# Integrated Ocean Drilling Program Expedition 336 Scientific Prospectus

# Mid-Atlantic Ridge Flank Microbiology

# Initiation of long-term coupled microbiological, geochemical, and hydrological experimentation within the seafloor at North Pond, western flank of the Mid-Atlantic Ridge


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This IODP *Scientific Prospectus* is based on precruise Science Advisory Structure panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists, the Staff Scientist/Expedition Project Manager, and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the science deliverables outlined in the plan presented here are contingent upon the approval of the IODP-USIO Science Services, TAMU, Director in consultation with IODP-MI.

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## Abstract

The upper ~500 m of igneous ocean crust is fractured and permeable, harboring the largest hydrologically active aquifer on Earth. We know that microbes inhabit this aquifer, and we also know that microbes are abundant and play active roles in rock alteration of exposed outcrops at the seafloor. We do not know the extent of microbial colonization in the subseafloor, the diversity and activity of this crustal biome, or its role in modulating geochemical exchange between crust and ocean. These fundamental questions will be addressed during Integrated Ocean Drilling Program (IODP) Expedition 336, the primary science objective of which is to investigate the nature of the subseafloor deep biosphere in oceanic crust and overlying sediments.

These investigations will be initiated during Expedition 336 by installing multilevel subseafloor borehole observatories ("CORKs") at three sites (395A, NP-1, and NP-2) for long-term coupled microbiological, biogeochemical, and hydrological experiments. The basaltic crust will also be characterized by coring parts of the crust, by collecting downhole in situ petrophysical data by wireline logging, and by conducting hydrologic (packer) experiments. Coring at four sites will characterize the overlying sediment section.

Operations during Expedition 336 will lay the foundation for long-term monitoring, experimentation, and observations by subsequent remotely operated vehicle (ROV) or submersible dive expeditions. The installed CORKs will be used in perturbation and monitoring points for single- and cross-hole experiments.

## Schedule for Expedition 336

Integrated Ocean Drilling Program (IODP) Expedition 336 is based on IODP drilling proposal Number 677 (available at **iodp.tamu.edu/scienceops/expeditions/midatlantic_ridge_microbio.html**). Following ranking by the IODP Scientific Advisory Structure, the expedition was scheduled for the R/V *JOIDES Resolution*, operating under contract with the U.S. Implementing Organization (USIO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in Barbados on 17 September 2011 and end in Ponta Delgada, Azores (Portugal), on 20 November 2011. A total of 50.3 days will be available for the drilling, coring, and downhole measurements described in this report (for the current detailed schedule, see

**iodp.tamu.edu/scienceops/**). Further details about the facilities aboard the *JOIDES Resolution* and the USIO can be found at **www.iodp-usio.org/.**

# Introduction

The upper ~500 m of igneous ocean crust is fractured and permeable, harboring the largest hydrologically active aquifer on Earth. Most of the oceanic crust is hydrologically active (at least 60%; Fisher, 2005), with a fluid flux through the crust that rivals global riverine input to the oceans (Wheat et al., 2003). Solutes and colloids (including microbes) circulate actively through the crustal aquifer, but the degree to which microbes "take seed," colonize, alter, and evolve in subsurface rock is not known. Sizable fractions of ocean crust remain uncovered by sediments for thousands to millions of years on the flanks of mid-ocean ridges (MORs) before being blanketed in the abyssal plains of the ocean and eventually subducted at trenches, and these basement outcrops serve as conduits for fluid flow. Laboratory studies, field examinations, and in situ field colonization and alteration experiments have shown that microbes are abundantly present and play active roles in rock alteration of exposed outcrops at the seafloor at low temperatures (e.g., Wirsen et al., 1993, 1998; Eberhard et al., 1995; Rogers et al., 2003; Edwards et al., 2003a, 2003b). In the subseafloor, the extent of direct participation in alteration by extant communities is not as clear. Abundant petrographic observations show that biological communities may be harbored in crust older than 100 Ma (e.g., Fisk et al., 1998). However, studies suggest that young subseafloor ocean crust may be the most redox active—and thereby the most likely to support active biological communities. Furnes et al. (2001) compared the degree of alteration in ocean crust aged 0–110 Ma. These data suggest that the majority of alteration features are established early and change little thereafter. Bach and Edwards (2003) compiled data concerning the oxidation state of the upper ocean crust. These data also suggest that oxidative ocean crust alteration occurs during the first 10–20 m.y. of crustal age and thereafter slows or ceases.

The principal science objectives for Expedition 336 address fundamental microbiological questions concerning the nature of the subseafloor deep biosphere in an oceanic hydrological, geological, and biogeochemical context. First, we plan to study the nature of subseafloor microbiological communities in young igneous ocean crust in order to understand the role of these communities in ocean crust alteration and their ecology in hydrological and biogeochemical contexts. Specifically, we will test the hypothesis that microbes play an active role in ocean crust alteration, while also exploring broad-based ecological questions such as how hydrological structure and geochemistry influence microbial community structures. Second, we intend to study the biogeography and dispersal of microbial life in subseafloor sediments.

The primary operational goal for Expedition 336 is to install multilevel subseafloor borehole observatories ("CORKs") for long-term coupled microbiological, geochemical, and hydrological experiments. Installation of these CORKs will enable us to monitor conditions and study processes in situ after drilling-induced disturbance and contamination of the borehole environment have dissipated.

Our specific operational goals are to

1. Drill a basement hole to ~565 meters below seafloor (mbsf) at Site NP-1, core the bottom ~200 m of the basaltic crust, conduct downhole hydrologic (packer) tests and wireline logging, and install a multilevel CORK to conduct experiments in the deeper portions of the upper basement hydrological environment;
2. Drill a basement hole to ~175 mbsf at Site NP-2, core ~70 m of the basaltic crust, conduct downhole hydrologic (packer) tests and wireline logging, and install a single-level CORK to conduct experiments in the uppermost basement hydrological environment;
3. Recover the existing CORK at Deep Sea Drilling Project (DSDP) Hole 395A, conduct downhole wireline logging, and install a multilevel CORK to conduct experiments in the deeper portions of the upper basement hydrological environment; and
4. Core the thin sediment cover using the advanced piston corer (APC) in a single hole at four sites (proposed Sites NP-1 [64 m] and NP-2 [85 m], Hole 395A [93 m], and Ocean Drilling Program [ODP] Site 1074 [64 m]).

Operations during Expedition 336 will include installation of the initial observatory experiments and will lay the foundation for subsequent long-term monitoring, experimentation, and observations using remotely operated vehicle (ROV) or submersible dive expeditions. CORKs will be used at perturbation and monitoring points for single- and cross-hole experiments and will include the recently developed, novel in situ microbiological experimentation system Flow-through Osmo Colonization Systems (FLOCS; Orcutt et al., 2010, in press; also see **www.darkenergybiosphere.org/**).

Expedition 336 will also include an enhanced education and outreach program intended to facilitate and communicate excitement about scientific drilling and exploration to a broad audience, build educational curricula, and create media products (photographic, sound, video, and web based) that will help achieve critical outreach goals.

# Background

## Geological setting

North Pond is an isolated, northeast-trending, ~8 km × 15 km sediment pond located on the western flank of the Mid-Atlantic Ridge (MAR) at 22°45′N and 46°05′W (Figs. **F1, F2**). This area exhibits normal polarity that has been interpreted as magnetic Anomaly 4 (Melson, Rabinowitz, et al., 1979), suggesting a basement age between 7.43 and 8.07 Ma (using the geomagnetic polarity timescale advised by Cande and Kent, 1995). Sediment thickness ranges up to a maximum of 300 m at the southernmost part of the pond. North Pond is bounded to the east and west by basement ridges as high as 2 km. Two holes cored using the rotary core barrel (RCB) at Site 395 (DSDP Leg 45) penetrated into the easternmost part of the sediment pond (Fig. **F2;** 22°45.35′N, 46°04.90′W; 4484 meters below sea level [mbsl]). A 93 m thick sediment sequence was cored in Hole 395, consisting of 89 m of foraminifer–nannofossil ooze underlain by 4 m of calcareous brown clays with manganese micronodules. Basement penetration was 91.7 m (Hole 395) and 576.5 m (Hole 395A); a reentry cone and casing to basement were installed in Hole 395A. The basement lithology at Site 395 is dominated by several units of massive and pillow lava flows, typically several tens of meters thick, that are separated by basalt- and serpentinite-bearing breccias (Bartetzko et al., 2001; Melson, Rabinowitz, et al., 1979). The serpentinite breccias result from mass wasting and contain cobbles of gabbro and serpentinized peridotite. A peridotite-gabbro complex several meters thick with brecciated contacts was cored in Hole 395 (Arai and Fujii, 1979; Melson, Rabinowitz, et al., 1979; Sinton, 1978). DSDP Leg 78B (Hyndman, Salisbury, et al., 1984), ODP Leg 109 (Detrick, Honnorez, Bryan, Juteau, et al., 1988), ODP Leg 174B (Becker, Malone, et al., 1998), and the French DIANAUT expeditions (Gable et al., 1992) returned to Hole 395A for logging operations, packer testing, and borehole fluid sampling. Temperature and flow logs indicated rapid fluid flow (~1000 L/h) down into Hole 395A (Becker et al., 1984) and low formation pressures. This flow apparently continued for many years after drilling (Becker et al., 1998; Gable et al., 1992). Despite more than two decades of recharge into and through Hole 395A, the hydrology of the North Pond system has not been significantly affected. Geothermal (temperature and heat flow) surveys indicate that recharge occurs dominantly in the southeastern part of the basin, which is consistent with basement fluid flow generally directed to the northwest (Fig. **F3;** Langseth et al., 1984).

Comparison of lithologic and downhole electrical resistivity logs for Hole 395A suggest a series of vertically distinct basalt flows (Bartetzko et al., 2001; Matthews et al., 1984). Each flow unit is characterized by an uphole decrease in electrical resistivity and an increase in gamma ray counts. Many of the low-resistivity intervals at the tops of the flow units correspond to recovery of cobbles or breccia, although recovery within the upper few hundred meters of basement was low. These results indicate that breccias developed between major flow units likely have a high present-day permeability. These zones also exhibit high gamma ray counts, suggesting high K and U concentrations indicative of increased oxidative alteration. The correlation between alteration chemistry and permeability indicates that the basalt flow boundaries acted as fluid conduits throughout the hydrological history of the basement at Site 395.

Downhole logging and packer results suggest that permeability at Site 395 decreases below 400 m subbasement (Hickman et al., 1984), where temperature increases. In 1998, bulk density, temperature, and spontaneous potential (SP) downhole logs were collected in Hole 395A during ODP Leg 174 (Becker, Malone, et al., 1998; Becker et al., 1998). SP logs are used in the petroleum industry to infer the locations of intervals within a borehole that receive or produce fluids. Deflections in the SP logs also correspond to the tops of individual resistivity sequences, suggesting that these thin intervals, interpreted independently on the basis of resistivity and lithologic data to have higher porosity and permeability, are indeed the most hydrologically active. The typical ratio in thicknesses of the most and least hydrologically active sections of this borehole is on the order of 1:10 to 1:100, suggesting that most of the fluid that entered the formation surrounding Hole 395A passed through a small fraction of the exposed rock (Bach et al., 2004; Fisher and Becker, 2000).

During Leg 174B, Hole 1074A was cored near the northwestern margin of North Pond (Fig. **F2**). Temperature and geochemical profiles are diffusive, indicating that there is no upward advection of basement fluids through the sediments, even in an area of local high heat flow (Becker, Malone, et al., 1998). This observation is consistent with the hydrologic model of Langseth et al. (1992, 1984), which indicates that fluid flow is predominantly lateral beneath all of North Pond and recharge/discharge is taking place through basement outcrops that surround the basin. Most of the seawater recharge in Hole 395A is accommodated by aquifers within the uppermost 300 m of basement. Below that depth, temperature increases (Becker et al., 1998; Fig. **F2**) and borehole fluid chemistry indicates significant chemical exchange with the rocks in the borehole walls (Gieskes and Magenheim, 1992; McDuff, 1984), which indicates a different hydrological regime below 300 m subseafloor that is not an artifact of drilling disturbance of the hydrological regimes.

## Site survey data: seismic, bathymetric, heat flow, and sediment coring

Seismic, sediment echo sounding, bathymetry, and heat flow measurements were recorded during R/V *Maria S. Merian* Cruise 11/1 in February/March of 2009 (Villinger et al., 2010). A 12 kHz swath-bathymetry multibeam echo sounding system (Kongsberg EM120) was used to conduct a detailed bathymetric survey (Figs. **F2, AF1**). Fourteen seismic lines with spacings between <1 and 3 km were collected across North Pond using a generator-injector gun and a 100 m long, 16 channel streamer. Eleven profiles are oriented southwest–northeast and three run southeast–northwest. All heat flow measurements and sediment gravity coring were conducted on these seismic lines. The seismic two-way traveltime (TWT) was used to estimate sediment thicknesses (Table **T1**). At the boundaries of North Pond, severe side echoes due to the steep slopes of the bounding basement outcrops deteriorate the record. Identifying the exact basement/sediment interface can be difficult because the rough basement topography does not produce a clear reflection pattern. Migrating the seismic data improves the imaging, and accurate sediment thicknesses for existing drill holes (395A and 1074B) were calculated using a sediment velocity of 1700 m/s. The degree of difficulty in estimating sediment thickness is similar to that at the Juan de Fuca Ridge flank, where experience from ODP Leg 168 and IODP Expedition 301 shows that uncertainties are on the order of ±5 m.

Fourteen gravity cores (up to 9.5 m in length) were collected from North Pond between 4040 and 4480 mbsl and were concentrated in areas of high heat flow in the northern and northwestern part of the basin. The sedimentary sequences recovered are preliminarily interpreted to represent pelagic sedimentation of clay-sized particles interrupted by abrupt deposition of foraminifer sand layers. The presence of sharp, irregular bottom contacts and normal-graded bedding may indicate that these coarse-grained intervals are the result of gravity flows supplied from the surrounding slopes. Consistent with this interpretation, the sand layers are commonly found at the deepest parts of the basin (>4300 mbsl) and are absent in cores retrieved from the less sedimented slopes of the basin.

Microbiological studies of the cores were also conducted. Oxygen is the terminal electron acceptor in all gravity cores and hence provides the most sensitive indicator of microbial activity and fluid flow in the North Pond sediments. Dissolved oxygen penetrated all cores recovered at all coring sites. Several dissolved oxygen profiles appeared to have been affected by a deep secondary source of dissolved oxygen that caused the oxygen profiles to increase toward the base of the core. Variability in flow within the underlying basalt is hypothesized to cause these deeper increases in dissolved oxygen. This effect appears to be greatest in the northern part of the basin, which is why the sites for new CORKs are located there and not in the Site 1074 area, as proposed in the original drilling proposal (Figs. **F2, F4**).

The supporting site survey data for Expedition 336 are archived at the **IODP Site Survey Data Bank.**

## Scientific objectives

Our objectives are to recover sediments that overlie a hydrological flow path previously studied in the basement underlying North Pond sediments (see below), recover basement at one site (NP-1), and establish CORKs to address two major scientific questions:

*1. Where do deep-seated microbial communities come from?*

Viable, diverse, and distinct microbiological communities occur in deeply buried marine sediments. Where they originate is unknown. There are (at least) two possibilities: (1) microorganisms from overlying bottom seawater are a steady source of inoculum that seeds microorganisms (particle attached and free living) to sediments. Hence, each sediment layer, no matter how deeply buried, can in principle harbor a population derived from this initial deepwater inoculum; or (2) microbial inoculum is provided by active transport (e.g., by vertical advective transport from the basement [passive transport] or by lateral active transport [swimming] from adjacent, older sediments following redox gradients). This hypothesis is consistent with known mechanisms (i.e., swimming by chemotactic response to chemical gradients or advective flow) and would explain how microbial communities persist in such nutrient-limited, deeply buried sedimentary sequences, that is, they have evolved very specifically for this niche. However, this mechanism implies that sediments need to be in physical contact for effective inoculum transfer in order for these specialized niches to be exploited. Hence, an isolated sedimentary sequence may be inactive, dormant, or harbor some evolutionarily distinct populations of microorganisms compared to sedimentary communities that receive the "ancient inoculum." North Pond is the ideal location to test these opposing hypotheses, which have important mechanistic implications concerning dispersal mechanisms in the deep biosphere and evolutionary consequences for microbial life on Earth. We will analyze the microbial communities in both the deep sediments (obtained from cores taken during the expedition) and the basement crustal fluids (obtained with the CORKs postexpedition).

2. *What is the nature of microbial communities harbored in young ridge flanks, and what is their role in ocean crust weathering?*

In the subseafloor, the extent of direct participation in weathering by extant communities is not clear. Abundant petrographic and geochemical data indicate that oxidative seafloor alteration occurs during the first 10–20 m.y. of crustal age and thereafter slows or ceases. These preliminary lines of evidence suggest that the most reasonable place to search for active subsurface microbial communities should be in young ridge flanks (<10 Ma). Most young ridge flanks lack sediment cover, which presents difficulty for intact recovery of upper ocean crust. One major exception is the Juan de Fuca Ridge flank. However, the high heat flow, rapid chemical reaction rates, and anaerobic conditions of this setting make it a poor site choice, given our principal interest in characterizing more "average," cold ridge flanks in order to reveal the role that microorganisms may play on a global basis in promoting weathering. Chemical reaction kinetics are inhibited at low temperatures, providing a window of opportunity for biological catalysts. The low heat flow ridge flank at North Pond represents an ideal model system for studying biologically mediated oxidative basement alteration. The work will also provide an excellent point of comparison for the studies taking place at the Juan de Fuca Ridge, which represents the warm, sedimented end-member in the global spectrum of ridge flanks.

# Operations plan and drilling strategy

The overall operations plan for Expedition 336, including target depths and anticipated cored intervals, is presented in Table **T2.** The highest-priority objective for this expedition is the installation of the three long-term CORKs. The exact sequence of operations presented here and in Table **T2** may change based on the results of ongoing CORK design and development as well as continuing evaluation of risks and contingency plans.

## APC coring at Sites 1074 and 395

We will begin with a single APC-cored hole at Site 1074 to recover the entire ~64 m thick sedimentary section. Without retrieving the drill string, we will move to nearby Hole 395A and APC core a single hole to recover the entire ~93 m sedimentary section. These cores will be the focus of intensive onboard incubation studies and analytical programs. In parallel with sediment coring, we will begin preparing all of the experiments that will be deployed with the CORKs.

## Hole 395A

Our next operation will be to remove the old-style CORK and thermistor string currently in Hole 395A. We will then deploy the water-sampling temperature probe (WSTP) and a self-contained temperature logging device to collect a deep sample of the borehole fluid at 550 mbsf. This process will be completed without circulating fluids to minimize borehole disturbance. After logging operations (see **"Logging/ Downhole measurements strategy"**), the status of the borehole will be checked and the hole will be cleaned to 610 mbsf with the least amount of fluid circulation possible to ensure that the hole is open for the CORK and that the hole is not overly disturbed with the introduction of surface seawater. Given the underpressure relative to hydrostatic at Hole 395A, we expect bottom seawater that flows into the borehole to flow primarily into the upper permeable formation and less so into the lower, warmer, less permeable formation below 350 mbsf. Provided the hole remains open to 600 mbsf, we will install a new multilevel CORK with downhole and surface experiments, as illustrated in Figure **F5.** Should the hole contain more than the anticipated amounts of fill, circulation will be used to clean the hole so that it is suitable for CORK emplacement.

## Site NP-1

Following the transit to Site NP-1, we will install the "deep" CORK observatory. After installation of a reentry cone and surficial 20 inch casing, we will drill a hole into uppermost basement for the 16 inch casing with a pilot bit and a 21½ inch underreamer through the ~85 m of sediment and into uppermost basement. We will then install and cement the 16 inch casing into uppermost basaltic basement. To minimize the risk of the casing strings and reentry cone sinking below the mudline (as happened during Expedition 301), we will use a special cement program (with lost circulation material and perhaps accelerants). We will then reenter the hole with a 14¾ inch tricone bit to drill out the cement and make a hole to ~215 mbsf for the 10¾ inch casing. This section will not be cored in order to allow rapid penetration in the most unstable uppermost basement. Whenever possible, while drilling in basement we will use a bottom-hole assembly (BHA) that consists of extra 8¼ inch drill collars to maximize the amount of slick pipe that is exposed to the unstable basement formations and keep the top of the BHA inside the 16 inch casing. After thoroughly cleaning the hole and verifying the amount of fill on the bottom, we will install the 10¾ inch casing. To ensure rapid emplacement of the casing string and unimpeded landing of the 10¾ inch casing hanger, we will install this casing without stopping to install the cementing manifold and subsea release system. We intend to use a special cement program (with lost-circulation materials and/or accelerants) for this casing string as well.

If we encounter substantial difficulties while drilling the 14¾ inch hole for the 10¾ inch casing, we may elect to use Site NP-1 as the shallow basement CORK observatory.

After tripping out of the hole to change to a 9⅞ inch RCB bit, we will drill out the cement plug and cut RCB cores from ~215 to ~415 mbsf in basaltic basement. After we change the RCB bit, RCB coring will continue to ~565 mbsf. The actual depth of penetration may differ, depending on rates of penetration, drilling conditions, and the nature of the rocks recovered. However, all of our operations (including anticipated hole conditions and penetration rates) are based on previous drilling in North Pond. Once coring is finished, wireline logs will be obtained to identify optimal placement of straddle packers as well as to provide formation properties of the oceanic crust (see **"Logging/Downhole measurements strategy"**). Our next step will be to conduct drill string hydrologic (packer) tests at three different depths. After verifying the depth of the open hole, the multilevel CORK will be deployed. This CORK will be configured to isolate three intervals of upper basement and will include borehole and surface instrument packages (Fig. **F6**).

## Site NP-2

Initial activities at Site NP-2 will nearly duplicate those at Site NP-1, except that the reentry cone will be installed with 16 inch casing to ~62 mbsf. We will then use a 14¾ inch tricone bit to drill out the remaining sediment and basement to ~105 mbsf for the 10¾ inch casing. The 10¾ inch casing will be cemented in place using the same procedure employed at Site NP-1.

After performing a round-trip of the drill string to change to a 9⅞ inch RCB bit, we will drill out the cement with the RCB bit and then RCB core from ~105 to 175 mbsf. Collection of downhole logs is included in this plan; however, there will be a very short interval of open hole, we expect poor hole conditions in this uppermost basement, and the priority is to conduct hydrologic (packer) experiments and install the CORK. Hydrologic (packer) tests will be conducted, and then the open hole depth will be verified before deploying a single-level CORK observatory. The CORK will be configured to isolate the uppermost basement below the sediment. This CORK will be instrumented with borehole and surface instrument packages (Fig. **F7**). The final configuration of the deepest portion of each CORK will be similar (Fig. **F8**). The retrievable experiments within the CORKs are intended to have identical instrument packages with four different basic configurations for different experiments (Fig. **F9**).

The last operation at Site NP-2 will be the recovery of a single copy of the entire ~85 m thick sedimentary section with the APC coring system, tagging basement. In the current operations plan and time estimate, there will be time to APC core only one hole at Site NP-2. If additional time is available, we may core a second or third hole at this site.

## Site NP-1

Our final operation will be the recovery of a single copy of the entire ~64 m thick sedimentary section at Site NP-1 with the APC system. Once again, additional time at this site may be used to core extra APC holes or perhaps a single RCB hole to collect upper basaltic basement.

## Hydrologic (drill string packer) testing at Sites NP-1 and NP-2

In situ hydrogeologic testing is essential for quantifying crustal properties (transmissive and storage) that control ridge-flank hydrothermal circulation. For this testing, we will use a drill string packer, which is reliable and relatively easy to integrate, as part of a comprehensive program of basement drilling, sampling, and experiments. Tests at multiple depth intervals will be conducted to discern difference between test results at two depths and to quantify differences in hydrologic properties within discrete depth intervals.

The drill string packer will be made up as part of a BHA that is compatible with logging so that a separate pipe trip is not required. Wireline logs are run before packer testing to assist with identification of suitable zones (massive, in gauge) at depths where the packer element can be inflated. Tests at multiple depth intervals within the open borehole at Site NP-1 will follow the standard approach: (1) inflate and set the packer at the deepest setting point first, (2) complete testing at that depth, and (3) deflate the packer and raise it up to a shallower depth and repeat the tests. The difference between test results at two depths can be used to quantify differences in hydrologic properties within discrete depth intervals. Tests are generally repeated at each testing depth, using two or more different pumping rates, to verify test response and formation properties.

Neglecting the time required to trip pipe into and out of the borehole, an experimental program involving packer testing at 2–3 depths in open hole and casing in a 500 m deep basement borehole will generally require 24–30 h. Testing of the shallower penetration hole at Site NP-2, based on setting the packer at a single depth (likely in the base of the 10¾ inch casing), might require 12–18 h. Additional time may be used to collect reliable baseline pressure data, set the packer at additional depths, or test at additional flow rates.

Pressure data are generally collected using autonomous downhole pressure gauges that are suspended below a "go-devil" that is dropped into the packer when it is positioned at depth in the borehole. These gauges are recovered when the complete testing sequence has been run. The shipboard Rig Instrumentation System (RIS) is used to record key pumping parameters: time, stroke rate, total number of strokes, BHA depth, and standpipe pressure, which is a backup for downhole pressure records.

## Logging/Downhole measurements strategy

Downhole measurements during Expedition 336 will focus on characterizing crustal physical properties and defining structural and lithologic boundaries as a function of depth. In addition, wireline logging data can be compared to results of laboratory analyses of discrete samples and should help delineate alteration patterns, fracture densities, and structural orientations and determine how these correlate with fluid flow. These measurements will complement core measurements by determining the thickness and structure of lithologic units in intervals where core recovery is poor. These logs will be also critical for both shipboard hydrologic (packer) tests as well as for the precise depth placement of the CORK experiments.

## Wireline logging

Wireline tool strings will be deployed at Sites 395, NP-1, and NP-2 (Table T3). Logging time estimates for each site are given in Table T3. These logs will provide measurements including temperature, natural gamma ray, density, porosity, resistivity, sonic velocity, and microresistivity. Descriptions of the wireline tools and their applications are available at **iodp.ldeo.columbia.edu/TOOLS_LABS/index.html.**

In Hole 395A, we intend to deploy an adapted triple combination (ATC) tool string. The ATC will include probes to measure natural gamma ray (Hostile Environment Natural Gamma Ray Sonde [HNGS]) and temperature (Modular Temperature Tool [MTT]). Additionally, we hope to add the Deep Exploration Biosphere Investigative Tool (DEBI-t) to this tool string. This tool is currently being developed to image the natural fluorescence of microbial communities exposed on the borehole wall.

At Sites NP-1 and NP-2, the first tool string deployed in the logged hole will be the triple combination (triple combo) tool string, which consists of several probes that record measurements of the penetrated formations and measure natural gamma radiation (HNGS), density (Hostile Environment Litho-Density Sonde [HLDS]), porosity (Accelerator Porosity Sonde [APS]), formation resistivity (Dual Induction Tool [DIT]), and borehole diameter. These measurements will be used for characterization of stratigraphic sequences, assessment of alteration, and reconstruction of the volcanic stratigraphy. Depending on borehole conditions, the Formation MicroScanner (FMS)-sonic tool string (composed of the Dipole Sonic Imager [DSI] and HNGS) will be run. The FMS-sonic tool string will provide high-resolution borehole images of lithostratigraphic sequences and boundaries, geographically oriented fractures, and structural features that could be related to present-day fluid flow and stress state. These images can also be used for reconstruction of the volcanic stratigraphy and reorientation of core pieces. The General Purpose Inclinometry Tool (GPIT) will be deployed with the image tool to collect accelerometer and magnetometer data, which will allow orientation of the images and provide information about borehole geometry. The DSI measurements will include compressional and shear wave forms as well as cross-dipole shear wave velocities measured at different azimuths. These types of measurements can be used to determine preferred mineral and/or fracture orientations, fracture densities, and paleostress directions. The velocity and density downhole measurements can also be used for constructing synthetic seismograms and tying the core and log measurements to regional seismic reflection data. In addition, if the DEBI-t is fully developed and successfully run as part of the ATC in Hole 395A and time permits, we hope to deploy it at Sites NP-1 and/or NP-2.

# Risks and contingency

Adverse weather conditions can cause reentry failures, and large swells may prevent safe operations. Coring was challenging during Leg 45. We expect that highly fractured volcanic and brecciated units may cause slow penetrations rates, poor core recovery, and poor hole conditions. Operations and time estimates were made after taking into consideration all previous drilling in North Pond. Poor weather and sea state can be problematic for borehole operations, in particular the installation of casing and CORK deployments. Experience from expeditions with similar drilling and instrumentation objectives on the Juan de Fuca Ridge flank (Expeditions 301 and 327) was also used in designing our operations and CORK observatory plans. We expect severe hole conditions in the uppermost basaltic crust; thus, we plan on drilling without coring through this region at each site (uppermost ~150 m of basement at Site NP-1; uppermost 20 m at Site NP-2) so that we can install 10¾ inch casing as quickly as possible. Poor hole conditions may require longer hole preparation than is currently planned, which may reduce the amount of time available for lower priority operations (e.g., coring). Poor hole conditions and rubbly basement may also prevent sealing the base of the 10¾ inch casing with cement, which is why we will use a mechanical casing seal system for use between the 16 and 10¾ inch casing strings. To the extent possible, we also intend to use a BHA that puts drill collars in the open hole to help prevent rubble from falling into the hole on top of the drill collars. Internal CORK experimental instrumentation will not extend outside the CORK casing to minimize problems related to poor hole conditions in deploying and retrieving them (Figs. **F6, F7, F8, F9**). Instead, we plan to deploy all CORK instrumentation so that it resides inside perforated 4½ inch fiberglass casing.

# Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations policy posted on the Web at **www.iodp.org/program-policies/.** This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of co-chief scientists, staff scientist, and IODP curator on shore and curatorial representative aboard ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling.

Shipboard scientists are expected to submit sample requests (**smcs.iodp.org/**) at least three months before the beginning of the expedition. Based on sample requests (shore based and shipboard) submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and cruise objectives. The sampling plan will be subject to modification depending on the actual material recovered and collaborations that may evolve between scientists during the expedition. Modification of the strategy during the expedition must be approved by the co-chief scientists, staff scientist, and curatorial representative aboard ship.

The minimum permanent archive will be the standard archive half of each core. All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the cruise objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

If critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling by a single investigator. A sampling plan coordinated by the SAC may be required before critical intervals are sampled.

The primary operations plan presented in Table **T2** includes only very limited coring for this expedition. The plan only includes time for a single, sediment APC-cored hole at each of Hole 395A and Sites NP-1 and NP-2. This would result in ~220 m of core (presuming 100% recovery). RCB coring in basaltic crust is only planned for Site NP-1 (~350 m of section from ~215 to ~565 mbsf) and Site NP-2 (~70 m from ~105 to 175 mbsf). However, due to potentially poor recovery (20%–40%?), this total planned RCB-coring penetration of ~420 m might result in as little as 100 m of recovered basalt.

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**Table T1.** Overview of primary and secondary drill sites for Expedition 336. (**See table notes.**)

| Site | P/S | Seismic line | Shotpoint | Latitude | Longitude | Water depth (mbsl) | Sediment thickness (s TWT) | Sediment thickness (m*) |
|---|---|---|---|---|---|---|---|---|
| 1074 | P | 3 | 2120 | 22°46.8447′N | 46°6.7069′W | 4445 | NA | 64 |
| 395 | P | 13 | 810 | 22°45.4409′N | 46°4.9598′W | 4470 | 0.110 | 94 |
| NP-1 | P | 2 | 1150 | 22°48.7083′N | 46°5.3459′W | 4448 | 0.070 | 60 |
| NP-2 | P | 5 | 3935 | 22°48.1149′N | 46°3.1753′W | 4395 | 0.100 | 85 |
| NP-3 | S | 14 | 1611 | 22°45.2143′N | 46°7.2100′W | 4470 | 0.300 | 255 |
| NP-4 | S | 5 | 3570 | 22°44.4597′N | 46°7.2607′W | 4470 | 0.315 | 268 |
| NP-5 | S | 10 | 7760 | 22°46.0935′N | 46°5.8247′W | 4470 | 0.145 | 123 |
| NP-6 | S | 8 | 6198 | 22°45.0651′N | 46°5.3795′W | 4448 | 0.165 | 140 |
| NP-7 | S | 9 | 6895 | 22°45.1449′N | 46°6.0619′W | 4470 | 0.250 | 213 |
| NP-8 | S | 10 | 7810 | 22°45.6069′N | 46°6.3677′W | 4472 | 0.220 | 187 |
| NP-9 | S | 11 | 295 | 22°45.6267′N | 46°7.4521′W | 4472 | 0.300 | 255 |
| NP-10 | S | 11 | 470 | 22°47.3415′N | 46°5.5339′W | 4466 | 0.150 | 128 |
| NP-11 | S | 11 | 494 | 22°47.5683′N | 46°5.2789′W | 4463 | 0.065 | 55 |
| NP-12 | S | 11 | 2300 | 22°47.5370′N | 46°4.8250′W | 4455 | 0.065 | 55 |
| NP-13 | S | 11 | 3960 | 22°47.5683′N | 46°5.2789′W | 4470 | 0.065 | 55 |

Notes: * = measured at 1.7 km/s. P/S = primary/secondary. TWT = two-way traveltime. NA = not applicable. Latitude, longitude, water depth, and sediment thickness are based on newly collected site survey data of Villinger et al. (2010).

**Table T2.** IODP Expedition 336, Mid-Atlantic Ridge Microbiology. (**See table notes.**)

| Site No. | Location (Latitude Longitude) | Sea Floor Depth (mbrf) | Operations Description | Transit (days) | Drilling Coring (days) | Log (days) |
|---|---|---|---|---|---|---|
| **Barbados** | | | **Begin Expedition** 4.0 | port call days | | |
| | | | Transit ~958 nmi to **Site 1074** @ 10.5 nmi/hr | 3.8 | | |
| **Site 1074** | 22° 46.8447' N | 4436 | Hole B - APC to 64 mbsf | | 1.3 | |
| EPSP Approval (pending) | 46° 6.7069' W | | | | | |
| | | | | | | |
| | | | **Sub-Total Days On-Site: 1.1** | | | |
| | | | Transit ~2 nmi to **NP- Hole 395A** @ 1.5 | 0.1 | | |
| **NP- Hole 395A** | 22° 45.3519' N | 4494 | **Hole B** - APC to 93 mbsf | | 1.3 | |
| EPSP Approval (pending) | 46° 4.8609' W | | **Hole 395A** - Remove existing CORK; Install new CORK | | 6.4 | 0.7 |
| | | | 1. Retrieve data logger and pull cork | | | |
| | | | 2. Clean out hole to ~ 600 mbsf | | | |
| | | | 3. Run CORK, deploy instrument string and deploy ROV platform | | | |
| | | | **Sub-Total Days On-Site: 8.5** | | | |
| | | | Transit ~3 nmi to **NP-1 Deep Corked Hole** @ 1.5 nmi/hr | 0.1 | | |
| **NP-1 Deep** | 22° 48.7083' N | 4459 | **Hole A** - Deep Cork | | 23.4 | 1.1 |
| **Corked Hole** | 46° 5.3459' W | | 1. Deploy reentry cone & jet-in 40 m 20" casing (to ~40 mbsf) | | | |
| EPSP Approval (pending) | | | 2. Drill 22" diameter hole w/ underreamer into basement (~85 mbsf) | | | |
| | | | 3. Deploy 16" casing; place shoe at ~75 mbsf | | | |
| | | | 4. Cement casing, release casing string, flush drill pipe, POOH | | | |
| | | | 5. Drill out cement with 14 3/4" bit and drill to 215 mbsf | | | |
| | | | 6. Deploy 10 3/4" casing to ~ 205 mbsf | | | |
| | | | 7. Cement casing | | | |
| | | | 8. Drill out cement with center bit and RCB core from 215 to ~415 mbsf | | | |
| | | | 9. Change bit and RCB core from ~415 to 565 mbsf | | | |
| | | | 10. Wireline Logging | | | |
| | | | 11. Drill string hydrologic (packer) testing | | | |
| | | | 12. Make up and run CORK | | | |
| | | | 13. Deploy thermistor string, land cork, inflate packers and deploy ROV platform. | | | |
| | | | **Sub-Total Days On-Site: 24.4** | | | |
| | | | Transit ~2 nmi to **NP-2 Shallow Corked Hole** @ 1.5 nmi/hr | 0.1 | | |
| **NP-2 Shallow** | 22° 48.1149' N | 4406 | **Hole A** - Shallow CORK | | 13.0 | 0.8 |
| **Corked Hole** | 46° 3.1753' W | | 1. Deploy reentry cone & jet-in 60m of 16" casing | | | |
| EPSP Approval (pending) | | | 2. Drill 14 3/4" diameter hole into basement to ~105 mbsf | | | |
| | | | 3. Deploy 10 3/4" casing to ~95 mbsf | | | |
| | | | 4. Cement casing shoe, release casing, flush pipe, POOH | | | |
| | | | 5. RCB coring from 105 to 175 mbsf | | | |
| | | | 6. Wireline Logging | | | |
| | | | 7. Drill string hydrologic (packer) testing | | | |
| | | | 8. Make up and run CORK | | | |
| | | | 9. Deploy thermistor string, land CORK, inflate packers, deploy ROV platform | | | |
| | | | **Hole B** - APC to 85 mbsf | | 1.3 | |
| | | | **Sub-Total Days On-Site: 15.1** | | | |
| | | | Transit ~2 nmi to **NP- 1** @ 1.5 nmi/hr | 0.1 | | |
| **NP- 1** | 22° 48.7083' N | 4459 | **Hole A** - APC to 64 mbsf | | 1.0 | |
| EPSP Approval (pending) | 46° 5.3459' W | | | | | |
| | | | | | | |
| | | | **Sub-Total Days On-Site: 1.0** | | | |
| | | | Transit ~1381 nmi to **Punta Delgado, Azores** @ 10.5 nmi/hr | 5.5 | | |
| **Ponta Delgado, Azores** | | | **End Expedition** | 9.7 | 47.7 | 2.6 |

| | | | |
|---|---|---|---|
| **Port Call:** | **4.0** | **Total Operating Days:** | **60.0** |
| **Sub-Total On-Site:** | **50.3** | **Total Expedition:** | **64.0** |

Notes: Site information not yet reviewed by Environmental Protection and Safety Panel (EPSP). APC = advanced piston corer, RCB = rotary core barrel. POOH = pull out of hole. mbrf = meters below rig floor, mbsf = meters below seafloor.

**Table T3.** Summary of logging time estimates for Expedition 336. (**See table notes.**)

| Hole/Site | Tool combination | Time | |
|---|---|---|---|
| | | Hours | Days |
| 395A | Adapted triple combination | 15.9 | 0.66 |
| | Subtotal for Hole 395A: | 15.9 | 0.66 |
| NP-1 (deep) | Triple combination | 10.5 | 0.44 |
| | Adapted triple combination | 12.0 | 0.50 |
| | FMS-sonic | 10.0 | 0.42 |
| | Subtotal for Hole NP-1 (w/ATC): | 34.5 | 1.44 |
| | Subtotal for Site NP-1: | 22.5 | 0.94 |
| NP-2 (shallow) | Triple combination | 8.5 | 0.35 |
| | Adapted triple combination | 7.7 | 0.32 |
| | FMS-sonic | 6.7 | 0.28 |
| | Subtotal for NP-2 (w/ATC): | 24.9 | 1.04 |
| | Subtotal for Site NP-2: | 17.2 | 0.72 |
| All sites | Total logging time (w/ATC): | 75.3 | 3.14 |
| | Total logging time: | 51.6 | 2.15 |

Notes: Black text = estimates for current operations plan (see Table **T2**). Blue text = estimates for possible logging runs using the adapted triple combination (ATC) tool.

**Figure F1.** Location of North Pond area on the western flank of the Mid-Atlantic Ridge.

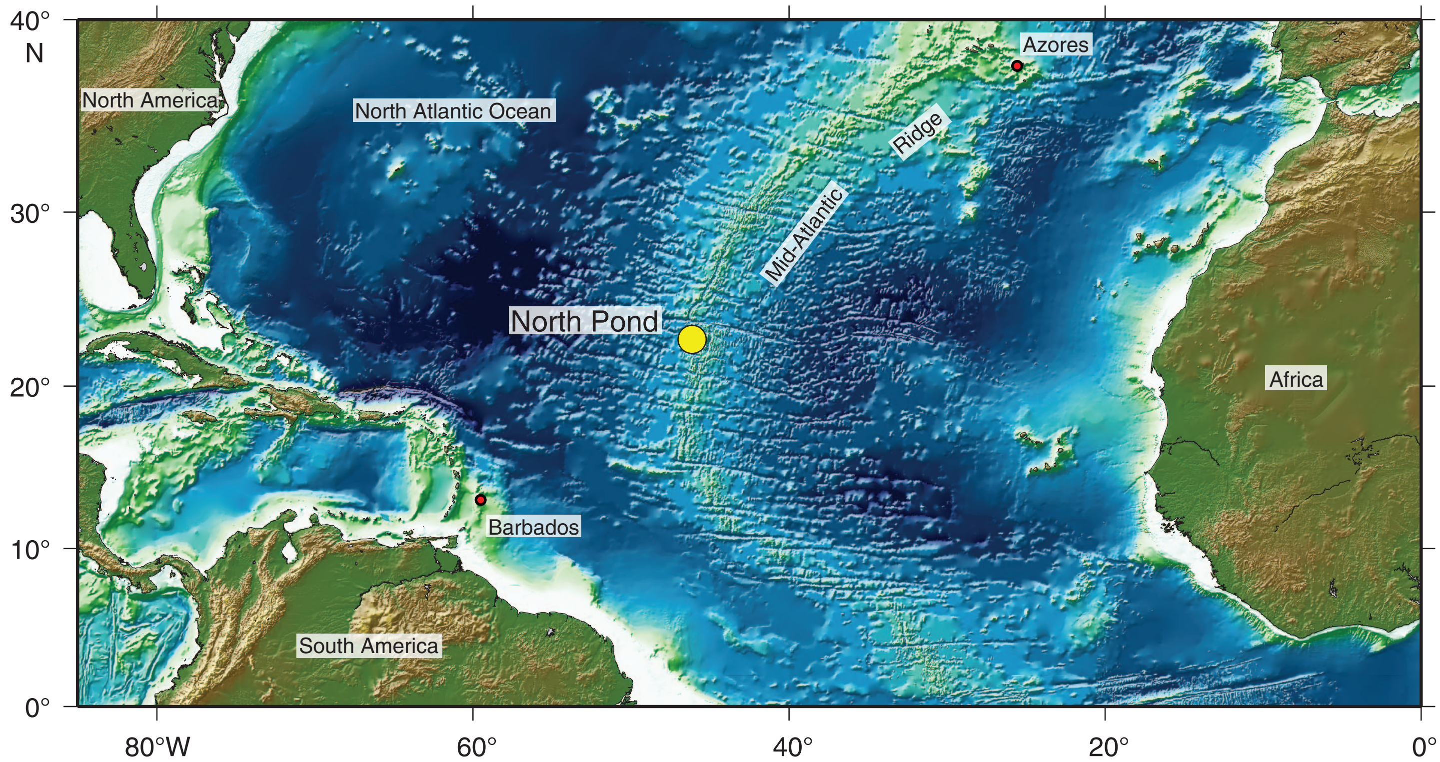


**Figure F2.** Bathymetric map of North Pond showing locations of DSDP Hole 395A, ODP Hole 1074A, and proposed Sites NP-1 and NP-2. Bathymetric data are from Villinger et al. (2010).

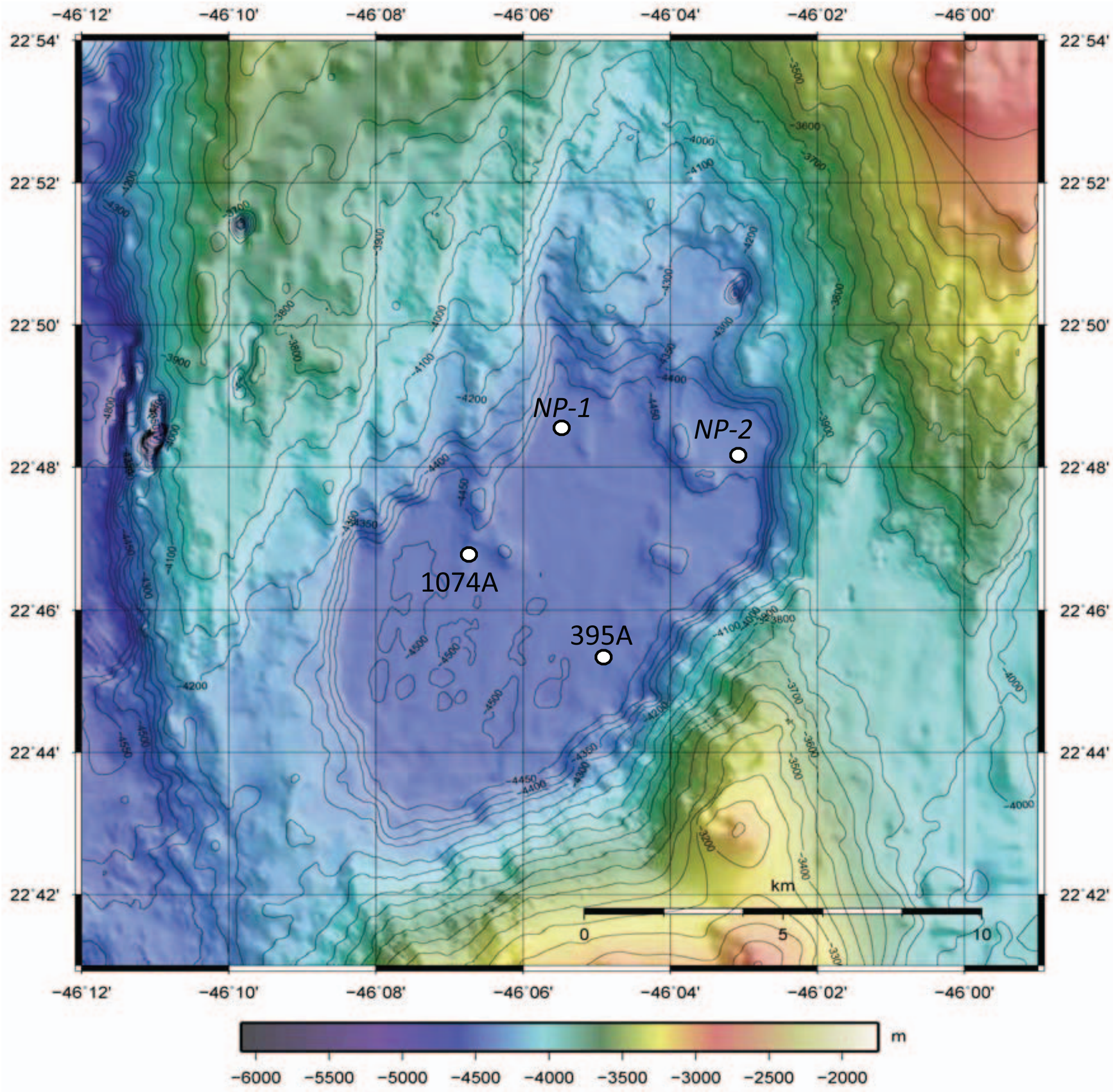


**Figure F3.** (**A**) Distribution of surface heat flow and (**B**) hypothesized fluid flow (blue arrows) and basement temperature (isotherms; red dashed lines) along a southeast–northwest transect across North Pond from ODP Hole 1074A to DSDP Hole 395A.

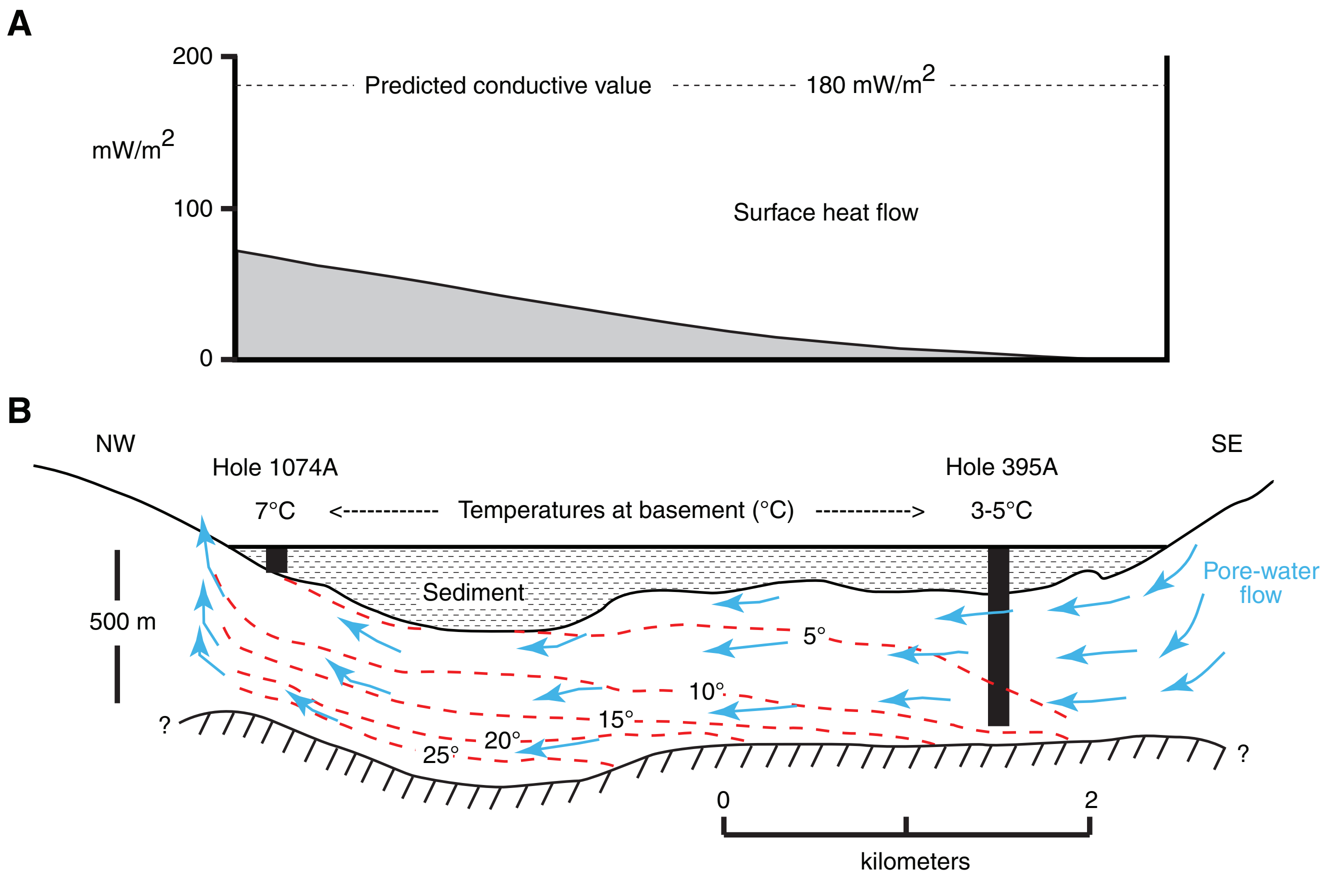


**Figure F4.** Sketch of North Pond with principal locations of basement borehole observatories superimposed on the expected fluid flow pattern.

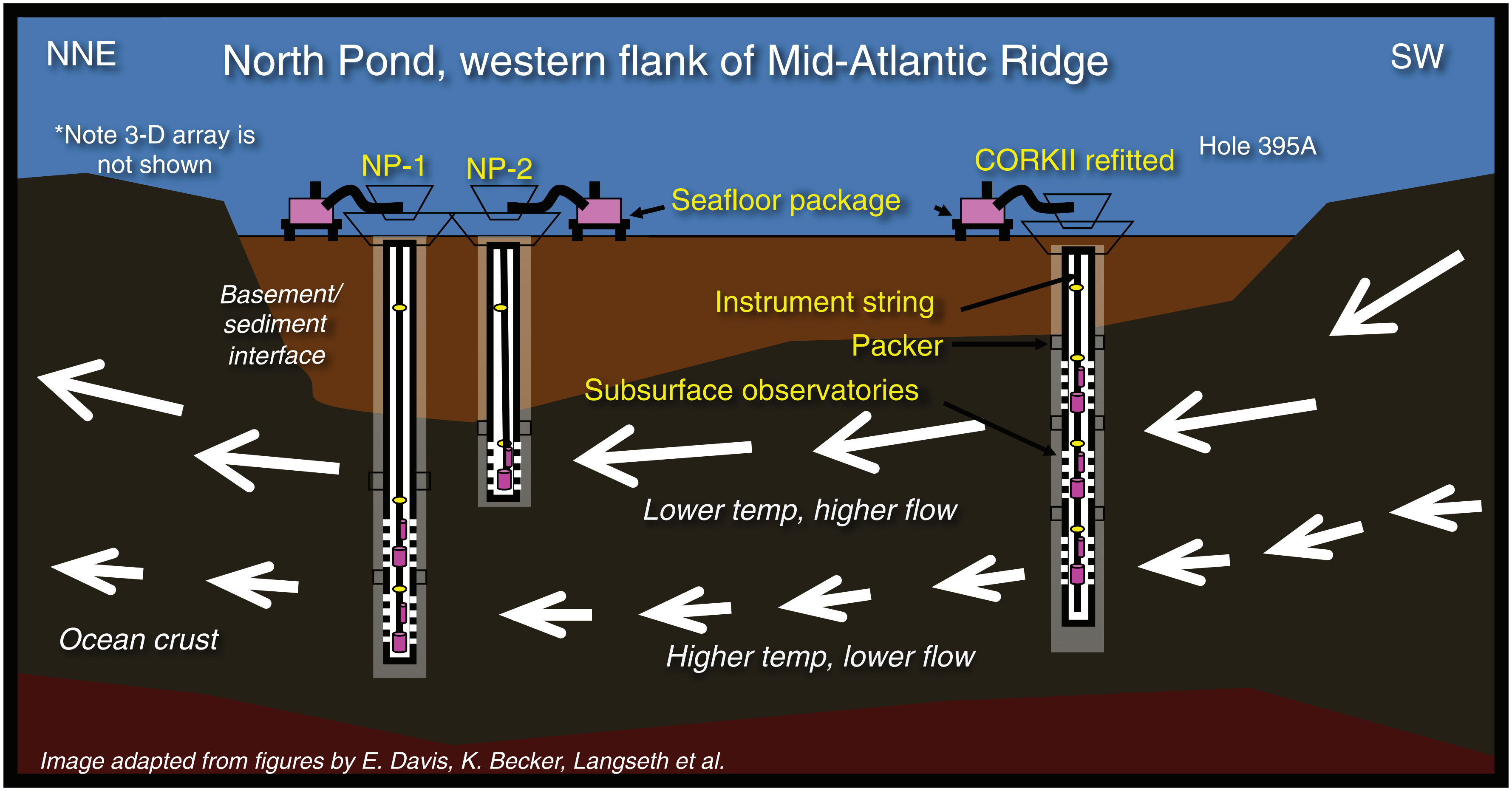


**Figure F5.** Schematic overview of instrument and sensor string plan for Hole 395A (not to scale).

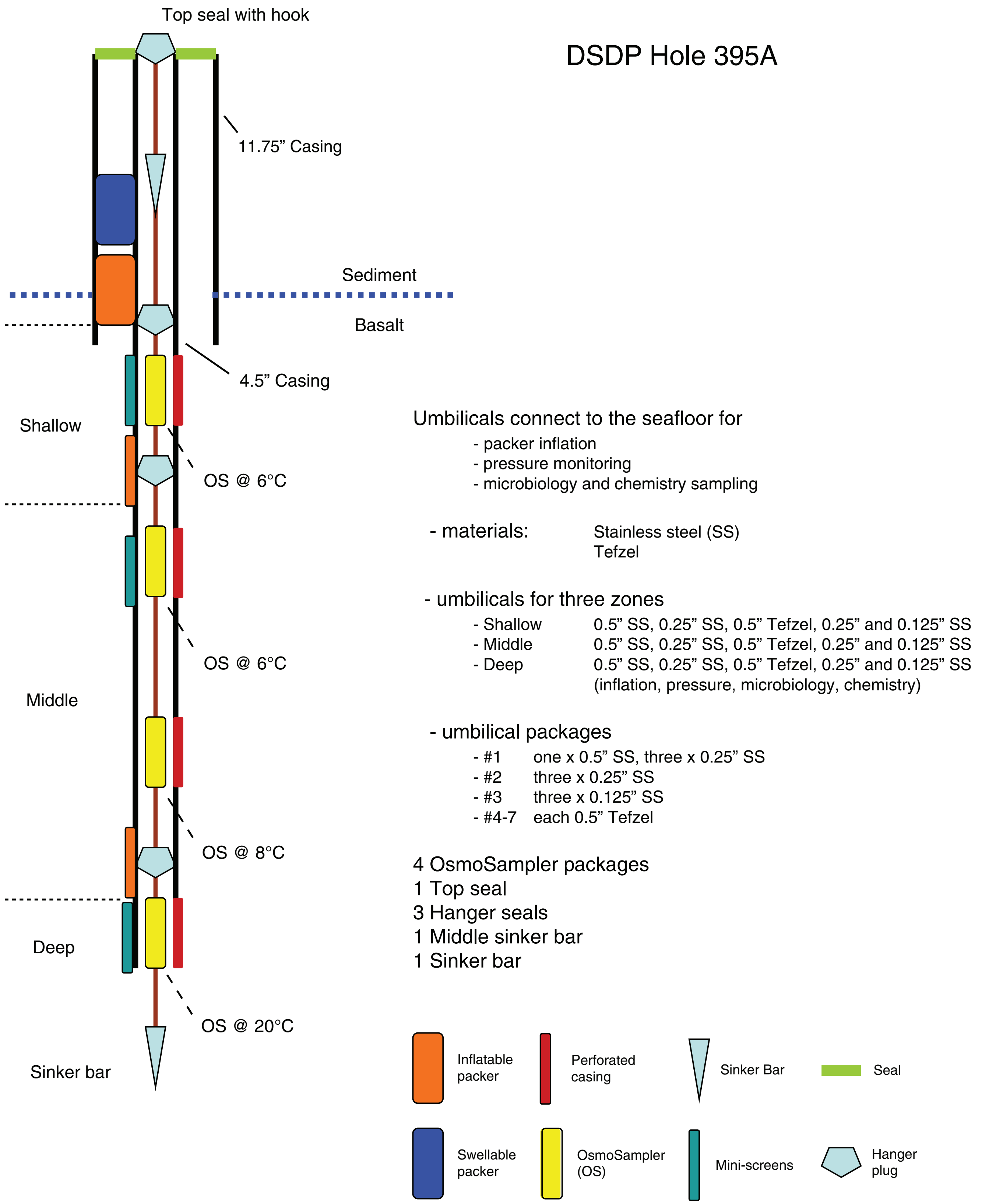


**Figure F6.** Schematic overview of the instrument and sensor downhole packages for Site NP-1 (deep hole).

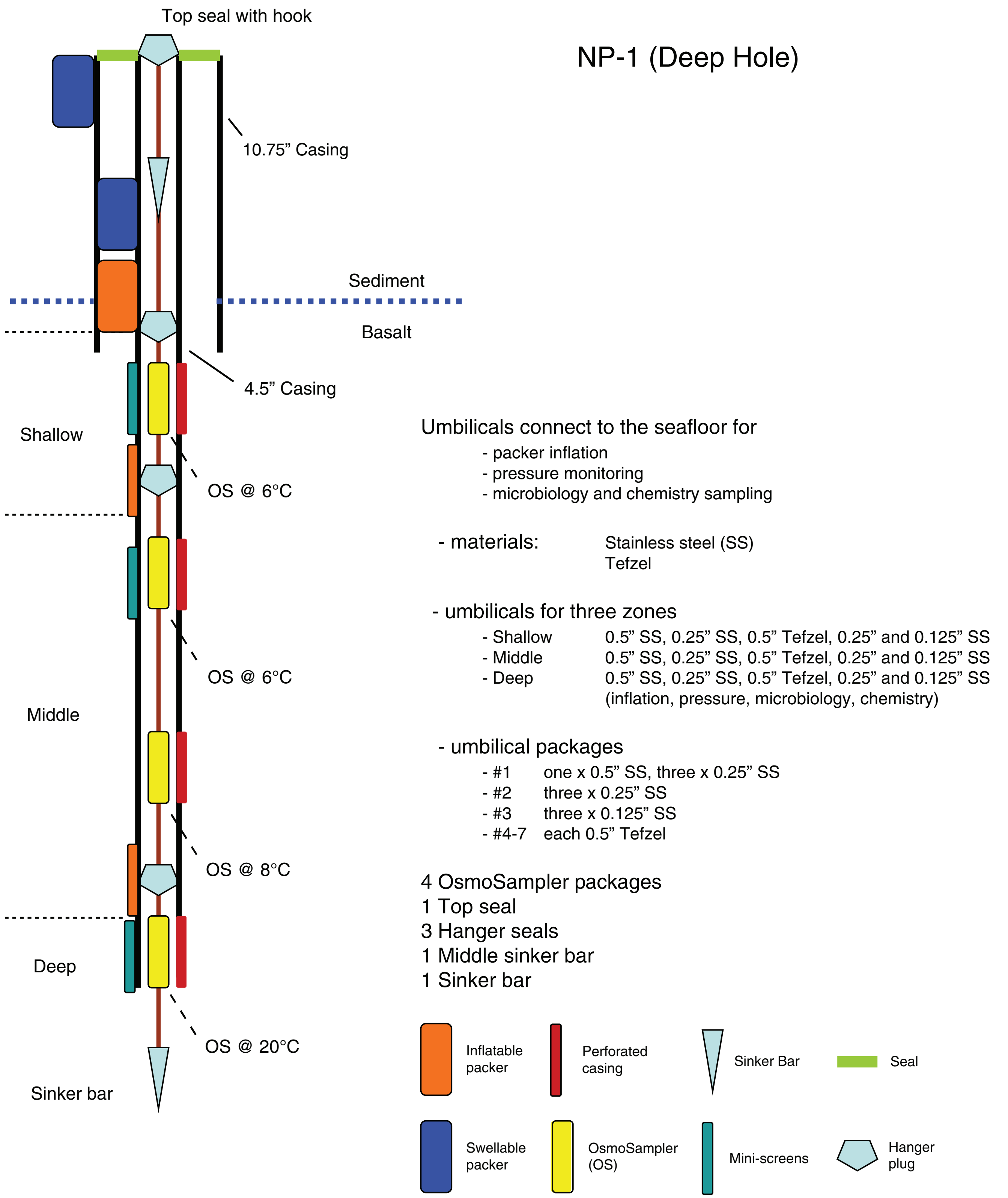


**Figure F7.** Schematic overview of the instrument and sensor downhole packages for Site NP-2 (shallow hole).

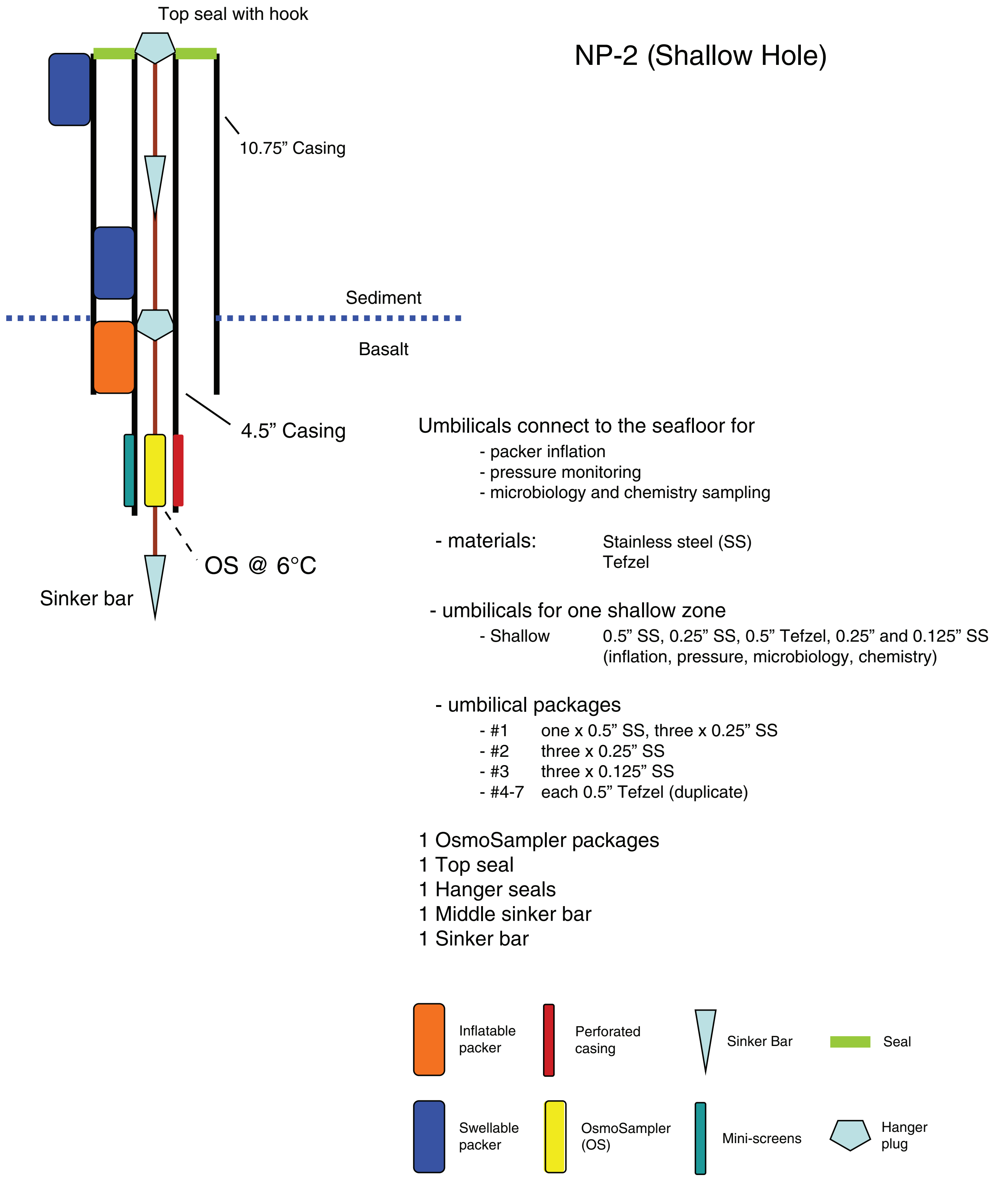


**Figure F8.** Schematic overview of the end of each planned CORK observatory at North Pond.

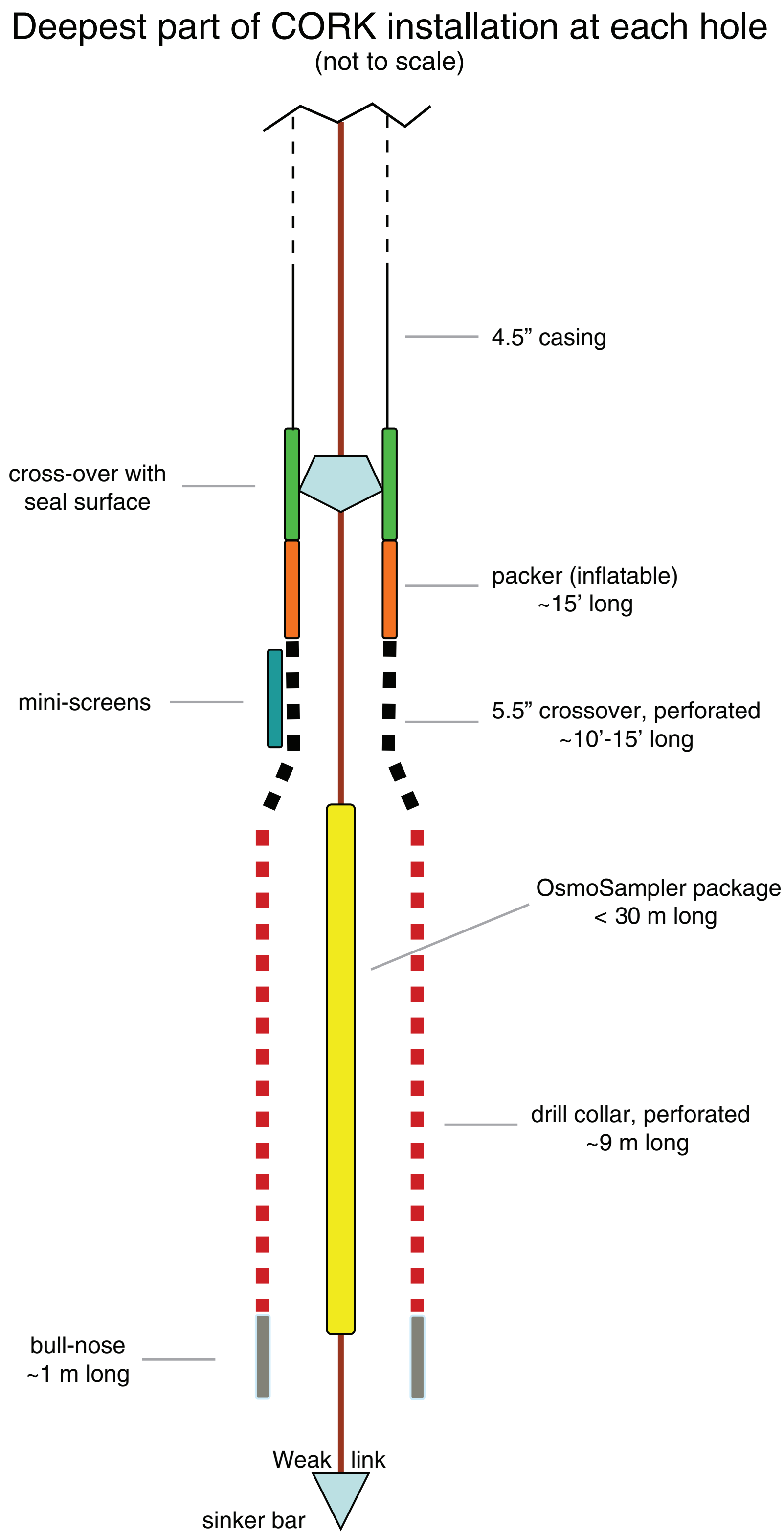
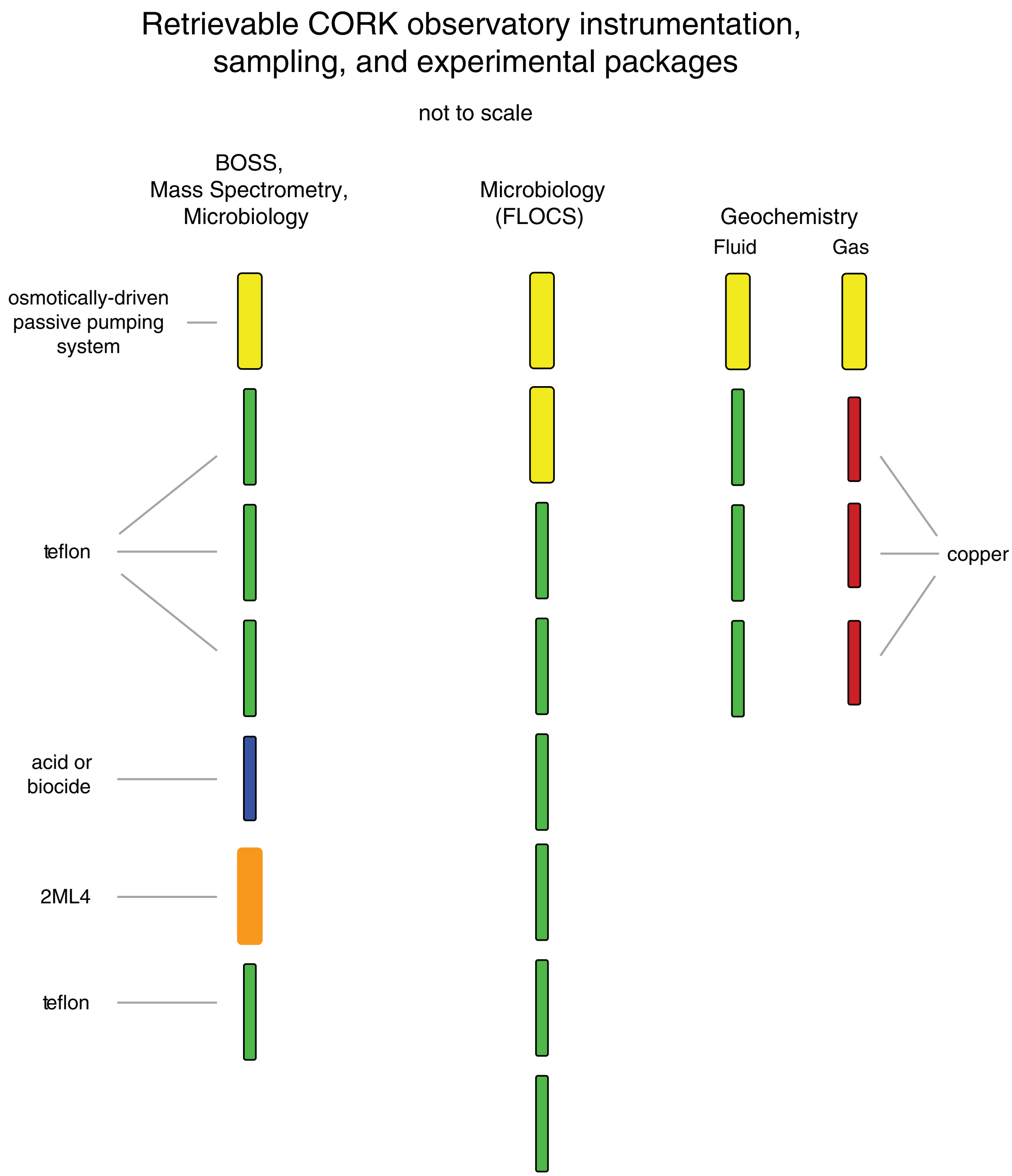


**Figure F9.** Schematic overview of retrievable CORK observatory instrumentation, sampling, and experimental packages to be deployed at each site during Expedition 336. The microbiology package is the Flow-through Osmo Colonization Systems (FLOCS) package (see Orcutt et al., 2010, and **www.darkenergybiosphere.org**). BOSS = BioOsmoSampling System (see **www.oeb.harvard.edu/faculty/girguis/BOSS/BOSS_index.html**). 2ML4 = osmotic membrane that pumps at a slower rate, thus diluting the sample with acid, biocide, or a microbial enrichment factor. Additional information about OsmoSamplers can be found in Jannasch et al. (2004) and at the Web sites above.



# Site summaries

## Site 1074

| | |
|---|---|
| **Priority:** | Primary |
| **Position:** | 22°46.8447′N, 46°6.7069′W |
| **Water depth (m below sea level):** | 4445 |
| **Target drilling depth (m below seafloor):** | 64 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS03, Shotpoint 2120<br>• Track map (Fig. **AF1**)<br>• Seismic profile (Fig. **AF2**) |
| **Objective(s):** | Recover sediment and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay, basalt |

# Site summaries (continued)

## Hole 395A

| | |
|---|---|
| **Priority:** | Primary |
| **Position:** | 22°45.3519′N, 46°4.8609′W |
| **Water depth (m below sea level):** | 4482.5 |
| **Target drilling depth (m below seafloor):** | 95 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS13, Shotpoint 810<br>• Track map (Fig. **AF1**)<br>• Seismic profile (Fig. **AF3**) |
| **Objective(s):** | 1. Core sediment and uppermost basement<br>2. Retrieve existing CORK from Hole 395A<br>3. Install new long-term borehole observatory (CORK) in Hole 395A |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | Temperature log of Hole 395A |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay, basalt |

# Site summaries (continued)

## Site NP-1

| | |
|---|---|
| **Priority:** | Primary |
| **Position:** | 22°48.7083′N, 46°5.3459′W |
| **Water depth (m below sea level):** | 4448 |
| **Target drilling depth (m below seafloor):** | 565 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS02, Shotpoint 1150<br>• Track map (Fig. **AF1**)<br>• Seismic profile (Fig. **AF4**) |
| **Objective(s):** | 1. Core sediments<br>2. Drill hole to ~500 m into basement, core lower half of hole<br>3. Install long-term borehole observatory (CORK) |
| **Drilling program:** | • APC/XCB to basement<br>• Drill/RCB core into basement<br>• Conduct wireline logging and drill string hydrologic (packer) experiments<br>• Install long-term borehole observatory (CORK) |
| **Logging program OR downhole measurements program:** | Full wireline logging program |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay, basalt |

# Site summaries (continued)

## Site NP-2

| | |
|---|---|
| **Priority:** | Primary |
| **Position:** | 22°48.1149′N, 46°3.1753′W |
| **Water depth (m below sea level):** | 4395 |
| **Target drilling depth (m below seafloor):** | 175 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS05, Shotpoint 3935<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF5**) |
| **Objective(s):** | 1. Core sediments (85 m) and uppermost basement (~90 m)<br>2. Install long term borehole observatory (CORK) |
| **Drilling program:** | • APC/XCB to basement<br>• RCB core into basement<br>• Conduct wireline logging and drill string hydrologic (packer) experiments<br>• Install long-term borehole observatory (CORK) |
| **Logging program OR downhole measurements program:** | Full wireline logging program |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay, basalt |

# Site summaries (continued)

## Site NP-3

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°45.2143′N, 46°7.2100′W |
| **Water depth (m below sea level):** | 4470 |
| **Target drilling depth (m below seafloor):** | 255 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS14, Shotpoint 1611<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF6**) |
| **Objective(s):** | Core sediments (255 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-4

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°44.4597′N, 46°7.2607′W |
| **Water depth (m below sea level):** | 4470 |
| **Target drilling depth (m below seafloor):** | 268 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS05, Shotpoint 3570<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF7**) |
| **Objective(s):** | Core sediments (268 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-5

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°46.0935′N, 46°5.8247′W |
| **Water depth (m below sea level):** | 4470 |
| **Target drilling depth (m below seafloor):** | 123 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS10, Shotpoint 7760<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF8**) |
| **Objective(s):** | Core sediments (123 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-6

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°45.0651′N, 46°5.3795′W |
| **Water depth (m below sea level):** | 4448 |
| **Target drilling depth (m below seafloor):** | 640 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS08, Shotpoint 6198<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF9**) |
| **Objective(s):** | Core sediments (140 m) and drill/core basement down to 640 mbsf |
| **Drilling program:** | • APC/XCB to basement<br>• RCB core to 640 mbsf<br>• Conduct wireline logging and drill string hydrologic (packer) experiments<br>• Install long-term borehole observatory (CORK) |
| **Logging program OR downhole measurements program:** | Full wireline logging program |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay, basalt |

# Site summaries (continued)

## Site NP-7

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°45.1449′N, 46°6.0619′W |
| **Water depth (m below sea level):** | 4470 |
| **Target drilling depth (m below seafloor):** | 213 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS09, Shotpoint 6895<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF10**) |
| **Objective(s):** | Core sediments (213 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-8

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°45.6069′N, 46°6.3677′W |
| **Water depth (m below sea level):** | 4472 |
| **Target drilling depth (m below seafloor):** | 187 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS10, Shotpoint 7810<br>• Track map (Fig. AF1)<br>• Seismic line (Fig. AF11) |
| **Objective(s):** | Core sediments (187 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-9

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°45.6267′N, 46°7.4521′W |
| **Water depth (m below sea level):** | 4472 |
| **Target drilling depth (m below seafloor):** | 255 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS11, Shotpoint 295<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF12**) |
| **Objective(s):** | Core sediments (255 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-10

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°47.3415′N, 46°5.5339′W |
| **Water depth (m below sea level):** | 4466 |
| **Target drilling depth (m below seafloor):** | 128 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS11, Shotpoint 470<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF12**) |
| **Objective(s):** | Core sediments (128 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-11

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°47.5683′N, 46°5.2789′W |
| **Water depth (m below sea level):** | 4463 |
| **Target drilling depth (m below seafloor):** | 55 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS11, Shotpoint 494<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF12**) |
| **Objective(s):** | Core sediments (55 m) and uppermost basement |
| **Drilling program:** | APC/XCB to basement |
| **Logging program OR downhole measurements program:** | None |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

# Site summaries (continued)

## Site NP-12

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°47.5370′N, 46°4.8250′W |
| **Water depth (m below sea level):** | 4455 |
| **Target drilling depth (m below seafloor):** | 555 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS03, Shotpoint 2300<br>• Track map (Fig. AF1)<br>• Seismic line (Fig. AF13) |
| **Objective(s):** | Core sediments (55 m) and drill/core uppermost basement to 555 mbsf |
| **Drilling program:** | • APC/XCB to basement<br>• RCB core to 555 mbsf<br>• Conduct wireline logging and drill string hydrologic (packer) experiments<br>• Install long-term borehole observatory (CORK) |
| **Logging program OR downhole measurements program:** | Full wireline logging program |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay, basalt |

# Site summaries (continued)

## Site NP-13

| | |
|---|---|
| **Priority:** | Secondary |
| **Position:** | 22°48.3597′N, 46°2.9089′W |
| **Water depth (m below sea level):** | 4470 |
| **Target drilling depth (m below seafloor):** | 160 |
| **Approved maximum penetration (mbsf):** | Pending IODP Environmental Protection and Safety Panel review |
| **Survey coverage (track map; seismic profile):** | SCS05, Shotpoint 3960<br>• Track map (Fig. **AF1**)<br>• Seismic line (Fig. **AF14**) |
| **Objective(s):** | Core sediments (55 m) and drill/core 105 m of basement |
| **Drilling program:** | • APC/XCB to basement<br>• RCB core to 160 mbsf<br>• Conduct wireline logging and drill string hydrologic (packer) experiments<br>• Install long-term borehole observatory (CORK) |
| **Logging program OR downhole measurements program:** | Full wireline logging program |
| **Nature of rock anticipated:** | Foraminiferal ooze and sand, clay |

**Figure AF1.** Bathymetric map with southwest–northeast trending seismic Lines 1–11 and crossing Lines 12–14. Shot points are labeled in small blue fonts, and proposed drill sites are marked in red (primary sites) and green (secondary sites).

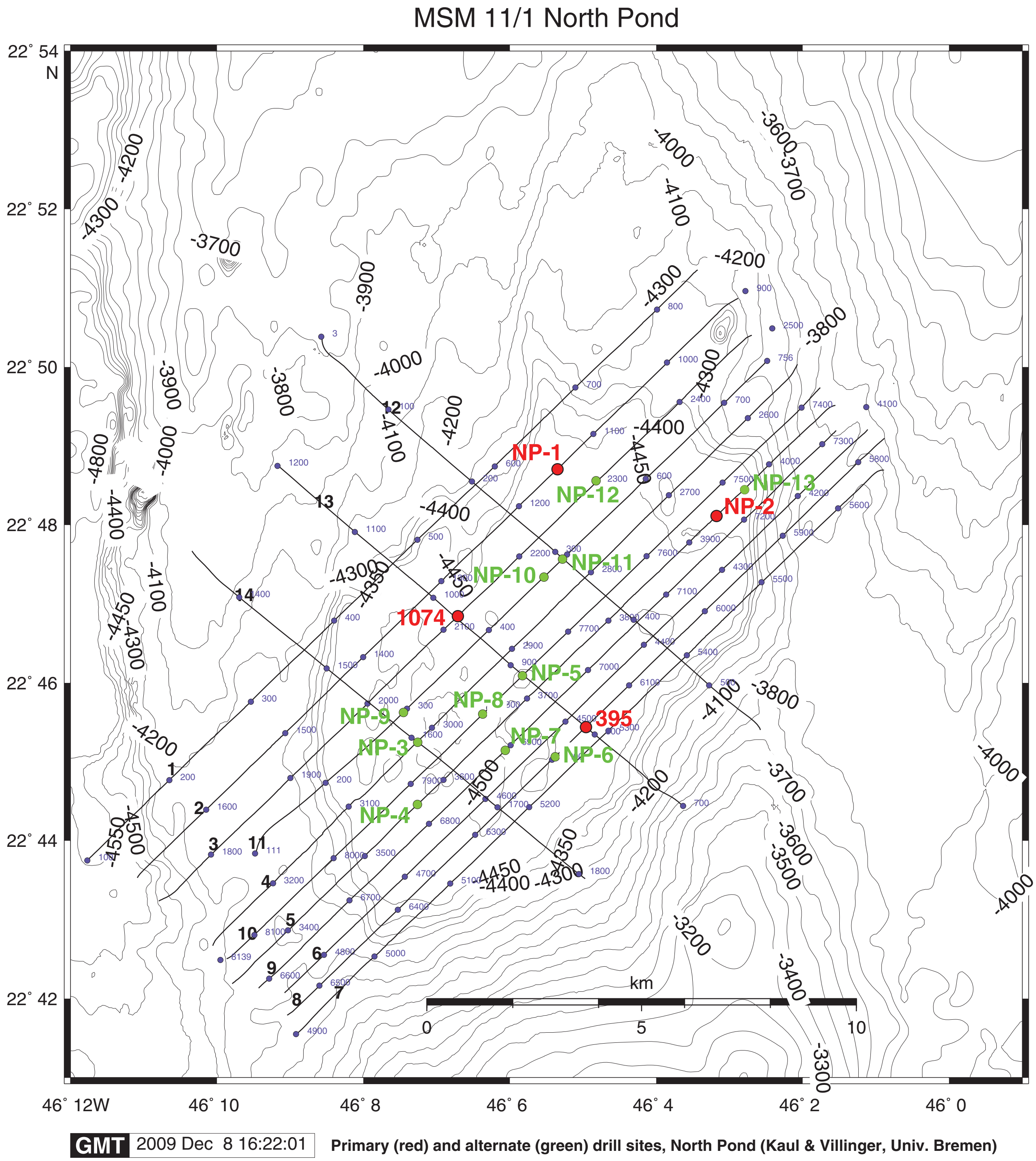


**Figure AF2.** Seismic profile along Line 3 (see track map in Fig. AF1) showing the location of Site 1074. Sediment thickness is 70 m.

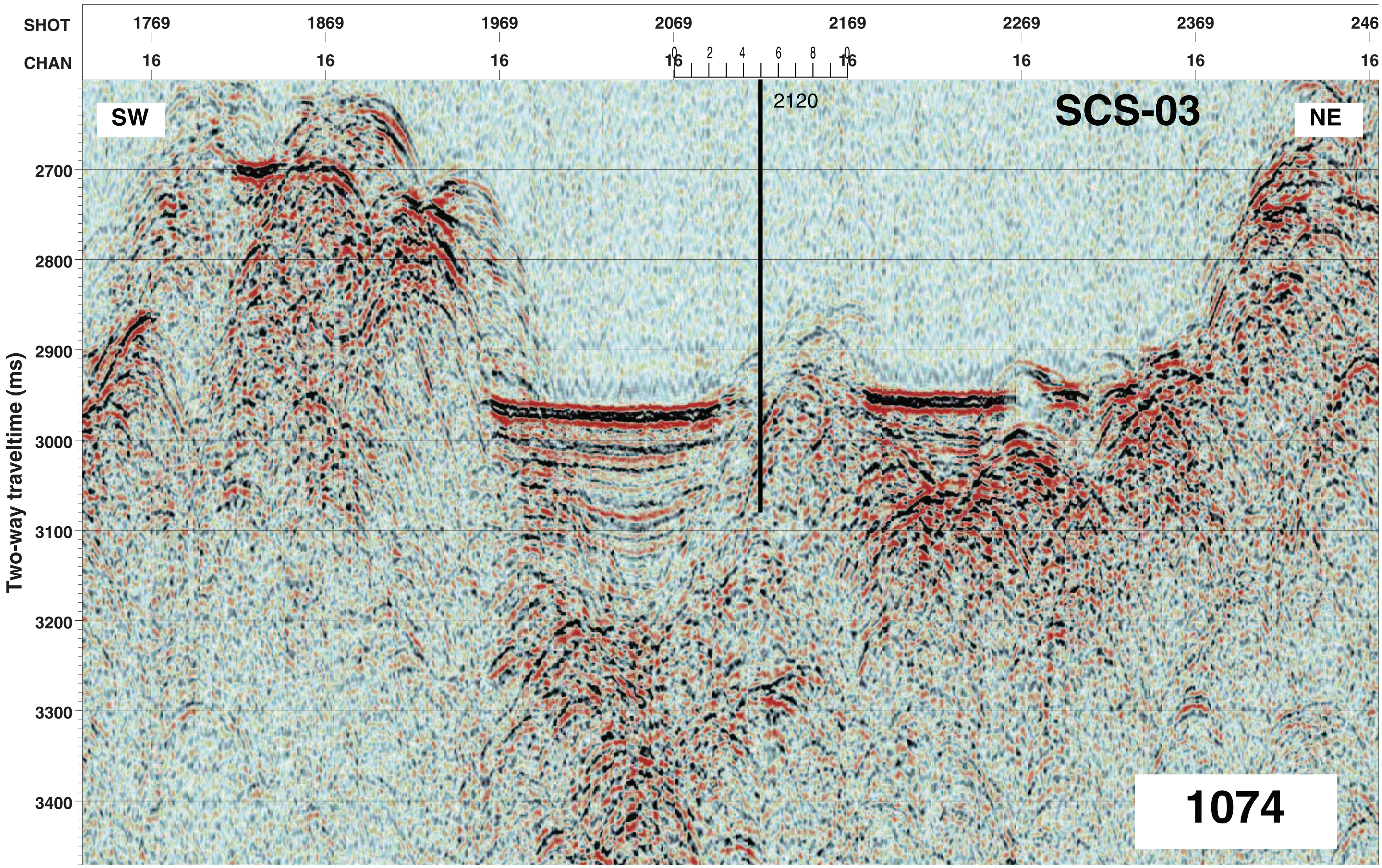


**Figure AF3.** Seismic profile along Line 13 (see track map in Fig. AF1) showing the location of Site 395. Sediment thickness is 93 m.

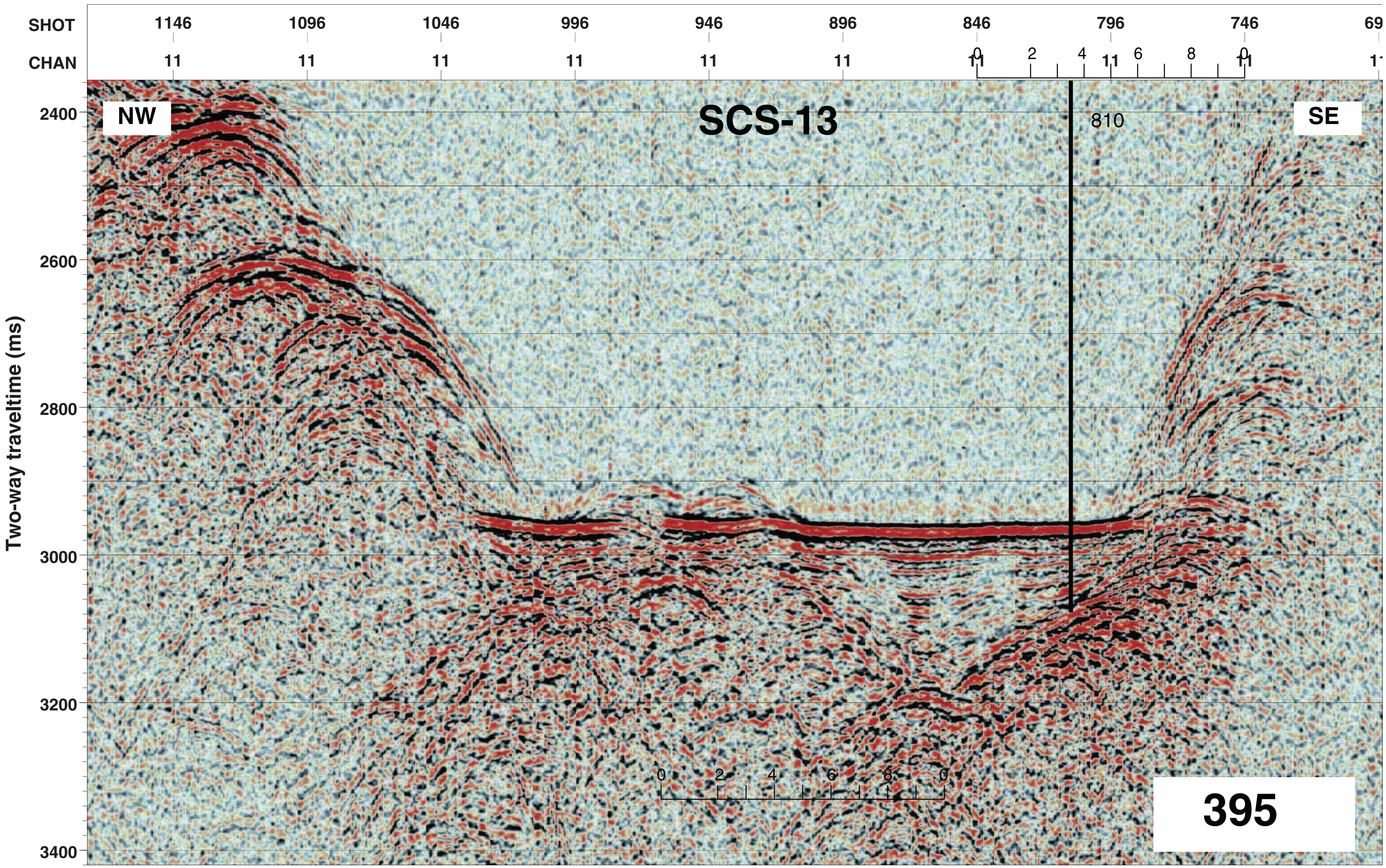


**Figure AF4.** Seismic profile along Line 2 (see track map in Fig. AF1) showing the location of Site NP-1. Sediment thickness is 60 m.

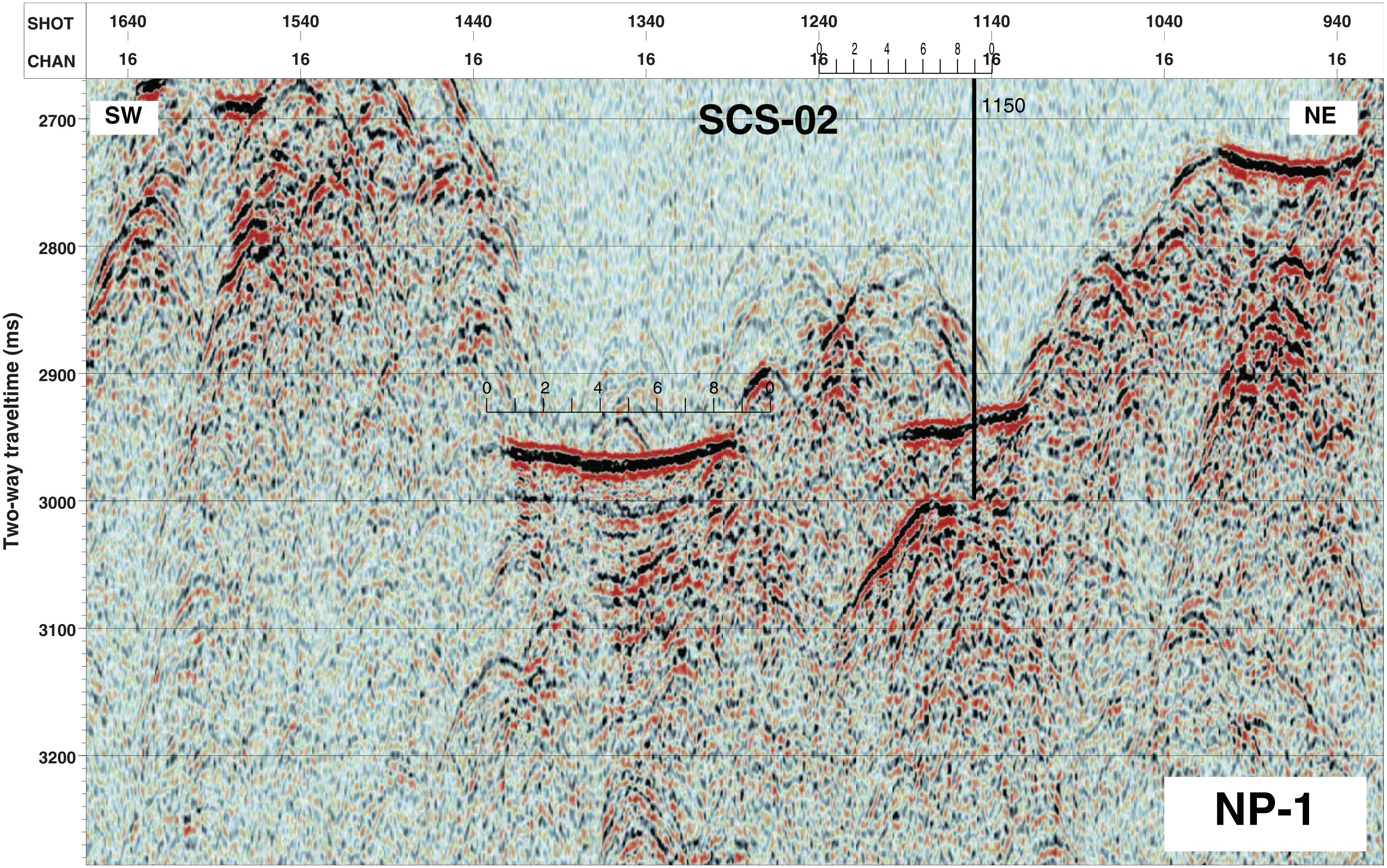


**Figure AF5.** Seismic profile along Line 5 (see track map in Fig. **AF1**) showing the location of Site NP-2. Sediment thickness is 85 m.

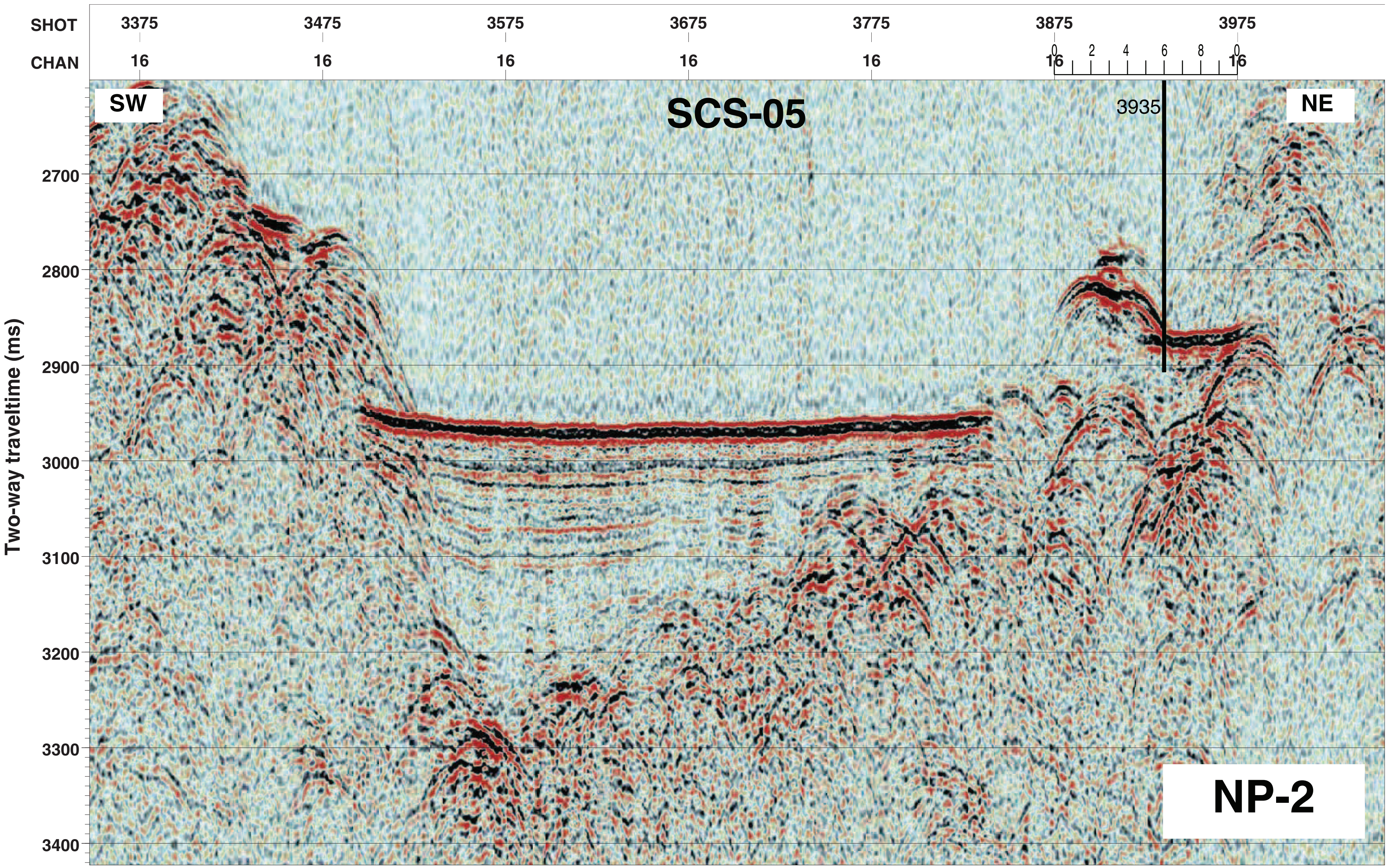


**Figure AF6.** Seismic profile along Line 14 (see track map in Fig. **AF1**) showing the location of Site NP-3. Sediment thickness is 255 m.

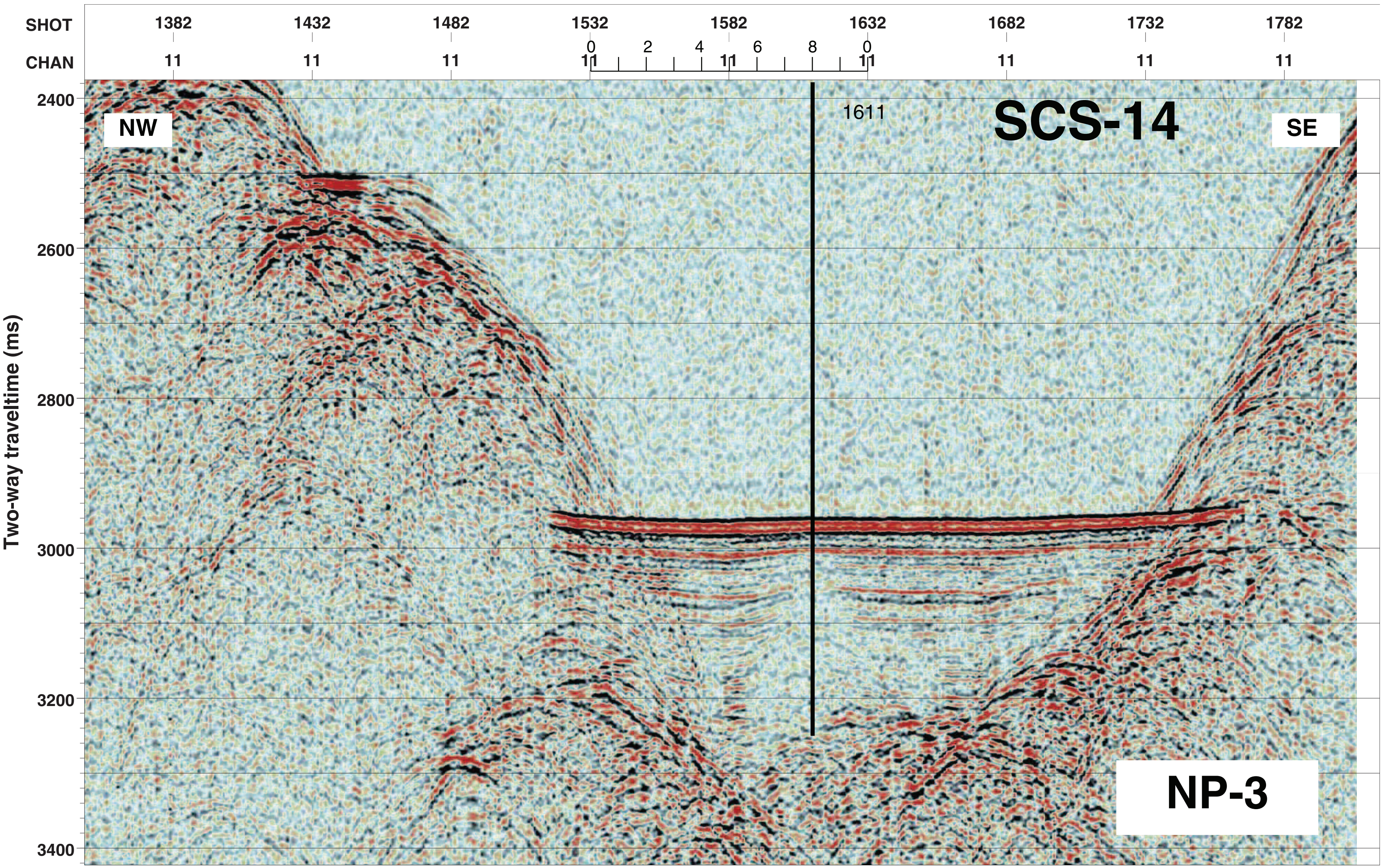


**Figure AF7.** Seismic profile along Line 5 (see track map in Fig. AF1) showing the location of Site NP-4. Sediment thickness is 268 m.

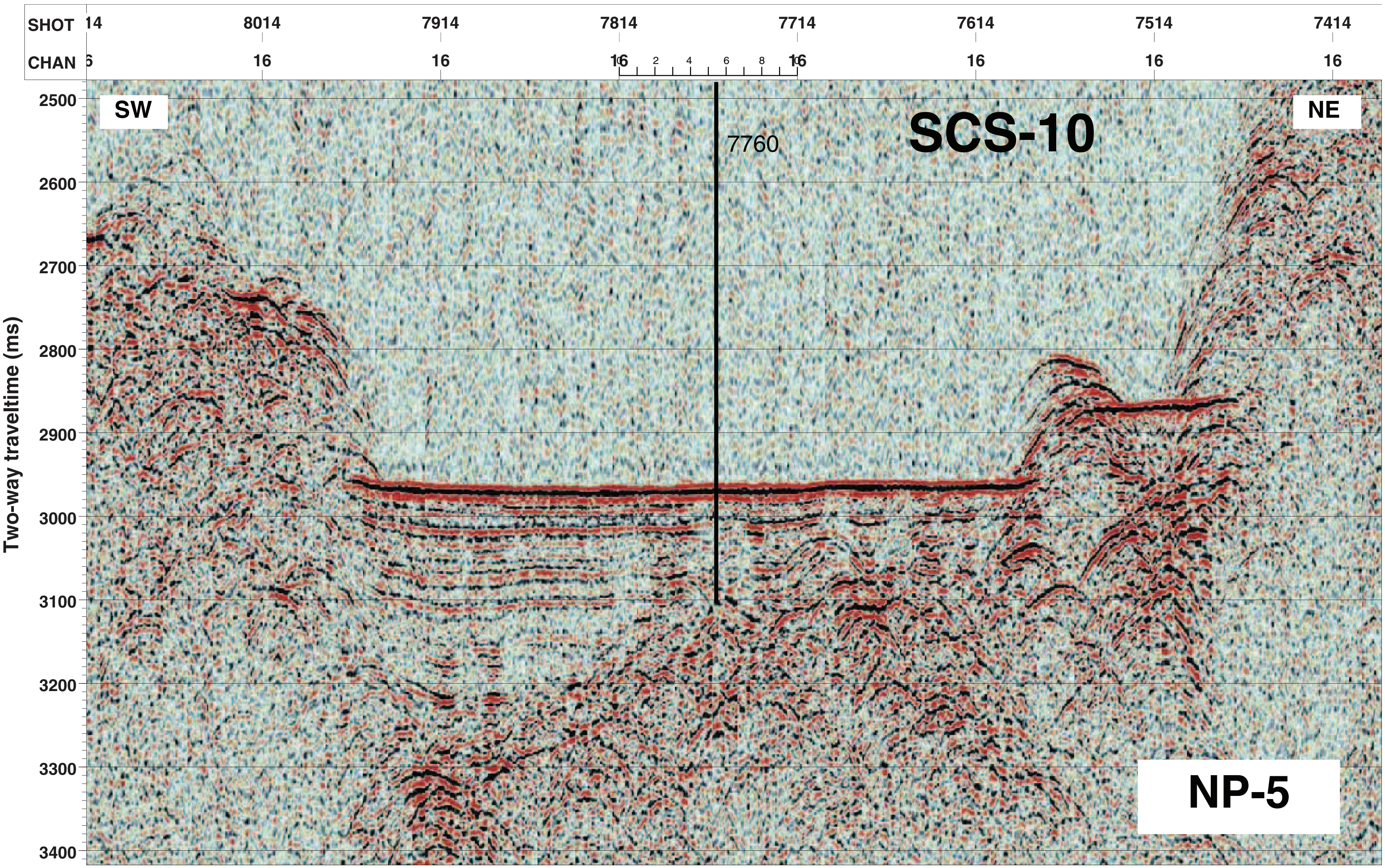


**Figure AF8.** Seismic profile along Line 10 (see track map in Fig. AF1) showing the location of Site NP-5. Sediment thickness is 123 m.

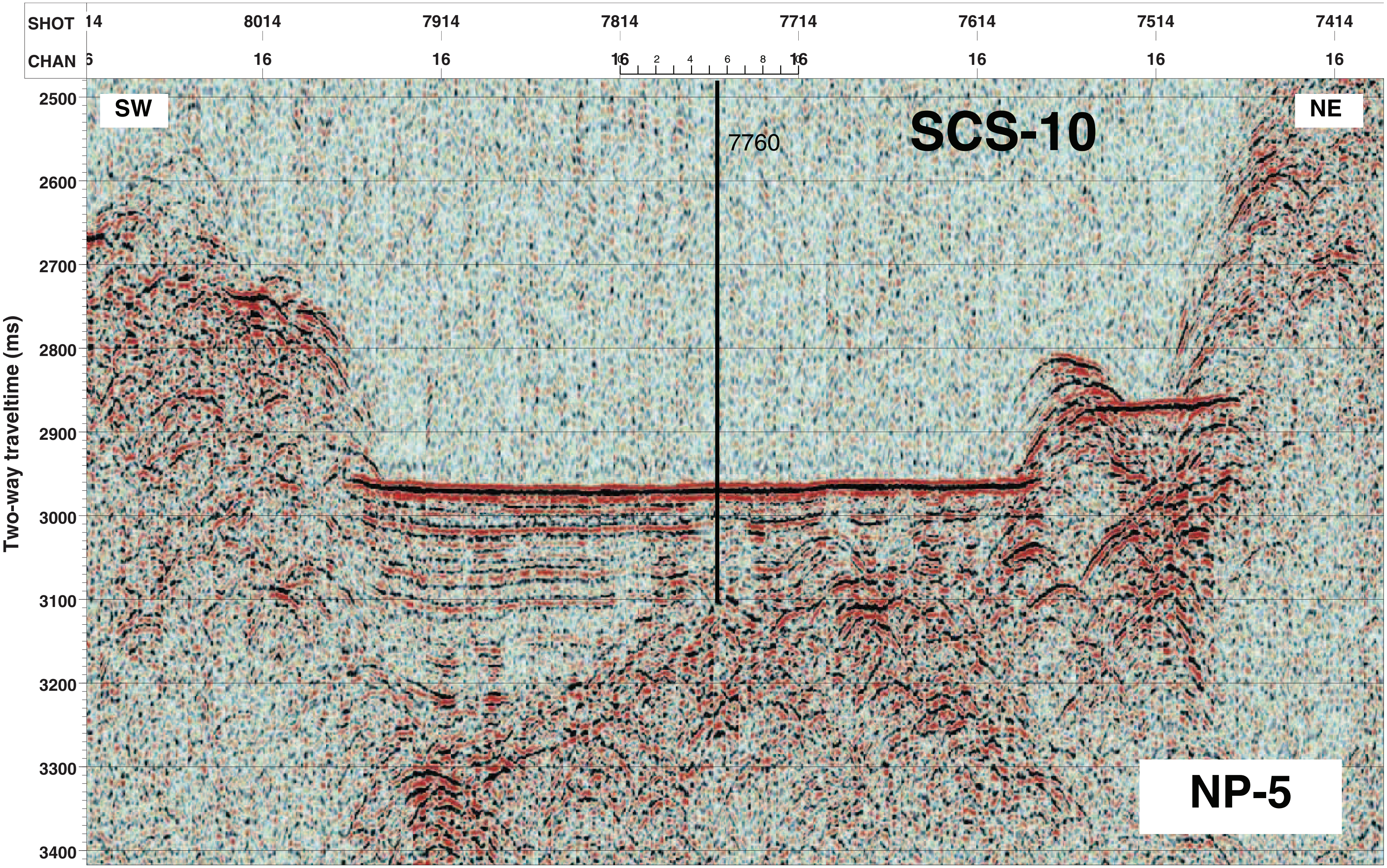


**Figure AF9.** Seismic profile along Line 8 (see track map in Fig. AF1) showing the location of Site NP-6. Sediment thickness is 140 m.

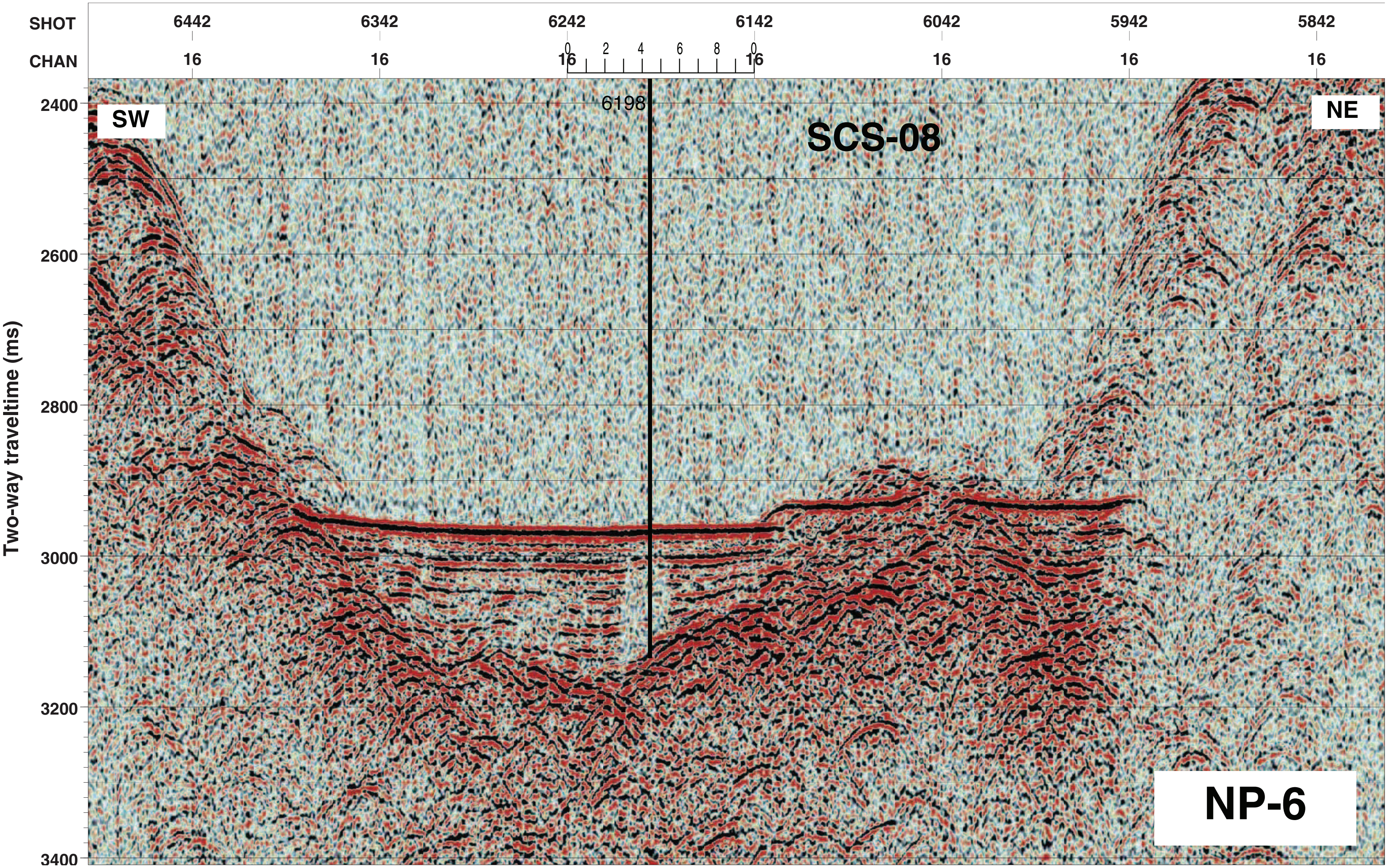


**Figure AF10.** Seismic profile along Line 9 (see track map in Fig. AF1) showing the location of Site NP-7. Sediment thickness is 213 m.

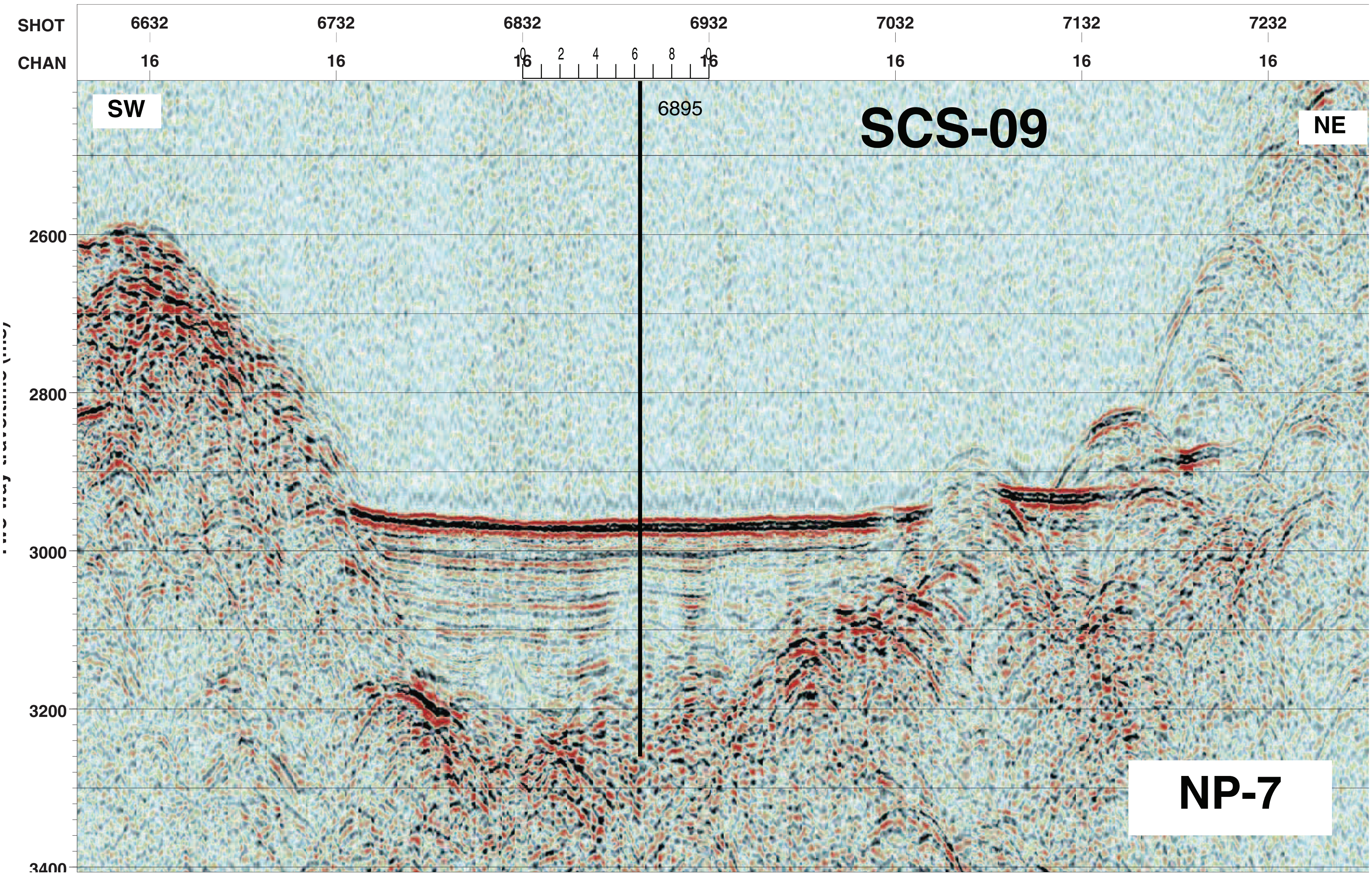


**Figure AF11.** Seismic profile along Line 10 (see track map in Fig. AF1) showing the location of Site NP-8. Sediment thickness is 187 m.

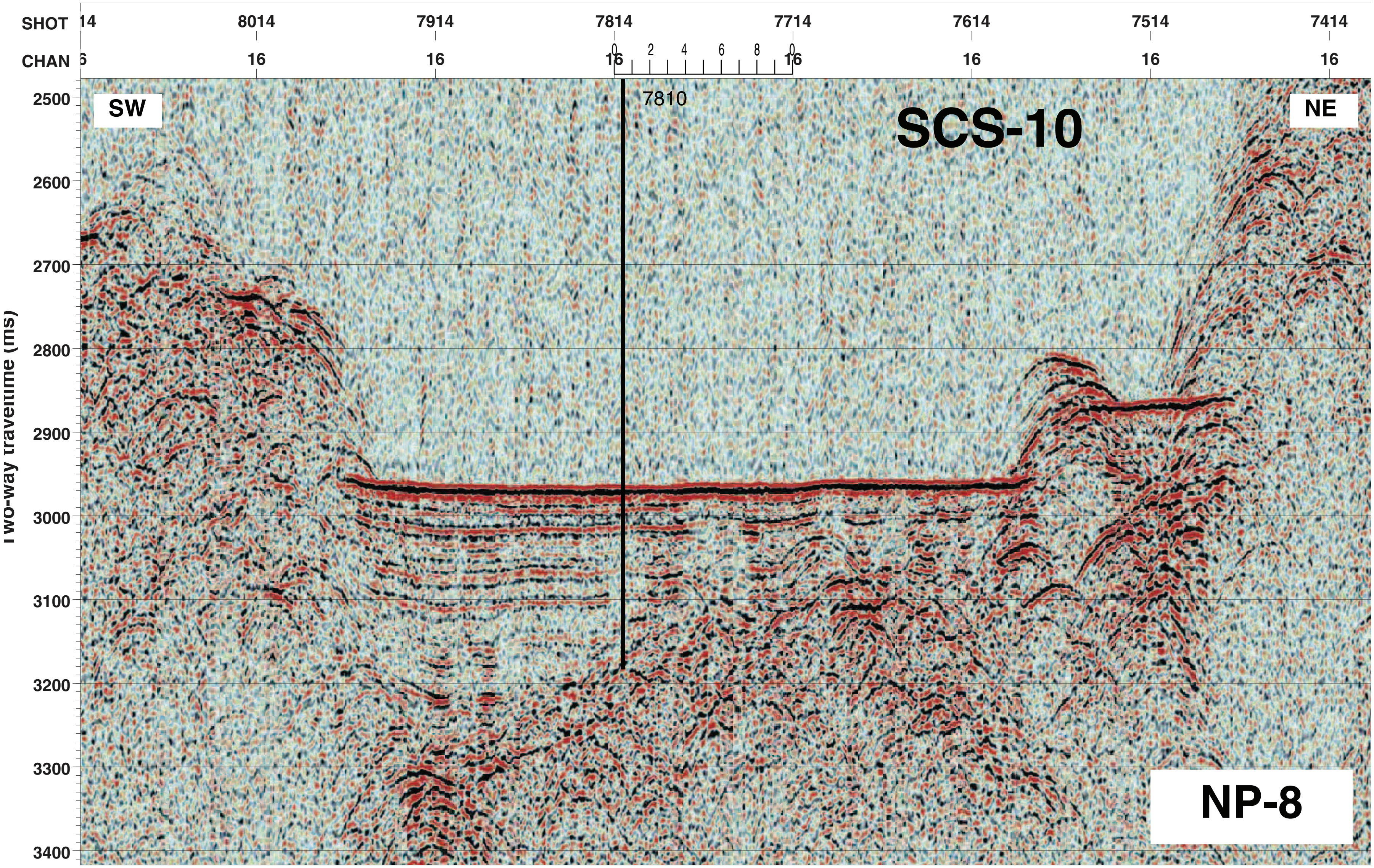


**Figure AF12.** Seismic profile along Line 11 (see track map in Fig. AF1) showing the locations of Sites NP-9, NP-10, and NP-11. Sediment thicknesses are 255, 128, and 55 m, respectively.

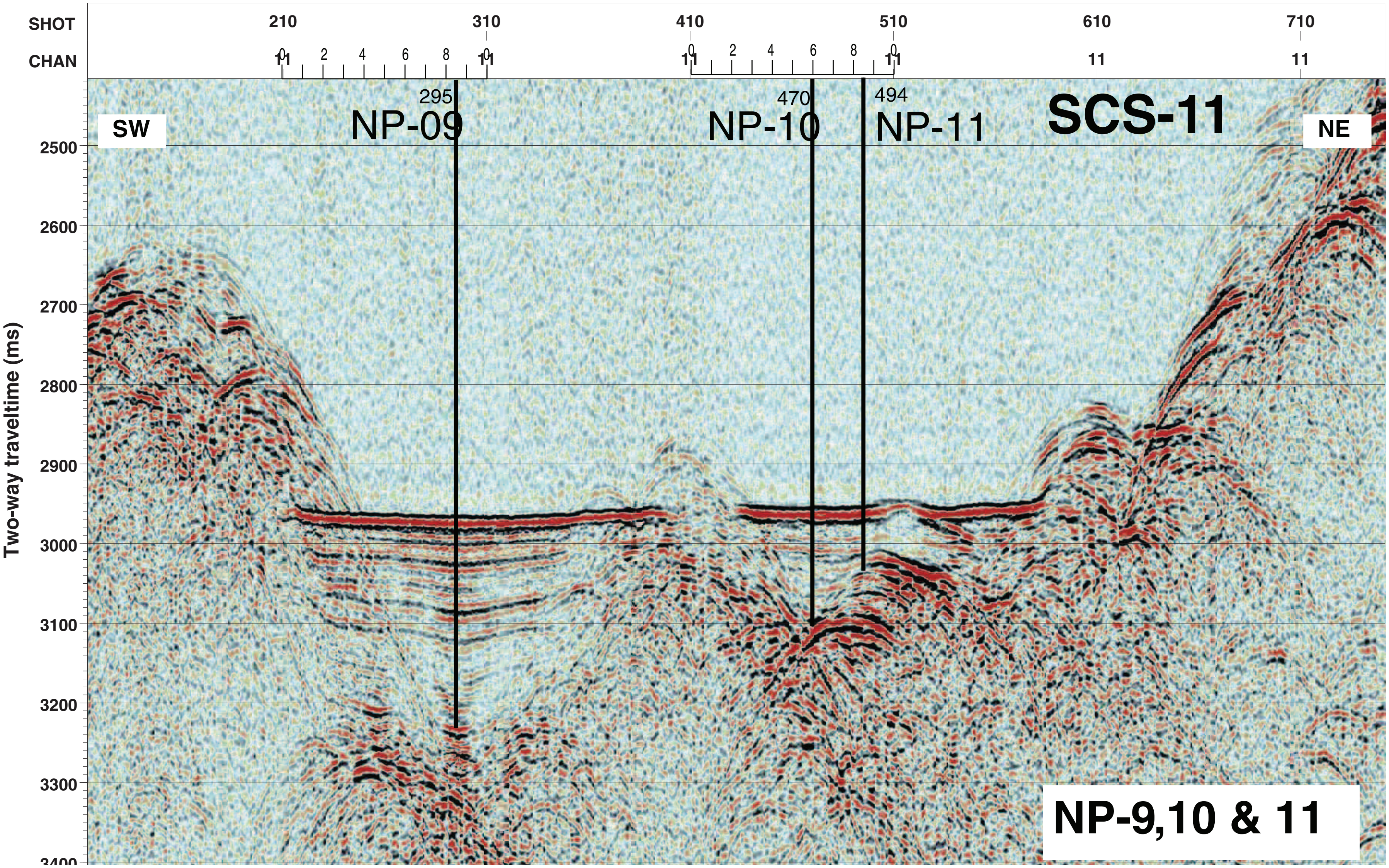


**Figure AF13.** Seismic profile along Line 3 (see track map in Fig. AF1) showing the location of Site NP-12 (NP-1 alternate). Sediment thickness is 55 m.

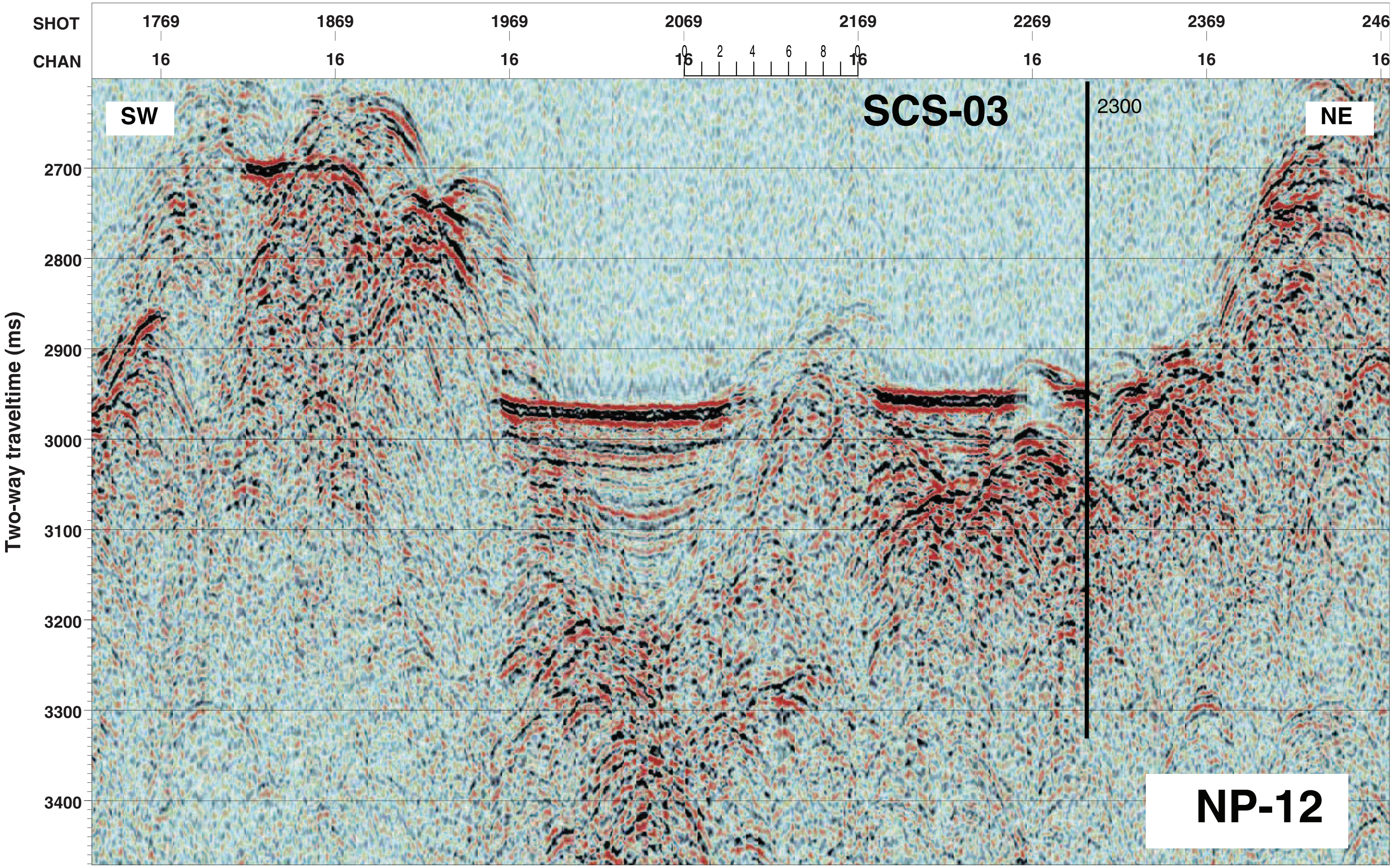
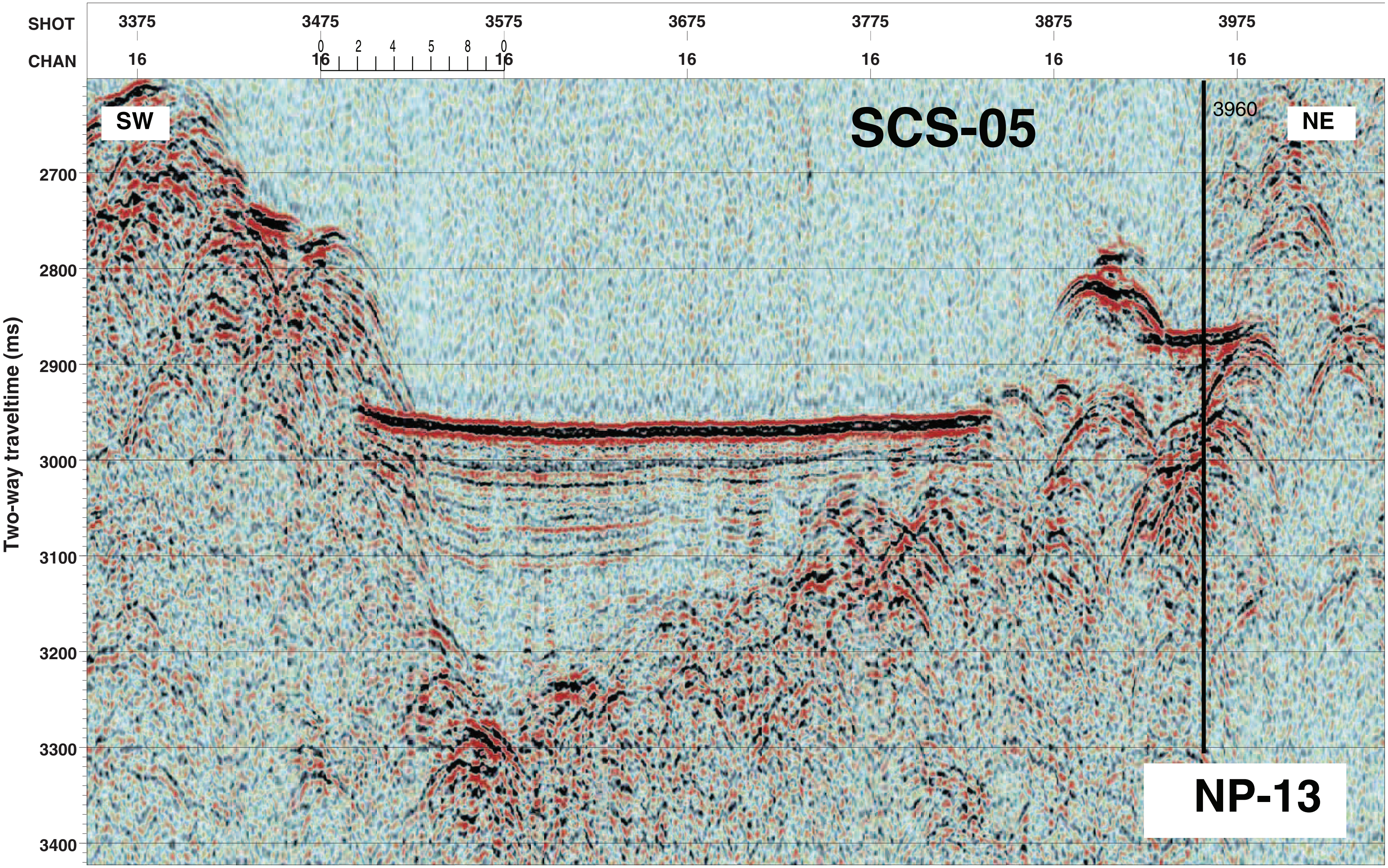


**Figure AF14.** Seismic profile along Line 5 (see track map in Fig. AF1) showing the location of Site NP-13 (NP-2 alternate). Sediment thickness is 55 m.



# Expedition scientists and scientific participants

The current list of participants for Expedition 336 can be found at **iodp.tamu.edu/sciencеops/precruise/marmicrobio/participants.html.**