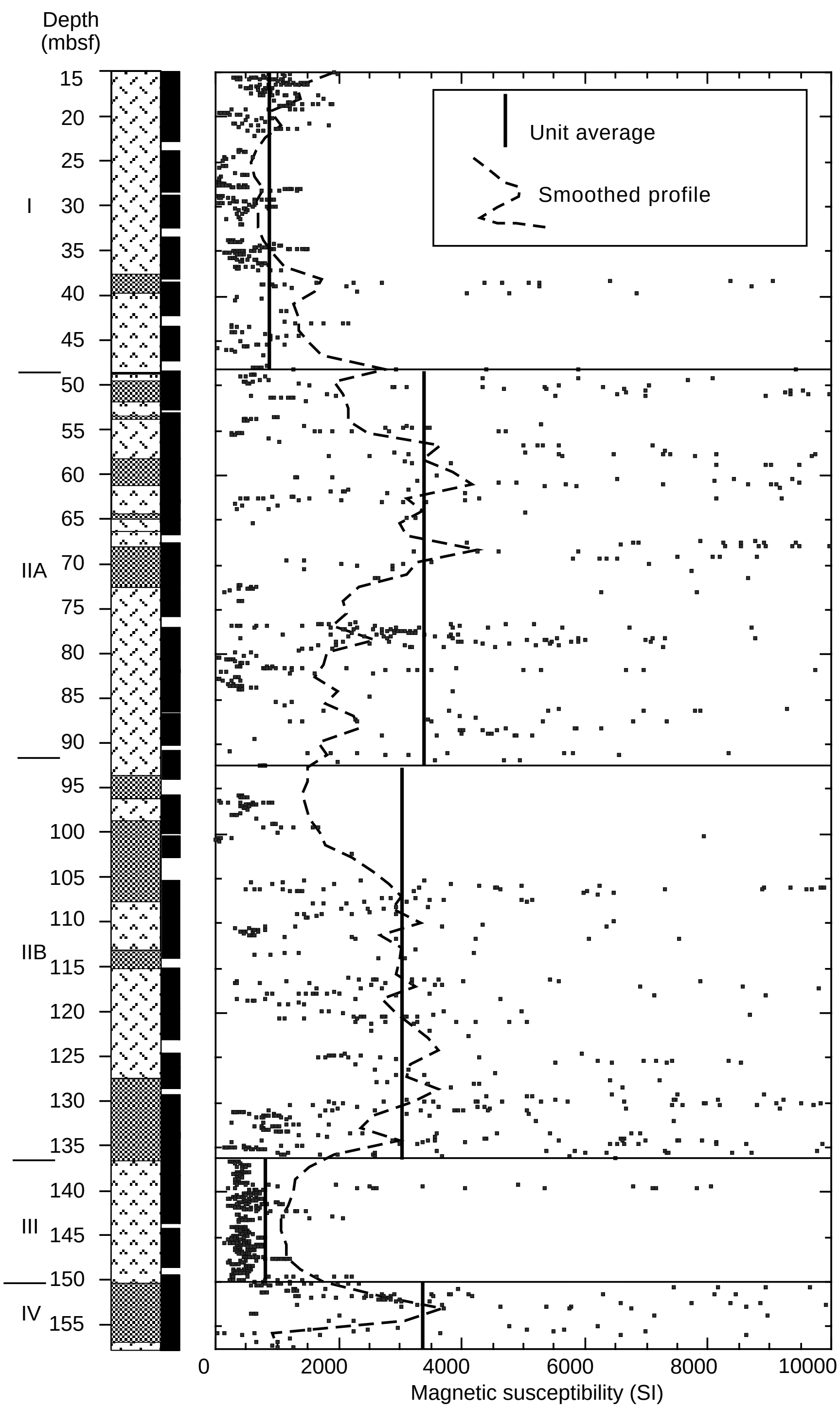

Figure F10. Digital photomicrograph of poikilitic clinopyroxene enclosing anhedral plagioclase grains in medium-grained olivine gabbro. Field of view = 5.5 mm (cross-polarized light; Sample 179-1105A-4R-3, 46–60 cm).

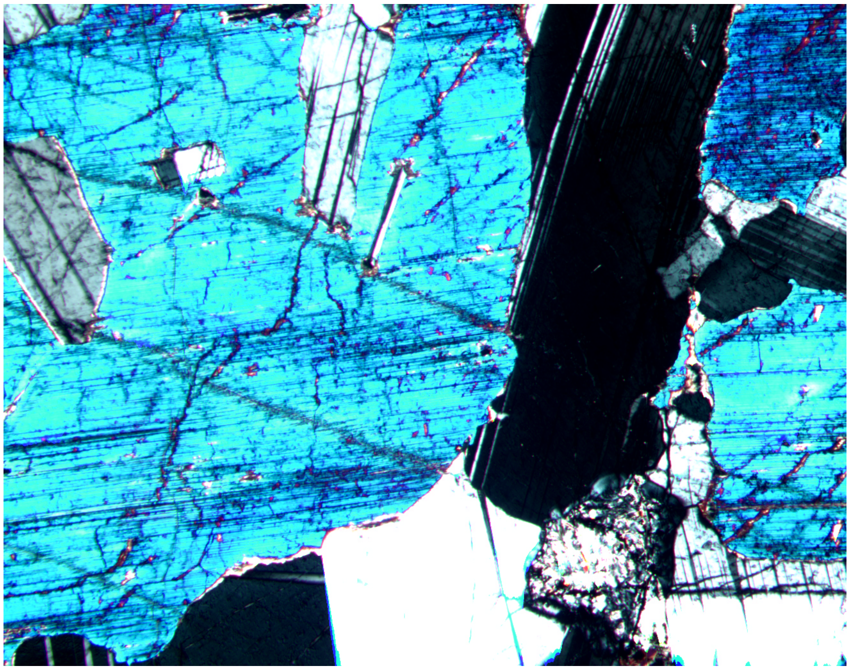

Figure F11. Digital photomicrograph of highly strained ribbon grains of plagioclase in mylonitic fine-grained matrix. Field of view = 5.5 mm (cross-polarized light; Sample 179-1105A-25R-3, 10–13 cm).

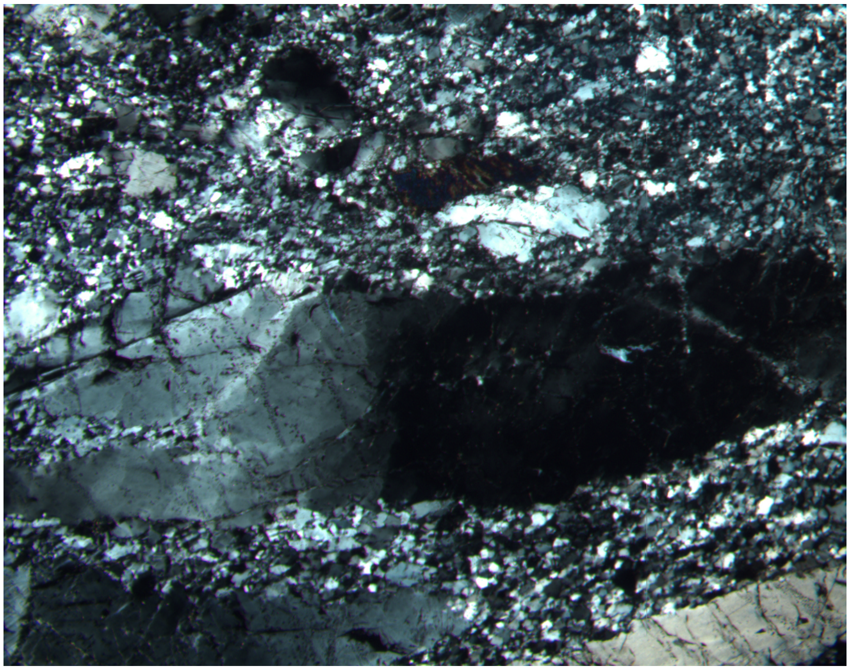

Figure F12. Site map in the eastern Indian Ocean showing the location of Ninetyeast Ridge, NERO Site 1107, and other ODP sites in the region (modified from Pierce, Weissel, et al., 1989). Contour = 3000 mbsl.

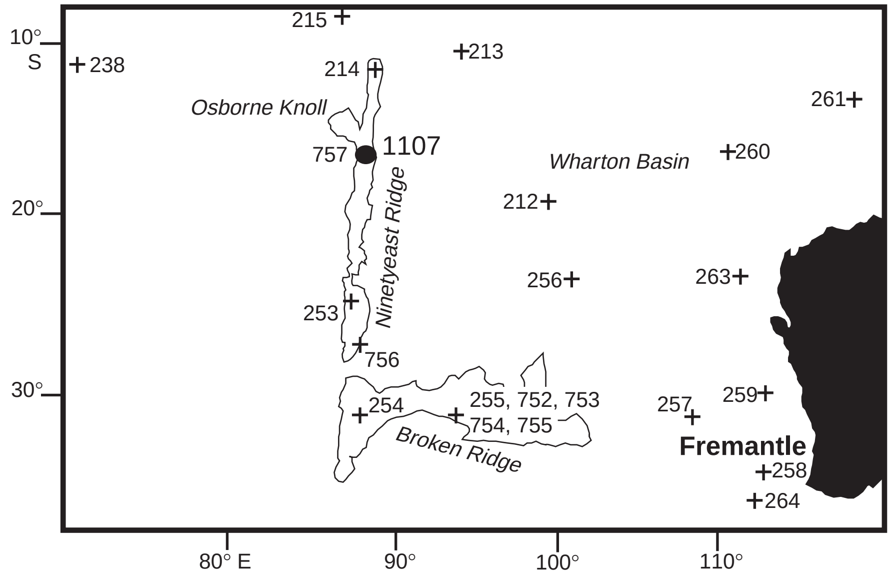

Figure F13. Schematic illustration of cased borehole configuration at Hole 1107A.