HOLE 491

Date occupied: 13 April 1979
Date departed: 20 April 1979
Time on hole: 182.1 hours
Position: 16°01.74′N; 98°58.33′W
Water depth (sea level; corrected m, echo-sounding): 2883
Water depth (rig floor; corrected m, echo-sounding): 2893
Bottom felt (m, drill pipe): 2870.0
Penetration (m): 542.0
Number of cores: 59
Total length of cored section (m): 542.0
Total core recovered (m): 388.0
Core recovery (%): 72
Oldest sediment cored:
   Depth sub-bottom (m): 542
   Nature: Muddy silstone and sand
   Age: Early Pliocene

Principal results: At Site 491 we penetrated 542 meters and recovered 59 cores that comprise three lithologic units (Table 1, Fig. 1). Unit 1 extends from 0 to 57.5 meters and consists of upper Pliocene to upper Quaternary mud. Unit 2 (57.5-437.5 m) is lower Pliocene muddy silt with minor fine sand layers. Unit 3 extends from 437.5 to 542 meters and is composed of lower Pliocene muddy silt and silstone with interbedded fine to coarse pebbly sand.

Tilted beds and fracturing first occur at about 120 meters and continue the total depth through the lower two lithologic units. In Unit 2 dips are variable and range to nearly vertical; fracturing is present throughout, though slickensides are rare. Dip angles in Unit 3 range up to 30° and are more uniform than in Unit 2. Fracturing and slickensides are more abundant in Unit 3 than in Unit 2, and a strong fissility develops locally. Paleomagnetic restorations of bedding in both Units 2 and 3 indicate modal dip directions to the north, with considerable scatter.

Unit 3 and much of Unit 2 probably accumulated in a trench and/or lower slope environment. Deformation of these sediments occurred shortly after deposition and prior to being uplifted to the present mid-slope position.

BACKGROUND AND OBJECTIVES

Site 491 is located on the inner slope of the Middle America Trench at 16°01.74′N, 98°58.33′W in about 2.9 km of water (Fig. 2). The site lies about 2.1 km above and 14.25 km north-northeast of the adjacent trench floor on a steep average slope of about 9°. The multichannel seismic reflection profile adjacent to the site (Fig. 3) shows a thin slope blanket overlying a series of landward-dipping reflectors that are cut by a bottom-simulating reflector at about 0.75 s below the mudline.

Outcrops of a Mesozoic to Precambrian crystalline basement complex and a Mesozoic magmatic arc, anomalously close to the modern trench, argue for tectonic truncation of the Pacific margin off southern Mexico during the late Cretaceous or Paleogene (Karig et al., 1978). Results from Sites 489 and 490 demonstrate that the seaward margin of the basement complex extends to within 30 to 35 km of the trench. Seaward of the basement complex, the lower trench slope may be underlain by pelagic, hemipelagic, and trench sediments accreted during Neogene convergence in the Middle America Trench. A fundamental goal at Site 491 is to date any accreted deposits and compare their ages to similar sediment at Site 488 downslope and Site 492 upslope. If the simple accretionary model holds, then any class of offscraped sediments should increase in age landward.

An imbricate stack of landward-dipping thrust faults constitutes one of the most popular structural models of accretion for the lower trench slope (e.g., Karig, 1974; Seely et al., 1974). The data supporting this model consist primarily of landward-dipping reflectors, which are exceptionally well shown in the seismic reflection line through Site 491 (Fig. 2). Packages of reflectors with slightly discordant contacts are interpreted bedded sedimentary sequences separated by thrust faults (Seely et al., 1974). Alternatively, some of the dipping reflectors beneath trench slopes may represent faults. Because none of the previous drilling at active margins has established the origin of landward-dipping reflectors, a prime objective at Site 491 is to penetrate these surfaces and determine whether they represent faults, tilted bed surfaces, or some other phenomena.

A prominent bottom-simulating reflector occurs beneath the lower slope on the multichannel seismic reflection profile adjacent to the site (Fig. 2) as well as on other reflection profiles in the site survey area (Shipley, this volume). Comparable bottom-simulating reflectors have been observed offshore northern Panama and Columbia and along the Middle America Trench margin between

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1 Initial Reports of the Deep Sea Drilling Project, Volume 66.
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Panama and Mexico (Shipley et al., 1979). These data all show increasing depth of the reflection with increasing water depth. They have high-amplitude reflections generally showing a reflection phase reversal and occurring at pressures and temperatures approximating the methane/hydrate, gas/solid phase boundary. Limited reflection amplitude and phase studies by Shipley et al. (1979), though restricted to areas where the seafloor is horizontal, suggest that the BSR along the Oaxaca-Guerrero transect may be a gas hydrate. However, 5° by 5° averages of thermal gradients (Langseth and Von Herzen, 1970) in the case of Mexico put the BSR well into hydrate stability field and not at the phase boundary. The bottom-simulating reflector may also represent a diagenetically induced mineral transition (e.g., Hein et al., 1978). In view of the uncertainty regarding the origin of the bottom-simulating reflector, we proposed to sample the sediments above it with a pressure core barrel to test for the presence of hydrate.

**OPERATIONS**

The *Glomar Challenger* steamed 9¾ nautical miles southeast from Site 490 to Site 491 in 2.25 hours. After dropping the beacon and lowering the pipe, we offset 850 meters to the north—southwest to attempt to locate on the multichannel reflection profile Line MX-16. Hole 491 was spudded at 0120 hours, 14 April and a completely full core obtained after the bit had been lowered to 2880 meters. One joint of pipe was set back, and a “punch core” extending to 2870.5 meters was attempted without recovery. Water depth was set at 2870 meters, 13 meters shallower than PDR depth. The pressure core barrel was utilized in two unsuccessful attempts to recover cores under pressure in hopes of capturing gas hydrates. Otherwise, coring proceeded smoothly through a long and monotonous section of muddy silts and siltstones. Because of use of a special core bit with the pressure core barrel, the core diameter was somewhat reduced. Recovery was excellent and no hole problems were encountered, even in the lower 70 to 80 meters of loose, coarse sand. We terminated coring at 542 meters below the seafloor because of scheduling considerations.

We made 15-stand wiper trip to clear the hole to total depth. Unfortunately, the bit did not release, which precluded logging. The hole was filled with barite-weighted mud and the drill string recovered.

**LITHOLOGIC SUMMARY**

Site 491 is located midslope in a water depth of 2877 meters. Drilling penetrated 542 meters of early Pliocene to upper Quaternary argillaceous to sandy sediments. On the basis of the sedimentary characteristics, three units can be distinguished (Fig. 4, Chart 1, back pocket).

*Unit I, upper Pliocene to upper Quaternary* (Cores 1-7, 0-67.0 m sub-bottom depth), consists mainly of grayish olive green (5GY 3/2) mud and muddy silt with minor thin lenses (1 mm–2 cm) of ash (Core 1, 4, 6) and calcareous concentrations (up to 6 cm, Cores 3–7). Sponge spicules (1–2 mm) and pyrite nodules are also present. The gas content of the sediment is high enough to produce numerous expansion cracks. Bedding has not been observed, and fracturing is not apparent.

*Unit 2, lower Pliocene* (Cores 8–48, 67.0–437.5 m sub-bottom depth), is grayish olive green muddy silt locally indurated into muddy siltstone. Minor thin, fine-
grained sand layers occur irregularly throughout the section (Figs. 5 and 6). The thickness of the sands is generally from 1 mm to 2 cm but ranges locally to 10 cm. Various normal graded sand layers have been observed, which indicate upright bedding. Also, disseminated in the muddy silt are ash beds or lenses (top of the unit, Cores 8 and 16), pyrite nodules, and calcareous concentrations (Cores 28–31). The size ranges for ash, pyrite, and calcareous concentrations are the same as for Unit 1. Gas expansion cracks are also common in Unit 2 down to Core 17. Low temperatures (1°C and 1.5°C) and gas bubbling were encountered in Core 19 at about 170 meters.

Bedding is manifested in this unit by thin, silty laminations and fine sand layers. The dips average 20° and range from 0° to 85° (mostly apparent dips); in individual cores variation is generally high. The variable dips with the presence of probable slump folds can be partly explained by original synsedimentary disturbance prior to tectonic deformation. Fracturing is present throughout the unit; however, slickensides are rare. Normal faults offsetting drilling laminations are clearly due to
drilling disturbance and complicate analysis of the fractures. Nevertheless some fractures seem to be essentially tectonic features—for example, the normal faults in Cores 15, 48, 14, 15, 33, and 37 and reverse faults in Cores 22 and 43.

Unit 3, early Pliocene (Cores 49–59, 437.5–542 m sub-bottom depth), consists of muddy silt to muddy siltstone interbedded with fine to coarse pebbly sand. The thickness of the sandy layers ranges from a few centimeters up to 40 cm in Core 50. Sand is the dominant lithology in Cores 52 and 53 and probably accounts for the poor recovery in this interval (Fig. 7). Normal graded sandy beds were observed in Cores 49, 58, and 59, indicating lack of overturning. A worm cast in Core 54 also suggests upright bedding.

Structural deformation exists also in Unit 3 but is obscured by both drilling disturbance and relative abundance of sand. Nevertheless, the bedding has a mean value of 15°, ranging from 4° to 31° (mostly apparent dips); dips seem to be more uniform in individual cores than was the case in Unit 2. Fracturing and slickensides are more abundant than in Unit 2. Drilling faults are also present but account for only a small fraction of the deformation. A normal fault appears in Core 37.

Conclusions

Sedimentologic Data

The sedimentary sequence of Site 491 is very similar to that of Site 488, with the mean grain size increasing downhole, from mud through muddy silt, to coarse pebbly sand. However, the sediments at Site 488 are Quaternary, whereas those at Site 491 are mainly Pliocene. In this terrigenous sequence a genetic distinction can be made between the sands at the base (Unit 3) and the overlying muddy silt/mud (Units 1 and 2), as was determined for Site 488. Much of the interpretive discussion for site conclusions applies here. The sedimentologic arguments alone do not allow us to assign the sandy unit (Unit 3) with certainty to a former lower Pliocene trench environment; such coarse clastic sediments could have been deposited for example in a slope basin or channel cutting the slope. Definitive sedimentologic proof of origin of the sands as trench deposits would be the oc-
currence of pelagic clay lower in the sequence. Alternatively, we might expect to obtain an approximate paleodepth for the sandy unit of Site 491 from the microfossils below Core 4 (2 Ma ~ Pleistocene/Pliocene boundary): planktonic foraminifers disappear and nannofossils are much less abundant; this probably indicates passage through the CCD (at approximately 3200 m) at this time. Lower in the sequence, in Core 27, a trace fossil assemblage suggests a depth of 4 km or greater (see Paleobathymetry and Vertical Tectonics), which favors deposition either in the trench or in a lowermost basin or channel.

**Structural Data**

Bedding dips of more than 10° and true tectonic fractures appear in Core 14, at about 120 meters in Unit 2 (lower to upper Pliocene). At greater depth, deformation becomes more intense. Variation in bedding dip in Unit 2 is probably due to synsedimentary disturbance before tectonic deformation. No unconformity (or disconformity) indicating the superposition of two different deformed units has been observed in this sequence. On the contrary, the increase of fracturing density is progressive; moreover, the first deformation appears about 300 meters above the top of coarse pebbly sands of Unit 3, in the so-called “slope apron deposits” (muddy silt of Unit 2). As for Site 488, we detected no tectonic repetition by paleontologic data in the whole drilled sequence.

**BIOSTRATIGRAPHY**

Site 491 penetrated a midslope lower Pliocene through Quaternary sedimentary section of sand and hemipelagic mud (Fig. 1). Calcareous fossils are partially or completely dissolved below Core 4 (40 m), but radiolarian and diatom preservation is generally good throughout. Reworked lower Miocene, upper Miocene, and Pliocene microfossils occur throughout the section, commonly in upper Pliocene and Quaternary sediments.

**Radiolarians**

Moderate to well-preserved radiolarians occur in nearly all cores from Site 491, although abundance varies markedly. Radiolarians are abundant and well preserved in Cores 1 to 9 but rare and poorly preserved in Cores 10 to 59, hampering biostratigraphic dating. This change in preservation and abundance coincides with an increase in sedimentation rate within Core 8. Reworking of lower and upper Miocene and Pliocene species, which occurs throughout the section at 491, hinders age determinations.

The good radiolarian preservation and reduced reworking in the upper part of Site 491 permit the identification and location of Quaternary and upper Pliocene radiolaria datum planes. As in other Leg 66 sites, mixtures of North Pacific and equatorial Pacific forms occur. The last occurrence of *Axoprunum angelinum* (0.4 Ma) occur at the base of Core 1 (10 m), and the last occurrence of *Anthocyrtidium angulare* (1.2 Ma) occurs in the lower part of Core 3 (28 m).

The lower part of Core 4 through Core 7 is within the *Pterocanium prismatium* zone, as suggested by the occurrence of *Lamprocyclas neoheteroporos* (Hays, 1970) and the first occurrences of *Amphirhopalum ypsilon* and *Anthocyrtidium angulare*, although *P. prismatium* itself is absent. The top of the *Spongaster pentas* zone,
Figure 5. Very thin discontinuous silt beds of Unit 2, Sample 491-15-2, 130-145 cm.

Figure 6. Fine-grained sand bed (Sample 491-19-4, 40-60 cm) representative of thickest sand beds observed in Unit 2. Note reverse fault of small displacement.
indicated by common Stichocorys peregrina and the appearance of Spongaster pentas shortly below, occurs within Core 9. Cores 10 to 59 may be within the S. pentas zone, as S. pentas is sporadic and Ommatarus penultimate never becomes common (Riedel and San-

filippo, 1971). The early Pliocene age of Cores 10 to 59 is supported by calcareous nanoplankton.

**Foraminifers**

At Site 491, Cores 1 through 59 penetrate a Quaternary through Pliocene sedimentary section. Planktonic foraminifers are few to common in Cores 1 through 3, rare to very rare in Cores 4 through 6, and absent in Cores 7 through 59. Benthic foraminifers show almost the same pattern of distribution in the samples. Some samples in Cores 7 through 59, however, contain a few dwarf shelf-derived planktonic and benthic foraminifers. The planktonic specimens are usually juvenile and give no age indication.

Cores 1 through 3 include the following Quaternary foraminifers: Globorotalia tumida, G. menardii, G. flexuosa, Globigerinoides ruber, G. sacculifer, G. tri
tolia, Neogloboquadrina dutertrei, and Orbulina universa. Although no index Pliocene species are encountered, occurrence of Globorotalia cf. acostaensis and Neogloboquadrina humerosa in Cores 4 and 5 may suggest an upper Pliocene age for these cores.

**Paleoecology and Depositional Environment**

Absence of in situ planktonic and benthic foraminifers in most of the Pliocene section indicates deposition below the CCD and dilution due to terrigenous influx. The occurrence of some shallow-water foraminifers in the samples, such as Bolivina, Ammonia, and Gave
linella, suggests reworking of the shelf assemblage. This Pliocene faunal assemblage corresponds to the modern trench fill fauna at Site 488. In contrast to the Pliocene environments, the upper Quaternary benthic foraminifers indicate a shallower depth (lower bathyal) corresponding to the modern water depth at this site. They include Melonis pompilloides, Planulina wuellerstorfi, Hoeglundina elegans, Uvigerina proboscidea, U. his
pida, Bulimina striata, and Pyrgo depressa. The Quater
nary assemblage contains both well-preserved and partially corroded foraminifers, indicating deposition within the foram lysocline or local excursions of the CCD.

**Calcareous Nanoplankton and Silicoflagellates**

The nanofossil assemblages of the sediment column from Section 491-1,CC to 491-59,CC can be assigned to four different biostratigraphic zones (Fig. 1):

1) Middle to upper Quaternary—Nanoplankton Zone NN20 in 1,CC to 2,CC (0.2-0.6 Ma): Gephyrocapsa oceanica, G. caribbeanica, Helicosphaera carteri, Cy
clococcolithus leptoporus, and Ceratolithus cristatus.

2) Upper Pliocene—Nanoplankton Zone NN18 in Core 4 (1.8-2.5 Ma): Discoaster brouweri, Gephyrocap
sas doronicoides, and Helicosphaera carteri. This sediment was deposited after the extinction of D. pen
taradiatus.

3) Upper Pliocene—Nanoplankton Zone NN17 in Cores 5-7 (2.5-2.7 Ma): Discoaster pentaradiatus, D. brouweri, and Helicosphaera carteri. Between Cores 7
and 8 there might be a hiatus, because the NN16 nannoplankton zone *D. surculus* was not found.

4) Lower Pliocene—Nannoplankton Zone NN15 in Cores 8–59 (3.5 Ma–?): *Reticulofenestra pseudoumbilica, Cyclococcolithus macintyre, Discoaster pentaradiatus,* and *Sphenolithus neoabies*. Because of unfavorable deposition within a mostly siliceous sediment, the nannofossil assemblages from Core 9 down are impoverished, with only the more sturdy species preserved. As all the listed species of this zone have a long range from the Miocene up, no subdivision of this core interval can be given. No species restricted to the Miocene are found. Therefore a lower Pliocene age is the most probable one for the reduced nannofossil assemblages from Core 8 down. Ages are those used by Perch-Nielsen (1977).

Silicoflagellate assemblages were studied in Sections 491-1,CC and 491-4,CC. They constitute only a minor part of the siliceous sediment fraction consisting of mainly diatoms and radiolarians.

1) Core Catcher 1—middle to upper Quaternary, NN20: *Dictyocha stapedia stapeda* and *D. fibula, 97%; Distephanus octogonus, 3%*. This is a typical upper Quaternary assemblage, which fits into the *D. epiodon* Zone of Bukry and Foster (1973) as well as into the *D. octangulatus* Zone of Bukry (1973) for the eastern and eastern north Pacific or the *Dictyocha aculeata aculeata* Zone of Bukry (1978), respectively.

2) Core Catcher 4—upper Pliocene, NN18: *Dictyocha fibula s.l., 96%; Distephanus speculum s.l., 4%*. No *Mesocena elliptica, or D. octogonus* is found to indicate a date older than Quaternary which suggests that the associated nannofossils are not reworked. The occurrence of *Actiniscus tetrasterias* also gives evidence of an age near the Pliocene/Pleistocene boundary.

**SEDIMENT ACCUMULATION RATES**

The sediment accumulation rate curve (Fig. 8) is based on biostratigraphic datum points and paleomagnetic datum levels; the exact method used to construct the curve is outlined in the introductory chapter. No corrections have been made for compaction or deformation. Sediment accumulation rates in the upper part of Site 491 vary between 34.2 m/m.y. and 5 m/m.y. Below 70 meters, the minimum rate is 1055 m/m.y., if all sediment below 81 meters accumulated within the *Spongaster pentas* and NN15 zones. The higher accumulation rate in the lower part of Site 491 may result partly from tectonic thickening of the section which occurred at the lower slope (see Paleobathymetry) as well as from higher initial sedimentation rates. After 3 Ma, slope sediments were deposited at a much slower rate.

**PALEOBATHYMETRY AND VERTICAL TECTONICS**

Sedimentologic and paleontologic data permit us to construct a paleobathymetric curve for Site 491 (Fig. 9). The three points used are the present water depths, the point where sediments of Site 491 pass through the CCD at 3.2 km at 2 Ma (see McMillen, this volume); the basal sandy sediments, which were probably deposited on the lower slope or trench at 5 km about 3.7 Ma; and the *Teichichnus-Zoophycos-Chondrites* trace fossil assemblage occurring at 4 km or greater water depth in Core 27.

These three points define the paleobathymetric curve for Site 491 (Fig. 8). The most striking feature of the curve is that the uplift began at a high rate of about 800 m/m.y. and slowed to a rate of about 135 m/m.y. from 2 Ma onward. The higher rate prior to 2 Ma probably represents the emplacement of lower slope or trench sediment into the zone of accretion, and the slower rate after 2 Ma probably represents regional uplift of the slope due to sediment underplating of the accretionary zone.

**PALEOMAGNETISM**

Paleomagnetic analyses at Site 491 established magnetostratigraphy and determined dips of certain beds and faults. Sediments in Site 491 can be correlated mainly with the Gilbert reversed polarity epoch. Paleomagnetically oriented cores dip generally northward.
Cores from the upper 50 meters are disturbed by drilling showing laminations concave downward along core margins. Cores deeper than 220 meters in the hole are separated into pieces of several centimeters in thickness which are rotated relative to one another. Several cores from the middle of the hole have irregular bedding, possibly caused by slumping.

Using a plastic tube in the upper 480 meters and a minicore drill below 480 meters 67, oriented samples were collected from less disturbed portions of cores with regular bedding direction. Stability of remanent magnetization of selected samples was examined with step-wise AF demagnetization (Niitsuma, this volume). The magnetization of the samples shows stable orientation and a slow decrease in intensity with AF demagnetization. The noise level of magnetometer is $10^{-7.6} \pm 0.5$ emu/cc. Structural corrections have been applied to the inclination values. Average intensity is $10^{-5.8} \pm 0.7$ emu/cc after 15 mT AF demagnetization, although the intensity of upper 70 meters of the hole is one order weaker ($10^{-6.7} \pm 0.7$ emu/cc). The sudden downhole increase in intensity at 70 meters coincided with lithologic change from calcareous nodule-bearing mud to mud with fine sand patches. Inclinations in the upper 140 meters of the hole changes sign frequently. Cores below 140 meters have mainly negative inclination except for three intervals of significant positive inclination. We believe that the Brunhes/Matuyama boundary occurs at about 24 meters, the Matuyama/Gauss boundary at about 53 meters, and the Gauss/Gilbert boundary at about 110 meters (Fig. 1). Below 100 meters the sediments probably are entirely in the Gilbert polarity epoch.

Sediment at Site 491 dip from 4° to 64°. Since the drilling core axis is nearly vertical, orientation of bedding plane can be calculated from magnetic inclination and declination (Niitsuma, this volume).

Dip direction of bedding plane are generally north-northeast, which is the opposite direction of submarine topographic slope. Clockwise direction of change of dips appears cyclically from westward to eastward depth (Niitsuma, this volume). Northward dip direction is accompanied with steeper dip angle and westward dip direction with shallower dip angle. This kind of regularity and cyclicity in dip angle and direction suggests either slump folding or small-scale tectonic deformation.

Several conjugate faults sets were observed in the lower portion of the cored section at Site 491 (Niitsuma, this volume). Paleomagnetic orientation of these faults suggests that the tensional axis is horizontal and almost parallel to the bedding dip direction.

**ORGANIC GEOCHEMISTRY**

The shipboard organic geochemistry monitoring program consisted of analysis of gases released in core liners, determination of organic carbon, hydrogen, nitrogen, and carbonate content of selected sediment samples, and visual inspection for fluorescence in split core.

**Gases**

Moderate amounts of gas were released in core liners from depths of about 20 meters and greater. The gas initially contained methane, CO$_2$, and small amounts of H$_2$S. The last, detectable by its distinctive odor, was present down to depths of about 60 meters. Methane content remained fairly constant with depth (Fig. 10) except for minima in the vicinity of 100, 175, 225, 350, and 450 meters.

Shallower than about 50 meters, ethane content was below the detection limit of the Carle gas chromatograph but increased gradually with depth and maintained a concentration of about 0.03% by volume except at the methane minima mentioned in the foregoing. The correspondence of low values in ethane + methane
suggest air dilution, probably due to washout. The ethane to methane ratio (Fig. 10) seldom varied from a value of about $3 \times 10^{-4}$ throughout the cored section.

CO$_2$ content in core liner gases varied from 0.06% to 2.04%, with both the highest and lowest concentrations occurring in the upper portion of the cored sequence.

Hydrocarbons in the C$_3$ to C$_5$ range were monitored on the Hewlett-Packard 5710-A gas chromatograph from a depth of 75 meters to TD. Their abundance was found to vary erratically with depth, showing a maximum of 381 ppm at 214.7 meters (Fig. 10).

Upon splitting Cores 10 and 19, gas-releasing ice inclusions or frozen sediment were observed from depths of 88.9 to 89.0 meters, 162.7 to 163.15 meters, and 168.3 to 168.35 meters, respectively (Figs. 1 and 11). One ice inclusion at 89 meters released gas equivalent to 7.2 times its volume, suggesting the presence of hydrate. The evolved gases consisted of methane and CO$_2$, with no ethane detectable on the Carle gas chromatograph.

**Fluorescence**

Split cores showed no evidence of fluorescence due to crude oil or bitumen impregnation.
Organic Carbon, Hydrogen, Nitrogen, and Carbonate

Samples for CHN and carbonate analysis were taken from selected cores. Within the cored sequence, the organic carbon content varied from 0.89% to 1.98% and the total nitrogen content from 0.08% to 0.17%. The organic potential of the sediments remained relatively constant and at an intermediate level throughout the hole.

The C/N ratio varied from 10.0 to 14.9, remaining approximately constant throughout the hole. This is in the range for organic matter associated with recent sediments (Fairbridge, 1972) and suggests that the organic matter present in these sediments has a low degree of thermal maturation. Low concentration of carbonates were detected, particularly in the lower portion of the hole.

Conclusions

Gases, mainly of biogenic origin, were detected throughout this hole, causing a low to moderate degassing of the cores. The organic potential of the sediments stayed at an intermediate level through the hole, being marginally higher for the upper section. The C/N ratio of the organic matter suggests a low degree of geothermal maturation. No evidence of petroleum or bitumen impregnation was detected.

Heavier hydrocarbons C<sub>3</sub> to C<sub>10</sub> varied erratically with depth without evidence of an increase in geothermal maturation. The origin of these gases is not known. They may originate in geothermally more matured sediments and be emplaced in shallower depths by migration, but a biogenic origin cannot be excluded.

The gas-generating ratio of one frozen sample at 88.9 to 89 meters suggests the presence of gas hydrate at Site 491.

**PHYSICAL PROPERTIES**

Physical property analyses of Site 491 sediments included porosity, water content, wet bulk density, and undrained shear strength (Fig. 12) (see Boyce, 1976, for procedures). Gas attenuation prevented compressional sound velocity measurements. Poor core recovery and increased core disturbance limited sampling density below 250 meters sub-bottom. The lack of logging precluded correlation with in situ properties.

Uniformly gradational changes in physical properties occur to 410 meters sub-bottom. Below 410 meters, variations in physical properties and the necessity to increase pump pressure to maintain drilling rates suggest increased induration. This increase may result from mass movement and/or tectonic processes or may reflect the influence of more permeable sand beds below which facilitated dewatering of the interbedded muds at the time of deposition.

**Porosity, Water Content, and Bulk Density**

Porosity decreases uniformly from 66% at 0.50 meters to 33% at 525 meters (Fig. 12). Water content decreases from 44% at 0.50 meters to 15% at 525 meters. Both porosity and water content decrease more rapidly below 410 meters. Bulk density increases from 1.58 Mg/m<sup>3</sup> to 2.07 Mg/m<sup>3</sup> from 6.60 to 520 meters, respectively (Fig. 12).

**Shear Strength**

Shear strength increases regularly from 13.5 kPa at 0.5 meters to 122.5 kPa at 69 meters (Fig. 12). Good correlation exists between vane shear and torvane results.

**INHOLE TEMPERATURE MEASUREMENTS**

Of three downhole temperature measurements at Site 491 with the Uyeda Probe, none yielded typical temperature curves. The measurement at 304.5 meters yielded a bottomhole temperature of 14.5°C and a gradient of 2.5°C/100 m. The measurement at 304.5 meters yields a thermal gradient which is about twice as high as predicted from methane hydrate-phase relationships (Shipley et al., 1979) and three times conventional heat flow work of Langseth and Von Herzen (1970). The postulated relationship between a prominent reflection and the base of gas hydrates of Shipley et al. (1979) is based on the pressure and temperature of hydrate stability. If the gradient is as high as 4°C/100 m, then the base of the hydrate stability occurs much shallower than the depth to the so-called "bottom-simulating reflection" (BSR). See Shipley and Shephard (this volume) for a complete discussion of the temperature data.

**CORRELATION OF SEISMIC REFLECTION DATA AND DRILLING RESULTS**

Site 491 coincides with a zone of landward-dipping reflectors about halfway up the inner slope of the trench between Sites 488 and 490. A wave-equation-migrated multichannel profile about 1000 meters northwest of Site 491 shows a zone of discontinuous and indistinct reflections, extending to perhaps a 0.4 s sub-bottom and clearly separate from the deeper landward-dipping, more coherent reflectors (Fig. 13). The actual boundary between the two zones is not well defined (Fig. 14). A high-amplitude reflection at 0.7 s sub-bottom may correlate with the base of the gas hydrate layer (Shipley et al., 1979).

The multichannel seismic data reveal a fairly high velocity (2.2 km/s) for the interval from the seafloor to the gas hydrate(?) reflection. Using this velocity, the total drilled section of 542 meters corresponds to at least 0.49 s sub-bottom (Fig. 13). The base of the discontinuous and indistinct reflectors occurs at about 440 meters sub-bottom, coinciding with the top of Lithologic Unit 3, which is defined by the first appearance of significant sand beds downhole. However, thick sand beds, which are probable reflectors, do not occur above 470 meters. The higher velocity for the sediments, compared to Site 488, is manifested in both the greater age and fissility of these rocks versus any significant lithologic changes.
SUMMARY AND CONCLUSIONS

At Site 491 we penetrated 542 meters and recovered 59 cores comprising three lithologic units. Unit 1 extends from 0 to 57.5 meters and consists of upper Pliocene to upper Quaternary mud and muddy silt with minor concentrations of ash and calcareous mud. Lower Pliocene muddy silt and muddy siltstone with minor fine sand layers constitutes Unit 2, cored between 57.5 and 437.5 meters. The most significant lithologic break occurs with Unit 3, which extends from 437.5 to 542 meters and is composed of lower Pliocene muddy silt and muddy siltstone with interbedded fine to coarse pebbly sand layers up to 40 cm thick.

Near-surface cores at Site 491 include a diverse microfossil assemblage; however, below 40 meters the calcareous components are partially or completely dissolved. Diatom and radiolarian preservation is good throughout the section, with radiolarians providing the best age control for deeper cores. Sediment accumulation rates, uncorrected for structure or compaction, are low (5-34 m/m.y.) above 70 meters but increase substantially (to about 1000 m/m.y.) below this depth to the base of the hole.

At Site 491 tilted beds and fracturing occur initially at about 120 meters and continue to total depth through the lower two lithologic units. In Unit 2 dips are variable and range to nearly vertical; fracturing is present throughout though slickensides are rare. Dip angles in Unit 3 range up to 30° and are more uniform than in Unit 2. A strong fissility develops locally. Paleomagnetic restorations of bedding in both Units 2 and 3 indicate modal dip directions to the north, though with considerable scatter. A separate deformational history for Unit 3 is suggested by discrete jumps in bulk density and porosity below 425 meters, though this variation may be simply the result of lithologic changes.

The multichannel seismic reflection profile through Site 491 shows a series of discontinuous and indistinct reflectors above about 0.4 s, overlying more coherent landward-dipping reflectors. At an interval velocity of 2.2 km/s the base of the discontinuous and indistinct reflections occurs at 440 meters near the top of Unit 3, which is defined by the first occurrence of sand. The
Figure 13. Detail of seismic profile Line MX-16.

Figure 14. Interpretive line drawing of Figure 13.
thick sandbeds, the probable reflectors, are not apparent until 470 meters sub-bottom. The mean low, north-erly dip of bedding in Unit 3 suggested by the paleo-magnetic restorations is subparallel to the dips of the seismic reflectors.

The depositional environment of Site 491 sediment is most directly interpreted by reference to the modern sedimentary regime as well as to the Quaternary sequence of Site 488. Coarse sands similar to those cored in Unit 3 at Site 491 occur in the modern trench and presumably in the large submarine canyon feeding the trench but have not been recovered in piston cores from the slope (McMillen and Haines, this volume). As such, we prefer to interpret the sand-bearing Unit 3 as trench sediment, since the profiles through the site show no evidence of buried canyons (Shipley, this volume). Alternatively, the coarse sands may have accumulated in a slope basin, though the seismic data show no evidence of remnants of such a basin. Much of the muddy silt of Unit 2 at Site 491 accumulated below the CCD at sedimentation rates comparable to those at Site 488. Thus Unit 2 sediments were probably deposited as lower slope hemipelagic muds.

Deformation occurs primarily in sands and muddy silts accumulated at high sedimentation rates, probably in the trench and or lowermost slope environments. This deformed sequence is overlain by about 120 meters of largely undisturbed sediment, most of which accumulated at a low rate at or above the CCD. Thus the structural history of this site indicates deformation in the trench and/or lower slope environment associated with rapid uplift from about 4 to 3 Ma, followed by an interval of slow deformation and uplift. Apparently the toe of the trench slope is a zone of concentrated tectonism that diminishes in intensity upslope.

Hydrocarbon gases from C\textsubscript{1} to C\textsubscript{5} were detected throughout the hole, causing low to moderate degassing of the cores. Gas-releasing frozen sediments were observed in the 88.9 to 89.0 meter, 162.7 to 163.15 meter, and 168.3 to 168.35 meter intervals. The gas-generating ratio (7.2) of one of the samples (88.9-89 m) suggests the presence of hydrated sediments. Failure of the pressure core barrel prevented an attempt to sample the gas hydrates in situ.

REFERENCES


The image contains a diagram with columns labeled SITE 491 HOI 2 CORE 1 CORED INTERVAL 0.0-10.0 m and SITE 491 HOI 2 CORE 2 CORED INTERVAL 9.5-10.0 m. The diagram includes columns for LITHOLOGIC DESCRIPTION, Fossil Characters, Graphic Lithology, and Mineral Analysis.

The descriptions include details such as:
- Muddy Silt, soft, grayish olive green (5GY 3/2) with sporadic white sponge specks.
- Textural analysis with percentages for sand, silt, and clay.
- Compositional analysis with percentages for quartz, mica, heavy minerals, glauconite, radiolarians, diatoms, and sponge spicules.
- Grain size analysis with percentages for sand, silt, and clay.
- Organic carbon and carbonate content.
- Color change from 5Y 2/2 to 5Y 4/2.
SITE 491 HOLE
CORE 3 CORED INTERVAL 19.0-28.5 m
LITHOLOGIC DESCRIPTION
MUD, grayish olive green (5GY 3/2) moderately deformed, with some concentrations of pyrite (5GY 4/2). Carbonate-rich lenses occur in 3 or 3 planes in each section. Section 4: gas expansion cracks occur between 80 and 130 cm. Section 5: gas expansion cracks occur from 3-90 cm; slight mottling 120-130 cm. Section 6: slight mottling, some pyrite concentrations are common. Section 7: slight mottling, some pyrite concentrations are common.

SMEAR SLIDES
TEXTURE:
Sand 0.0
Silt 0.0
Clay 0.0
COMPOSITION:
Quartz 35
Feldspar 18
Mica 4
Heavy minerals 2
Pyrite 2
Radiolarians 1
Diatoms 1
Spiney echinoids 1
Planktonic foraminifers 1
Organic carbon and carbonate
7.39
% Organic Carbon 0.0
% CaCO3 0.0

SITE 491 HOLE
CORE 4 CORED INTERVAL 26.0-30.0 m
LITHOLOGIC DESCRIPTION
MUD, grayish olive green (5GY 3/2). Diffuse ASH concentrations occur in each section. Section 4: gas expansion cracks occur between 80 and 130 cm. Section 5: gas expansion cracks occur from 3-90 cm; slight mottling 120-130 cm. Section 6: slight mottling, some pyrite concentrations are common.

SMEAR SLIDES
TEXTURE:
Sand 0.0
Silt 0.0
Clay 0.0
COMPOSITION:
Quartz 39
Feldspar 8
Mica 4
Heavy minerals 1
Pyrite 2
Diatoms 0.0
Organic carbon and carbonate
7.39
% Organic Carbon 0.0
% CaCO3 0.0

CALCAREOUS NOCKLE
Voids
Diffuse ash concentrations occur in upper 20 cm.
**SITE 491 HOLE CORE 5 CORED INTERVAL 38.0-47.5 m**

**LITHOLOGIC DESCRIPTION**

MUD, grayish olive green (5GY 3/2), homogeneous, soft to firm; small calcareous zones (CHALK) which were originally burrows. Section 5: firm, no gas expansion cracks.

**SMERE SLIDES**

- Gas expansion cracks
- Pyrite
- Clay
- Sponge spicules

**ORGANIC CARBON AND CARBONATE**

- Organic Carbon (%): 1.2
- CaCO₃ (%): 0.0

---

**SITE 491 HOLE CORE 6 CORED INTERVAL 47.5-57.5 m**

**LITHOLOGIC DESCRIPTION**

MUD, grayish olive green (5GY 3/2), homogeneous, soft to firm; small calcareous zones (CHALK) which were originally burrows. Section 6: firm, no gas expansion cracks.

**SMERE SLIDES**

- Gas expansion cracks
- Pyrite
- Clay
- Sponge spicules

**ORGANIC CARBON AND CARBONATE**

- Organic Carbon (%): 1.2
- CaCO₃ (%): 0.0

---

**SITE 491 HOLE CORE 7 CORED INTERVAL 47.5-57.5 m**

**LITHOLOGIC DESCRIPTION**

MUDDY SILT, grayish olive green (5GY 3/2), Small areas of AMM, light grayish (3/1 5/2) with areas of carbonate (KOECHLICH) moderate silica lenses (54 4/4). Occasional veticles (1-2 mm) with concentrations of sponge spicules (4/1). Glauconite concretions.

**SMERE SLIDES**

- Gas expansion cracks
- Pyrite
- Clay
- Sponge spicules

**ORGANIC CARBON AND CARBONATE**

- Organic Carbon (%): 0.0
- CaCO₃ (%): 0.0

---

**SITE 491 HOLE CORE 8 CORED INTERVAL 47.5-57.5 m**

**LITHOLOGIC DESCRIPTION**

LITHIFIED BY 64% carbonate (64). Glauconite concretions (64). Sponge spicules (64).
### SITE 491 HOLE 7
#### CORED INTERVAL 57.5 - 67.0 m

#### LITHOLOGIC DESCRIPTION

|深度 (m) | 矿物 | 组成 | 砂 | 粘土 | 泥质 | 有机碳 | 碳酸钙
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### SITE 491 HOLE 8
#### CORED INTERVAL 67.0 - 76.5 m

#### LITHOLOGIC DESCRIPTION

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**SITE 491 HOLE 11 CORED INTERVAL 95.5-100.0 m**

**LITHOLOGIC DESCRIPTION**

MUDDY SILT, grayish olive green (5GY 3/2) mottled with minor olive gray (5Y 3/2) soupy to soft.

**TEXTURE:**

- Fine sand: 49%
- Clay: 47%
- Silt: 5%

**COMPOSITION:**

- Quartz: 52%
- Feldspar: 10%
- Mica: 2%
- Heavy minerals: 1%
- Pyrite: 2%
- Clay: 30%
- Foraminifers: 1%
- Nannofossils: 1%
- Radiolarians: 1%
- Diatoms: 1%
- Sponge spicules: 1%

**SMEAR SLIDES**

Smears on core liner. Deviation of the hole: 1.0°.

**TIME - ROCK UNIT**

LOWER PLIOCENE

**BIOSTRATIGRAPHIC ZONE**

NN 15

**PROGRAM LITHOLOGY**

**SMARS**

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**SITE 491 HOLE 12 CORED INTERVAL 100.5-105.0 m**

**LITHOLOGIC DESCRIPTION**

MUDDY SILT, grayish olive green (5GY 3/2) mottled with minor olive gray (5Y 3/2) soupy to soft.

**TEXTURE:**

- Fine sand: 37%
- Clay: 33%
- Silt: 30%

**COMPOSITION:**

- Quartz: 52%
- Feldspar: 10%
- Mica: 2%
- Heavy minerals: 1%
- Pyrite: 2%
- Clay: 30%
- Foraminifers: TR
- Nannofossils: TR
- Radiolarians: TR
- Diatoms: TR
- Sponge spicules: TR
**SITE 491 HOLE**

### CORED INTERVAL 114.5-124.0 m

#### LITHOLOGIC DESCRIPTION

**MUDDY SILT, grayish olive green (5GY 3/2):** with few SAND layers, slightly mottled, with gas expansion cracks. Also some muddy grits, slightly darker and without gas expansion cracks, fine and even.

**SMEAR SLIDES**

- **Apparent bedding:**
  - Dip 20°
  - Dip 25°
- **Fine sand**
- **Apparent dip:**
  - 25°
- **Texture:** Sand, Silt, Clay
- **Composition:** Quartz, Felspar, Mica, Mica, Pyrite, Clay
- **Organic Carbon and Carbonate (%):**
  - 4-100
- **Grain size:** 4-98

#### GRAIN SIZE

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#### ORGANIC CARBON AND CARBONATE

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**SITE 491 HOLE**

### CORED INTERVAL 124.0-133.5 m

#### LITHOLOGIC DESCRIPTION

**Sand bed; dip 14°**

**Possible fault with effect of sandy layer**

**SMEAR SLIDES**

- **Apparent bedding:**
  - Dip 20°
- **Fine sand**
- **Apparent dip:**
  - 20°
- **Texture:** Sand, Silt, Clay
- **Composition:** Quartz, Felspar, Mica, Mica, Pyrite, Clay
- **Organic Carbon and Carbonate (%):**
  - 4-100
- **Grain size:** 4-98

#### GRAIN SIZE

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SITE 491

HOLE 16

CORED INTERVAL: 133.0–143.0 m

LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), firm, slightly mottled, some fine sand laminae (1 to 2 mm thick). One ASH bed and mud, grayish olive green (5GY 3/2) and olive gray (5Y 3/2), very fine mottled, some draping, blocks in Section E.

SMearing Slides:

Zeolites (yellow patch)

COMPOSITION:

ASH BED: apparent dip: 40°

FLINT: apparent dip 14°

Sandy bed: apparent dip 22°

FRACTURE: apparent dip 10°

Sandy beds: apparent dip >.

Sandy laminations: apparent dip 20°

ORGANIC CARBON AND CARBONATE

Organic Carbon 1.4

Fracture: apparent dip 15°

Sandy laminations: apparent dip 6°

TEXTURE:

SAND: 10

Silt: 55

Clay: 35

Quartz: 55

Feldspar: 8

Mica: 2

Clay 30

Carb. unspec.: 2

Radiolarians TR

Sponge spicules TR

STRAIN ANALYSIS:

FRACTURE: apparent dip 10°

Fracture with possible weakly developed slickensides, apparent dip 6°.
### Lithologic Description

#### Site 491 HOLE CORE 18 CORED INTERVAL 152.5-162.0 m

#### Development of chilled surfaces, dickimovite

<table>
<thead>
<tr>
<th>Depth</th>
<th>Lithology</th>
<th>Texture</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>152.5-162.0 m</td>
<td>Muddy Silt, greyish olive green (5GY 5/3) to olive gray (5Y 3/2). Becomes sandier from top to base (15-25%).</td>
<td>Very fine sand</td>
<td>Disturbed bedding</td>
</tr>
</tbody>
</table>

#### Smear Slides

- Fine sand layer (deformed by drilling)
- Fine to very fine sand, apparent dip 12°
- Diffuse sand

#### Grain Size

<table>
<thead>
<tr>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>60</td>
<td>30</td>
</tr>
</tbody>
</table>

#### Microfossils

- Foraminifers
- Nannofossils
- Radiolarians
- Diatoms
- Sponge spicules

### Site 491 HOLE CORE 19 CORED INTERVAL 162.0-171.5 m

#### Lithologic Description

<table>
<thead>
<tr>
<th>Depth</th>
<th>Lithology</th>
<th>Texture</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>162.0-171.5 m</td>
<td>Very fine sand, 10GY 5/3. Very fine sand over mud.</td>
<td>Very fine sand</td>
<td>Disturbed bedding</td>
</tr>
</tbody>
</table>

#### Smear Slides

- Fine sand, apparent dip 12°
- Diffuse sand

#### Grain Size

<table>
<thead>
<tr>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>60</td>
<td>30</td>
</tr>
</tbody>
</table>

#### Microfossils

- Foraminifers
- Nannofossils
- Radiolarians
- Diatoms
- Sponge spicules

### Notes

- Disturbed sand bed.
SITE 491 HOLE CORE 20 CORED INTERVAL 171.5-181.0 m

LITHOLOGIC DESCRIPTION

Muddy Silt, olive gray (5Y 3/2) with minor fine to medium sand. Only trace in Core. Section 2 probably deformed.

SMEAR SLIDES

Pyrite
Clay
Radiolarians
Diatoms
Sponge spicules

GRAIN SIZE

sand
silt
clay

Section 2

Texture: Sandy
Composition:

QUARTZ: 45%
Feldspar: 15%
Mica: 10%
Heavy minerals: 10%
Pyroxene: 10%
Clay: 5%
Radiolaria: TR
Silicoflagellates: TR

Organic Carbon and Carbonate

% Organic Carbon: 1.1
% Carbon: 0.5
### Lithologic Description

#### SITE 491 HOLE CORE 22 CORED INTERVAL 190.5-200.0 m

- **Lithology:** Extensive fissilaty. Polished surfaces; all soupy and MUDDY SILT, grayish olive green (5GY 3/2) with minor fissility. No fissility.

- **Smeared Slides:**
  - **Silt:** 45%
  - **Clay:** 25%

- **Composition:**
  - **Quartz:** 66%
  - **Feldspar:** 8%
  - **Mica:** 4%
  - **Heavy minerals:** 1%
  - **Pyrite:** 1%
  - **Clay:** 20%
  - **Glauconite TR**
  - **Radiolarians TR**
  - **Diatoms TR**
  - **Sponge spicules TR**

- **Sand:** Apparent dip 85° near vertical beds.

#### Site 491 Holes 23 and 24

- **Lower Pliocene:**
  - **Spongaster spretus**
  - **BIOSTRATIGRAPHIC UNIT:** Lower Pliocene
  - **Lithology:** Very diffuse, poorly indurated sand MUDDY SILT, grayish olive green (5GY 3/2) and fine SAND beds intercalated (5GY 5/2). Muddy silt fissile with polished surfaces.

- **Smeared Slides:**
  - **Heavy minerals:**
  - **Pyrite:**
  - **Clay:**
  - **Foraminifera:**
  - **Radiolarians:**
  - **Diatoms:**

- **Grain Size:**
  - **Sand:**
  - **Silt:**
  - **Clay:**

#### Site 491 Holes 23 and 24

- **Lower Pliocene:**
  - **Spongaster spretus**
  - **BIOSTRATIGRAPHIC UNIT:** Lower Pliocene
  - **Lithology:**
  - **Smeared Slides:**
  - **Heavy minerals:**
  - **Pyrite:**
  - **Clay:**
  - **Foraminifera:**
  - **Radiolarians:**
  - **Diatoms:**
  - **Sponge spicules:**

- **Grain Size:**
  - **Sand:**
  - **Silt:**
  - **Clay:**

---

**Note:** The diagram and table sections are from the image, but the text content is provided in the above description.
**Lithologic Description**

- **VOID**
  - Sandy beds
  - Sparsely distributed, irregular with polished faces and slickensides.
  - Apart from fine spots and beds (as shown) no other features observed.

- **Fault with slickensides**
  - Faults displacing drilling laminations common.

**SMEAR SLIDES**

- **Bioturbations**
- **Plant fragment**
- **Diffuse sandy layer**
- **Examples of drilling faults**

**TEXTURE:**
- Sand: 1
- Silt: 1
- Clay: 1

**COMPOSITION:**
- Quartz: 1
- Feldspar: 1
- Mica: 1
- Pyrite: 1
- Clay: 1
- Sponge spicules: 1

**GRAIN SIZE**

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>95.8</td>
<td>65.5</td>
<td>24.5</td>
<td>8.7</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Silt</td>
<td>3</td>
<td>58.0</td>
<td>42.0</td>
<td>7.0</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Clay</td>
<td>2</td>
<td>58.0</td>
<td>42.0</td>
<td>7.0</td>
<td>2.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Organic Carbon and Carbonate**

- % Organic Carbon: 0.0
- % CaCO₃: 0.0

**Section 4:**

- Mudstone with internal structure.
- Drilling laminations throughout, some laminations thick, some thin.

**Drilling faults**

- Examples of drilling faults causing displacement of laminations.
SITE 491 HOLE
CORE 27 CORED INTERVAL 238.5-238.0 m

LITHOLOGIC DESCRIPTION
MUDDY Silt, grayish olive green (5GY 3/2), firm to hard
drilling laminations abundant. Section 3: distinct, iso-
earmed serpilial color sample, invaded by microfossil
drilling laminations, as shown in example. Section 4:
45-50 cm: conglomerates of normal faults reflecting ill-
<ling laminations.

SMEAR SLIDES
TEXTURE:
- Sand
- Silt
- Clay

COMPOSITION:
Carb. unspec.
Nannofossils
Radiolarians
Diatoms
Sponge spicules

GRAIN SIZE
- Sand
- Silt
- Clay

ORGANIC CARBON AND CARBONATE
% Organic Carbon
% CaCO₃

SITE 491 HOLE
CORE 28 CORED INTERVAL 238.5-247.5 m

LITHOLOGIC DESCRIPTION
MUDDY Silt, grayish olive green (5GY 3/2), with thin
(1-2 mm) drilling laminations of dark gray (10Y 3/2)
mud every 3-4 cm, soft to firm, occasional opaque ossicles,
slight mottled coloring.

SMEAR SLIDES
TEXTURE:
- Sand
- Silt
- Clay

COMPOSITION:
Diatoms
Feldspar
Mica
Heavy minerals
Perthite
Clay
Glass
Calcite
Feldspar
Plankton
Sponge spicules

GRAIN SIZE
- Sand
- Silt
- Clay

ORGANIC CARBON AND CARBONATE
% Organic Carbon
% CaCO₃
LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), soft to firm. Drilling laminations abundant, laminae and bioturbation of mixed texture, minor normal faults affecting drilling laminations.

SMEAR SLIDES

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<tr>
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COMPOSITION:

- Quartz: 57%
- Feldspar: 20%
- Mica: 5%
- Heavy minerals: 2%
- Pyrite: 1%
- Clay: 15%
- Carb. unspec.: TR
- Radiolarians: TR
- Diatoms: TR
- Sponge spicules: TR

GRAIN SIZE

- Sand: 0.5
- Silt: 67.1
- Clay: 26.1

LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), soft to firm. Drilling laminations abundant, laminae and bioturbation of mixed texture, minor normal faults affecting drilling laminations.

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- Radiolarians: TR
- Diatoms: TR
- Sponge spicules: TR

GRAIN SIZE

- Sand: 0.5
- Silt: 67.1
- Clay: 26.1

LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), soft to firm. Drilling laminations abundant, laminae and bioturbation of mixed texture, minor normal faults affecting drilling laminations.

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- Pyrite: 1%
- Clay: 15%
- Carb. unspec.: TR
- Radiolarians: TR
- Diatoms: TR
- Sponge spicules: TR

GRAIN SIZE

- Sand: 0.5
- Silt: 67.1
- Clay: 26.1

LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), soft to firm. Drilling laminations abundant, laminae and bioturbation of mixed texture, minor normal faults affecting drilling laminations.

SMEAR SLIDES

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COMPOSITION:

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- Feldspar: 20%
- Mica: 5%
- Heavy minerals: 2%
- Pyrite: 1%
- Clay: 15%
- Carb. unspec.: TR
- Radiolarians: TR
- Diatoms: TR
- Sponge spicules: TR

GRAIN SIZE

- Sand: 0.5
- Silt: 67.1
- Clay: 26.1

LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), soft to firm. Drilling laminations abundant, laminae and bioturbation of mixed texture, minor normal faults affecting drilling laminations.

SMEAR SLIDES

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<td>Clay</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td>10%</td>
<td></td>
</tr>
</tbody>
</table>

COMPOSITION:

- Quartz: 57%
- Feldspar: 20%
- Mica: 5%
- Heavy minerals: 2%
- Pyrite: 1%
- Clay: 15%
- Carb. unspec.: TR
- Radiolarians: TR
- Diatoms: TR
- Sponge spicules: TR

GRAIN SIZE

- Sand: 0.5
- Silt: 67.1
- Clay: 26.1

LITHOLOGIC DESCRIPTION

MUDDY SILT, grayish olive green (5GY 3/2), soft to firm. Drilling laminations abundant, laminae and bioturbation of mixed texture, minor normal faults affecting drilling laminations.
**Lithologic Description**

**MUDDY SILT**, grayish green (5GY 2/2), soft to firm. Sections 1 and 2: broken up by drilling, aggregates found towards top of 2 mm white nodules. Section 3: firm, drilling laminae throughout. Section 4: slightly bioturbated.

**Smear Slides**

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sections 1 and 2</td>
<td>15%</td>
<td>80%</td>
<td>5%</td>
</tr>
<tr>
<td>Section 3</td>
<td>20%</td>
<td>80%</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Texture:**
- Smoooth

**Composition:**
- Quartz
- Feldspar
- Mica
- Heavy minerals
- Pyrite
- Clay

**Organic Carbon and Carbonate**

<table>
<thead>
<tr>
<th>% Organic Carbon</th>
<th>% CaCO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**Grain Size**

<table>
<thead>
<tr>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.1</td>
<td>68.7</td>
<td>8.2</td>
</tr>
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</table>

**Drilling Lamination**

- Thin, discontinuous, wavy laminae
- Three thin (1 mm) layers of fine sand
- 24° apparent dip
- Drilling lamination

**Organic Matter**

- % Organic Carbon: 1.1
- % CaCO₂: 0.6

**Fractures**

- Eleven fractures over 80 cm (drilling)

**Smear Slides**

- Sections 1 and 2: more firm material and less soup material and less soup material
- Sections 3 and 4: soft to firm, slightly bioturbated, still very light grey
MUDDY SILTSTONE, greyish olive green (5GY 3/2), fine to well-indurated internally structureless. Section 2: irregular and straight discontinuous fractures. Section 6: well-indurated, with minor softer material between the large blocks. Section 5: minor irregular discontinuous fractures. Section 6: straight fractures with polished surfaces.

LITHOLOGIC DESCRIPTION

2: well indurated, with minor softer material between the large blocks. Section 5: minor irregular discontinuous fractures. Section 6: straight fractures with polished surfaces.

ORGANIC CARBON AND CARBONATE

7-40%

% Organic Carbon: 1.5

% CaCO3: 0.0

TEXTURE:

Sand: 4

Gr. Clay: 40

COMPOSITION:

Quartz: 60

Fluorite: 3

Mica: 3

Manganese: 1

Pyrite: TR

Cleat: 30

Calcite: 2

Ferromagnesite: TR

Salt: 2

Sponge: 1

Impact but apparently structureless

Same as above but for occasional vague healed fractures (QD/MSW)
MUDDY Silt, greenish olive gray (5GY 3/2). Section 1: some drilling lamination, deformed endorse molding test core 1 bioturbation. Sections 2 and 3 same as Section 1, except in reverse. Section 3: all tests were discontinuous. Silt, fine mud silt, 100-150 um normally graded.

SMEAR SLIDES

TEXTURE: Sand 3
Silt 57
Clay 40

COMPOSITION:
Quartz 55
Feldspar 5
Mica 1
Porphyric 1
Clay 30
Glauconite TR
Sponge spicules TR

GRAIN SIZE: Sand 2-50
Silt 57
Clay 40

ORGANIC CARBON and CARBONATE
2-60
% Organic Carbon 1.5
Traces of carbonate

VOG

Unusual drilling lamination

OTHER FOSSILS

Sponge spicules TR
Diaporas TR

SITE 401 HOELE 491 CORE 37 CORED INTERVAL 323.5-332.0 m

LITHOLIC DESCRIPTION

MUDDY SILT, greenish olive gray (5GY 3/2) with fine SAND beds. Section 1: some and soft structures. Section 2: sand very disturbed; only fragments of beds. Section 2: no apparent bedding, all chaotic.

SMEAR SLIDES

TEXTURE: Sand 5
Silt 55
Clay 40

Discontinuous sandy layer

COMPOSITION:
Quartz 32
Feldspar 4
Mica 8
Porphyric 1
Clay 27

GRAIN SIZE 2-90
Sand 11.4
Silt 66.3
Clay 21.2

SPECIAL CHARACTER

<32 RRF

SIGNIFICANCE

1.0-1.5 Meters
LITHOLOGIC DESCRIPTION

MUDDY SILTSTONE, greyish olive green (6GY 3/2) with fine to medium SAND and SILT layers. Section 1: fine sand, 0° true dip. Section 2: fine sand, 10° true dip. Section 3: fine sand, 10° true dip. Section 4: fine sand, 10° true dip. Section 5: fine sand, 10° true dip. Section 6: fine sand, 10° true dip.

TEXTURE:
- Sand
- Silt
- Clay

COMPOSITION:
- Quartz
- Feldspar
- Mica
- Heavy minerals
- Pyrite
- Glauconite
- Carbonate
- Diatoms
- Sponge spicules

GRAIN SIZE:
- Sand
- Silt
- Clay

ORGANIC CARBON AND CARBONATE:
- Organic Carbon
- Calcium Carbonate

Fragments only
<table>
<thead>
<tr>
<th>LITHOLOGIC DESCRIPTION</th>
<th>TEXTURE</th>
<th>COMPOSITION</th>
<th>GRAIN SIZE</th>
<th>ORGANIC CARBON AND CARBONATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUSCOVITE Siltstone</td>
<td>Soft</td>
<td>Quartz 70</td>
<td>5-15</td>
<td>% Organic Carbon: 1.3</td>
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<tr>
<td></td>
<td>Fractured</td>
<td>Feldspar 9</td>
<td>Silt 56</td>
<td>% CaCO₃: 2.0</td>
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<tr>
<td></td>
<td></td>
<td>Mica 3</td>
<td>Clay 10</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Heavy minerals TR</td>
<td>14</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Sponge spicules TR</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>Diatoms TR</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foraminifers TR</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nannofossils TR</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiolarians TR</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sponge spicules TR</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**LITHOLOGIC DESCRIPTION**

- MUDDY SILTSTONE, greyish olive green (5SY 3/2)
  - On place soft to firm slick, fine sand size.

**TEXTURE:**

- Fine sand: 30% apparent dip
- Fine sand: 15% apparent dip
- Fine sand: 10% apparent dip
- Tense sand: 10% apparent dip
- Vuggy sand: 10% apparent dip
- Vuggy sand: 5% apparent dip
- Vuggy sand: 1% apparent dip
- Vuggy sand: 0.5% apparent dip

**COMPOSITION:**

- Quartz: 92% (mostly detrital)
- Feldspar: 8%
- Mica: 2%
- Heavy minerals: TR
- Sponge spicules: TR
- Diatoms: TR
- Foraminifers: TR
- Nannofossils: TR
- Radiolarians: TR
- Sponge spicules: TR

**GRAIN SIZE:**

- Vuggy sand: 10% apparent dip
- Vuggy sand: 5% apparent dip
- Vuggy sand: 1% apparent dip
- Vuggy sand: 0.5% apparent dip
**Lithologic Description**

**SITE 491 HOLE**

**CORE 44 CORED INTERVAL** 390.0-399.5 m

- **MUDDY SILTSTONE** with MUDSTONE both greyish olive-green (5GY 3/2) and fine to medium SAND, Section 1: fractured blocks in drilling breccia, soupy matrix.

**SMEAR SLIDES**

- Void
- Bedding, 22° apparent dip
- Healed fracture: 30° apparent dip
- Healed fault: 30° apparent dip
- Healed fracture: 22° apparent dip

**TEXTURE**: Sand 1 TR, Sil 30, Clay 40, Mica 3, Pyrite 1, Clay 30, TR-

**COMPOSITION**: Quartz 64, Felspar 7, Mica 2, Heavy minerals TR, Pyrite TR, Clay 30, TR-

**ORGANIC CARBON AND CARBONATE**

- % Organic Carbon: 0.4
- % CaCO₃: 1.0

---

**SITE 491 HOLE**

**CORE 45 CORED INTERVAL** 399.0-409.0 m

- **MUDDY SILTSTONE** with MUDDY SINTER, greyish olive-green (5GY 3/2), Section 1: firm to hard, locally classifiable as MUDDY SINTER

**SMEAR SLIDES**

- Bedding, 16° apparent dip
- Healed fault: 16° apparent dip
- Healed fracture: 16° apparent dip

**TEXTURE**: Sand 1 TR, Sil 30, Clay 40, Mica 3, Pyrite 1, Clay 30, TR-

**COMPOSITION**: Quartz 64, Felspar 7, Mica 2, Heavy minerals TR, Pyrite TR, Clay 30, TR-

**ORGANIC CARBON AND CARBONATE**

- % Organic Carbon: 0.4
- % CaCO₃: 1.0

---

**SITE 491 HOLE**

**CORE 46 CORED INTERVAL** 409.0-418.5 m

- **MUDDY SILT, Sandy mud,** grayish olive-green (5GY 3/2), Section 1: firm to hard, locally classifiable as MUDDY SINTER.

**SMEAR SLIDES**

- Bedding, 22° apparent dip
- Healed fracture: 30° apparent dip
- Healed fault: 30° apparent dip

**TEXTURE**: Sand 1 TR, Sil 30, Clay 40, Mica 3, Pyrite 1, Clay 30, TR-

**COMPOSITION**: Quartz 64, Felspar 7, Mica 2, Heavy minerals TR, Pyrite TR, Clay 30, TR-

**ORGANIC CARBON AND CARBONATE**

- % Organic Carbon: 0.4
- % CaCO₃: 1.0

---

**SITE 491 HOLE**

**CORE 47 CORED INTERVAL** 418.0-418.5 m

- **MUDDY SILT, Sandy mud,** grayish olive-green (5GY 3/2), Section 1: firm to hard, locally classifiable as MUDDY SINTER.

**SMEAR SLIDES**

- Bedding, 22° apparent dip
- Healed fracture: 30° apparent dip
- Healed fault: 30° apparent dip

**TEXTURE**: Sand 1 TR, Sil 30, Clay 40, Mica 3, Pyrite 1, Clay 30, TR-

**COMPOSITION**: Quartz 64, Felspar 7, Mica 2, Heavy minerals TR, Pyrite TR, Clay 30, TR-

**ORGANIC CARBON AND CARBONATE**

- % Organic Carbon: 0.4
- % CaCO₃: 1.0

---

**SITE 491 HOLE**

**CORE 48 CORED INTERVAL** 418.0-418.5 m

- **MUDDY SILT, Sandy mud,** grayish olive-green (5GY 3/2), Section 1: firm to hard, locally classifiable as MUDDY SINTER.

**SMEAR SLIDES**

- Bedding, 22° apparent dip
- Healed fracture: 30° apparent dip
- Healed fault: 30° apparent dip

**TEXTURE**: Sand 1 TR, Sil 30, Clay 40, Mica 3, Pyrite 1, Clay 30, TR-

**COMPOSITION**: Quartz 64, Felspar 7, Mica 2, Heavy minerals TR, Pyrite TR, Clay 30, TR-

**ORGANIC CARBON AND CARBONATE**

- % Organic Carbon: 0.4
- % CaCO₃: 1.0

---

**SITE 491 HOLE**

**CORE 49 CORED INTERVAL** 418.0-418.5 m

- **MUDDY SILT, Sandy mud,** grayish olive-green (5GY 3/2), Section 1: firm to hard, locally classifiable as MUDDY SINTER.

**SMEAR SLIDES**

- Bedding, 22° apparent dip
- Healed fracture: 30° apparent dip
- Healed fault: 30° apparent dip

**TEXTURE**: Sand 1 TR, Sil 30, Clay 40, Mica 3, Pyrite 1, Clay 30, TR-

**COMPOSITION**: Quartz 64, Felspar 7, Mica 2, Heavy minerals TR, Pyrite TR, Clay 30, TR-

**ORGANIC CARBON AND CARBONATE**

- % Organic Carbon: 0.4
- % CaCO₃: 1.0
**LITHOLOGIC DESCRIPTION**

**MUDDY SILT, grayish olive green (5GY 3/2).** Section 1: sandy to firm, drilling laminations abundant. Section 2: firm, drilling laminations absent.

**SMEAR SLIDES**

Texture: 50% sand, 20% silt, 30% clay

Composition:
- Quartz
- Feldspar
- Mica
- Heavy minerals
- Pyrite
- Clay
- Glass
- Nannofossils
- Radiolarians
- Diatoms
- Sponge spicules
- Plant fragments

**GRAIN SIZE**

<table>
<thead>
<tr>
<th>Grain Size</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>15</td>
<td>20</td>
<td>65%</td>
</tr>
</tbody>
</table>

**ORGANIC CARBON AND CARBONATE**

<table>
<thead>
<tr>
<th>% Organic Carbon</th>
<th>% CaCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**TEXTURE:**

- 1.0 cm thick laminated bed of fine sand
- 43° apparent dip (fracture)
- 1 cm thick laminated bed of fine sand
- 43° apparent dip (fracture)

**NORMAL FAULT**

- 51° true dip
- 1.6 cm thick bed (20° true dip)
- Faulted face
MUDDY SILT, grayish olive green (5GY 3/2). Section 2: firm muddy silt (140-150 cm), soupy where. Section 3: poorly indurated muddy siltstone with thin (1-2 mm) sand layers. Section 5 (below 95 cm): unconsolidated 5GY 5/2 medium to fine sand with interbeds of indurated muddy siltstone. Section 6: unconsolidated grayish olive HOY 4/2) medium to fine sand with minor sponge spicules and foraminifers.

SMEAR SLIDES

TEXTURE:

GRAIN SIZE

ORGANIC CARBON AND CARBONATE

% Organic Carbon 1.5
% CaCO₃ 2.0

SAND 4-119
SILT 17.3
CLAY 58.9

QUARTZ 50
FELDSPAR 25
MICHA 7
HEAVY MINERALS 3
PYRITE 1
GLASS 1
FORAMINIFERS TR
NANNOFOSILS TR
RADIOLARIANS TR
DIATOMS 1
Sponge spicules 1

Drilling breccia of muddy siltstone set in unconsolidated sand
**SITE 491 HOLE**

**CORE 54**

**CORED INTERVAL** 485.0-494.5 m

**LITHOLOGIC DESCRIPTION**

MUDDY SILTSTONE, grayish olive green (5GY 3/2), indurated, some probably in original position. In Section 2 fewer muddy silt blocks, none in original position.

Section 1, 70 cm:
- Trace fossil or base of bed (x 3/4)
- Vague annular markings

**GRAPHIC LITHOLOGY**

![Graphic Lithology Diagram]

**TEXTURE:**
- Very intense fracturing
- Fine sand distributed as lenses, some without visible bedding

**COMPOSITION:**
- Diatomaceous earth (DE) (60-80)
- Feldspar (8-12)
- Mica (4-6)
- Heavy minerals (1-2)
- Pyrite (10-20%)
- Clay (20-40)
- Organic Carbon and carbonate (1-9%)

<table>
<thead>
<tr>
<th>% Organic Carbon</th>
<th>% CaCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**SMOKE SLIDES**

- Very intense fracturing
- Fine sand distributed as lenses, some without visible bedding
- Trace fossil or base of bed (x 3/4)
- Vague annular markings
### Lithologic Description

**MUDDY SILTSTONE, grayish olive green (5GY 3/2).**

- **Section 1:** Fracture-bounded blocks separated by minor, soupy matrix. Horizontal and sub-horizontal fracturing often closely-spaced and flaggy predominates. Probably bedding. Section 2: becoming more matrix-rich, so that blocks are all displaced. Section 4: is soft to firm, core largely intact, little internal structure visible.

- **Section 2:** Becoming more matrix-rich, so that blocks are all displaced.

- **Section 4:** Soft to firm, core largely intact, little internal structure visible.

**SMEAR SLIDES**

- **Texture:** Sand, Silt, Clay
- **Composition:** Quartz, Feldspar, Mica, Heavy minerals, Pyrite, Clay, Glass, Carb. unspec., Foraminifers, Nannofossils, Radiolarians, Diatoms, Sponge spicules, Plant fragments

**Organic Carbon and Carbonate**

- **Organic Carbon:** 0.9%
- **% CaCO3:** 0.0%

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### Lithologic Description

**MUDDY SILTSTONE, grayish olive green (5GY 3/2) with fine to medium sand.**

- **Section 3:** Soft to firm, core largely intact. Vertical laminations in fabric.

**SMEAR SLIDES**

- **Texture:** Sand, Silt, Clay
- **Composition:** Quartz, Feldspar, Mica, Heavy minerals, Pyrite, Clay, Glass, Carb. unspec., Foraminifers, Nannofossils, Radiolarians, Diatoms, Sponge spicules, Plant fragments

**Organic Carbon and Carbonate**

- **Organic Carbon:** 5-9%
- **% CaCO3:** 6-10%
SITE 491   HOLE CORE 58  CORED INTERVAL 533.0–532.0 m

Lithologic Description

Muddy Siltstone, grayish olive green (5GY 3/2) with very fine to coarse sand.

Drilling breccia

SMEAR SLIDES

Texture:
- Sand
- Silt
- Clay

Composition:
- Quartz
- Feldspar
- Mica
- Heavy minerals
- Pyrite
- Clay
- Diatoms
- Sponge spicules

SITE 491   HOLE CORE 59  CORED INTERVAL 532.5–542.0 m

Lithologic Description

Medium sand drilling breccia

Muddy Siltstone and coarse to medium sand.

SMEAR SLIDES

Texture:
- Sand
- Silt
- Clay

Composition:
- Quartz
- Feldspar
- Mica
- Heavy minerals
- Pyrite
- Clay
- Diatoms
- Sponge spicules