OCEAN DRILLING PROGRAM

LEG 160 PRELIMINARY REPORT

MEDITERRANEAN I

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ABSTRACT

Leg 160 was the first in a two-leg program to investigate the tectonic and paleoceanographic history of the Mediterranean Sea. One focus of this leg was on accretionary and collisional processes associated with the convergent boundary between the African and European plates. The other focus was on the origin and paleoceanographic significance of sapropels, organic-rich layers that are intercalated in the Plio-Pleistocene sediments of the Mediterranean Basin.

One focus of drilling concerned collisional processes related to the tectonic history of the Eratosthenes Seamount. This is a crustal fragment in the process of collision with a convergent margin to the north, including Cyprus. A transect of four holes was drilled across the Eratosthenes Seamount, extending from the crestal area of the seamount, to its upper and lower slopes, and on the lower Cyprus margin. On the lower slope, an intact Upper Cretaceous and middle Eocene section was drilled, overlain by Plio-Quaternary deep-sea sediments. Shallow-water limestones, including corals and algae, and evidence of faulting and rapid subsidence, were recovered at the crestal site. Matrix-supported breccias, with a matrix of lower Pliocene microfossils, accumulated in rapidly deepening seas. Water depths increased during the early to late Pliocene, to a maximum depth today of around 2000 m. The Messinian(?) and Plio-Pleistocene sediments on the Cyprus margin record contrasting paleoenvironments and tectonic settings. The results from the Eratosthenes drilling are interpreted in terms of flexural faulting and collapse related to loading by an overriding Cyprus plate. The drilling has therefore documented a process of initial collision that is of fundamental importance to the interpretation of many mountain belts.

A further tectonic-related objective was the drilling of a transect of holes across the Milano and Napoli mud volcanoes. These are located on the northern margin of the Mediterranean Ridge accretionary complex in an area where the Mediterranean Ridge is believed to be thrust over a backstop of continental crust to the north. Drilling revealed that both volcanoes are well over 1 m.y. old and showed that much of the flank and crestal regions are composed of debris flows. These include clasts of mainly Miocene lithologies that were transported within the debris flows. The Milano volcano shows evidence for the existence of clathrates (solid methane hydrates) close to the seafloor. Gas (mainly methane) was detected at both mud volcanoes. Pore-fluid compositions indicate the presence of evaporites beneath. Drilling has thus shed important new light on the origin of the mud volcanoes, and will form a basis for future exploration.

More than 80 individual sapropels were recovered in distinctive packets and time intervals, which are separated by yellowish-brown, oxidized and carbonate-rich sediment. Individual beds in the packets were correlated between holes, separated by several hundred meters, and packets of sapropels could be matched between sites up to several hundred kilometers apart. Many individual sapropels are extraordinarily rich in organic carbon (up to 30% by weight and of predominantly marine origin) and display highly unusual magnetic properties. Sapropel occurrences mark periods when the Mediterranean catchment area experienced increased humidity and relatively high average temperatures. Once such conditions became established, they profoundly changed processes in the biologically active surface layer and at the seafloor. Our findings suggest that the development of deep-water anoxia in the eastern Mediterranean was an essential prerequisite for sapropel formation. The development of anoxia may be triggered by a reduction of deep-water formation, which is dependent on the salinities and temperatures in the surface layer. At the same time, sapropels indicate a dramatically increased carbon flux in the Eastern Mediterranean, which today is oligotrophic.

INTRODUCTION

Leg 160 includes sites from the Mediterranean Ridges proposal from three areas (Fig. 1): (1) the Eratosthenes Seamount (ESM), in a zone of incipient continental collision; (2) the Mud Volcano (MV) site on the Mediterranean Ridge, an accretionary wedge in a collisional setting; and (3) the Ionian transect (MR) in the west , where subduction and accretion are still taking place. The leg also includes four sites from the Mediterranean Sapropels proposal (MEDSAP 1-4), and sapropels are being drilled at additional sites during Leg 161 in the Western Mediterranean. The Mediterranean Ridge objectives were largely concerned with tectonic processes, while the Sapropels objectives were largely paleoceanographic. However, strong overlaps in the science between the two sets of objectives exist, and a fully integrated program of drilling was conducted.

The African/Eurasia plate boundary in the Eastern Mediterranean region (Fig. 1) reflects tectonic settings ranging from effectively steady-state subduction to incipient collision and more advanced collision in different areas. The Eastern Mediterranean is thus an ideal area in which to investigate the transition from subduction to collision, processes that may be recorded on land in orogenic belts but that are still poorly understood. Tectonically oriented drilling on Leg 160 focused on relatively shallow objectives (mainly <600 m). The first objective was to study the collision of the Eratosthenes Seamount with the Cyprus margin in the easternmost Mediterranean, by drilling a north-south transect of four sites. The second objective was to study the origin of mud volcanism by drilling at both crestal and flank locations of an active and an inactive mud volcano on the Mediterranean Ridge.

The third objective was to study subduction and accretion in an area where subduction is still taking place, by drilling on the inner deformation front of the accretionary wedge. The information obtained by drilling will be combined with other data (e.g., land studies) to synthesize the Neogene-Holocene subduction/accretion history of the Eastern Mediterranean.

Sediment cores from the Mediterranean Sea and land sections in southern Italy and Crete contain numerous dark-colored layers that are rich in organic carbon and often laminated. These layers, termed sapropels, are intercalated with carbonate-rich and organic-carbon-poor hemipelagic sediments of Pliocene to Holocene age. They appear to be a characteristic deposit of many silled marginal seas (e.g., the Japan Sea and Red Sea). In all cases it seems that the deposition of organic-rich sediments in the geological past occurred in response to dramatic changes of climate, circulation, and biogeochemical cycling. The Mediterranean sapropels of late Pleistocene to Holocene age have been particularly well studied, and a series of - in part contradictory - hypotheses on their origin and significance have been published in the last three decades. A broad consensus is that sapropels represent a paleoceanographic showcase, because they contain high-resolution records of key processes leading to enhanced burial and preservation of carbon at the seafloor.

Leg 160 made an effort to fully develop this showcase. Drilling on a transect of sites recovered several complete Pliocene to Holocene sediment sequences that represent a range of depositional environments, water depths, and oceanographic and biological characteristics in the modern Mediterranean (Fig. 2).

RESULTS

Site 963

Site 963 in the Strait of Sicily is the westernmost location drilled during Leg 160 (Figs. 1 and 2). The site is located on the unstable foreland of North Africa close to the deformation front of overriding thrust sheets (Gela nappe); movement last occurred prior to the early Pleistocene, allowing subsequent tectonically undisturbed sedimentation. Seismic reflection profiles suggest that Plio-Quaternary sediments here are 0.3 to 0.4 s or approximately 200 to 300 m thick and overlie a strong irregular reflector; and an additional irregular reflector is seen below an interval of strongly chaotic reflectors of unknown age.

Recovery and core quality in the four APC holes was excellent (average recovery 101%) and yielded a complete sediment section that spans the early Pleistocene to the Holocene (Figs. 2 and 3). Detailed records of magnetic susceptibility and density were generated using the shipboard multisensor track to facilitate core correlation and to ensure that a complete sedimentary record has been recovered. These high-resolution records were supplemented with measurements of color reflectance on split core surfaces.

The sediments of the one sedimentary unit recognized are olive-green nannofossil oozes with minor quartzose silt, volcanic ash, and clay. Six discrete and thin-bedded (<18 cm) ash layers were recognized in the upper 100 m. The nannofossil ooze of the upper section is bioturbated, homogeneous, and rich in calcareous microfossils. In the uppermost section (at approximately 5 mbsf), the color changes from brownish gray to light olive gray. Below 100 mbsf in Holes 963A and 963B scattered small (cm offset) soft-sediment normal faults were noted. Below 125 mbsf, a series of increasingly darker colored zones of 10 to 50 cm thickness occur. The two darkest of these zones were encountered at the base of the section and are distinctly laminated on a millimeter scale. In the section below 125 mbsf the amplitudes of cyclic variations in the physical properties (monitored by the multisensor track, reflectance, and color data) increase significantly. The carbonate content of the sediment varies between 20% and 45% by weight, and organic carbon values are between 0.1% and 1.5%, with maximal values occurring in the laminated dark layers at the bottom of the section. The pore water and interstitial gas concentrations suggest that diagenesis of organic matter is only moderate; methane concentrations remain below 300µL/L where sulfate is depleted (60 mbsf). Depth profiles of dissolved ions indicate carbonate precipitation in the sediment and require a source of sulfate and calcium at depth.

The sequence at Site 963 spans the time interval from the early Pleistocene (1.5 Ma) to the Holocene at an extraordinary resolution. Age assignments are based on calcareous nannofossil assemblage datums supplemented by planktonic foraminifers, and on a detailed paleomagnetic reversal stratigraphy (Fig. 3). According to the preliminary shipboard assessment, the sediment section is complete and was deposited at rates between 70 m/m.y. in the section below 150 m and up to 230 m/m.y. in the upper part of the section (Fig. 4).

Calcareous nannofossils are well preserved and the assemblage is characterized by considerable admixtures of reworked species from Pliocene, Miocene, Eocene, and Upper Cretaceous strata, as exposed on land and on the seafloor on Adventure Bank. The planktonic foraminifer assemblage shows no significant reworking and is well preserved. Benthic foraminifers are present throughout the section; radiolarians are rare, and diatoms are absent.

The paleomagnetic record of Site 963 extends into the Matuyama Chron and clearly shows the Jaramillo Subchron. In addition, several short intervals of reverse polarity are evident in the Brunhes Chron (Fig. 3).

Site 963 achieved both objectives: We recovered a complete and highly resolved sediment record with high stratigraphic potential (physical properties, biostratigraphy, magnetostratigraphy, and stable isotope stratigraphy), and we were able to recover lower Pleistocene sapropels that shore-based research will tie to the occurrences of sapropels in land sections.

Site 964

Site 964 is located at the foot of the Calabrian Ridge on a small bathymetric high. Here, an upper sedimentary unit of approximately 200 ms two-way traveltime (TWTT) overlies a strong seismic reflector that dips slightly to the northeast. The high is interpreted as being on the toe of the accretionary prism near the Ionian Abyssal Plain (Figs. 1 and 2). Based on piston-core information, the location was chosen to recover a Pliocene to Pleistocene sedimentary record of sapropel formation in the Ionian Basin. Our objectives were (1) to recover a deep-water sedimentary sequence that records the history of sapropel deposition in the Ionian Basin and the variations in deep-water formation from the Pliocene to the Holocene, and (2) to establish a high-resolution stratigraphy based on paleontological, geochemical, magnetic, and lithological properties and to correlate it with coeval sequences in Calabria.

Six holes were drilled at Site 964 to a maximum depth of 112 mbsf. Recovery and core quality in the APC cores and the single XCB core (160-964C-12X) were excellent (average recovery 102%) and a complete sediment section was recovered that spans the lower Pliocene to the Holocene (Fig. 5). Each hole contained locally discontinuous and tectonically attenuated sedimentary sequences. The striking sedimentological features and detailed records of physical properties (most notably color reflectance) of the sediment provided unambiguous markers that greatly facilitated correlation between holes. High-resolution core logs were also used during operations on site to ascertain if a complete record had been recovered and to identify poorly constrained intervals to be cored again.

Outstanding features of the sequence recovered at Site 964 are the occurrence of more than 50 distinct sapropels in the composite section (Fig. 5), the occurrence of numerous ash layers and ashy turbidites, and marked color banding of the sediments. The host sediments comprise light-colored (brownish to greenish) clayey nannofossil ooze, nannofossil ooze, and nannofossil clays. Some of the light-colored intervals are interpreted as being normally graded turbidites (decimeters to meters thick). Limited intervals of foraminifer sand were recovered in the lower parts of the sequence. Tuffs are present as discrete beds, 2nd volcanic glass is disseminated throughout. The sapropels, which are centimeters to decimeters thick, are enriched in pyrite, plant material, and amorphous organic matter. Individual sapropels display a wide range of depositional and post-depositional features that include laminations, bioturbation, and oxidation fronts (“burn-down”). Together, sedimentological and physical features in sapropels, ash layers, and turbidites permitted detailed correlation between the holes and the construction of complete sections despite erosional hiatuses at the bases of turbidites, high-angle extensional faults, and possible fault-like drilling artifacts.

Organic carbon concentrations in the sapropels reach up to 25 wt%, values that prior to Leg 160 were known only from Mesozoic black shales and sapropelic coals. Based on the amount of hydrocarbons liberated by pyrolysis, the organic matter is interpreted to be of mixed marine and terrigenous origin with a more strongly pronounced marine character in the older sapropels. High organic carbon concentrations are associated with high sulfur concentrations of up to 10 wt% and are inversely correlated with carbonate content (0-80 wt%).

Stratigraphic control was achieved using calcareous nannofossils and planktonic foraminifers; siliceous microfossils were not encountered. A total of 18 biostratigraphic events were recognized in Hole 964A ranging from the late early Pliocene to the late Pleistocene (Fig. 5). The occurrence of sapropel S1 in the uppermost section demonstrates that the Holocene is present. Based on composite depth, the resulting age vs. depth relationship reveals that the sedimentation rate at Site 964 varied between 10 and 64 m/m.y., with an average of 30 m/m.y. Initial evaluation of planktonic foraminifers in sapropels, as compared to surrounding lithologies, suggests that these sapropels are characterized by unique environmental conditions at the sea surface and have distinct assemblages that differ between individual sapropels.

Constructing the magnetostratigraphic record at Site 964 was hampered by suspected overprints that could not be removed with the maximum fields that could be applied in the shipboard laboratory. However, the detailed records of individual holes hold promise for successful shore-based work on a composite section.

The occurrence of hematite in the cores, which made them colorful but difficult to demagnetize, is certainly due to the limited diagenetic mineralization of organic matter. Sulfate is never depleted in the cores, and methane concentrations are very low. Pore-water gradients point to some carbonate precipitation below 60 m, however, and gradients of dissolved cations imply that solutions characteristic of late-stage brine, possibly derived from dissolving evaporites at depth, are present below the penetration depth of our holes.

The setting of the site at the toe of the Calabrian accretionary wedge carries significant tectonic information concerning the processes of final closure of the Ionian Basin, a Tethyan remnant. The “cobblestone topography” at Site 964 is clearly tectonically influenced in view of the evidence of high-angle normal faulting observed in the cores and inferred from the sedimentary record.

Site 964 was a success: we were able to compile a complete sequence of sedimentation since the late early Pliocene, which includes more than 50 sapropels and numerous discrete layers of tephra. The sequence recovered is calcareous and contains evidence for cyclic variations of conditions in the bottom water, an assumption that will be tested by benthic isotope and faunal analyses. The sapropels, some of which are extremely rich in organic carbon, will undoubtedly help answer questions related to the origin and significance of black shales in the Mesozoic oceans.

Site 965

This was the first of a north-south transect of holes designed to test the tectonic hypothesis that the Eratosthenes Seamount is a continental fragment that is in the process of collision and underthrusting along the Cyprus active margin to the north (Figs. 1 and 6). Specific objectives were (1) to determine if there is evidence of tectonically induced subsidence during the Plio-Quaternary, possibly related to collision; (2) to determine the lithology, age, and paleoenvironments of a prominent reflector beneath the Plio-Quaternary succession; (3) to determine the timing, magnitude, and rate of any tectonic subsidence at this site.

Site 965 is located on the fault-controlled upper northern slope of the seamount (Fig. 6A, B). The site was chosen where seismically transparent reflectors, characteristic of the Eratosthene plateau area, are greatly reduced, owing to mass wasting and/or nondeposition. The present-day bathymetry is relevant to interpretation of Plio-Quaternary sedimentation at Site 965. A pre-spud survey revealed the ideal site location on the crest of a small (ca. 5 km-wide) north-south-trending ridge. This is surrounded by fault scarps that are affected by active normal faulting and mass-wasting processes.

Hole 965A was drilled to a maximum depth of 250.4 mbsf. After excellent recovery and core quality in the upper part of the section, APC coring was terminated by hard layers at ca. 30 mbsf. The following XCB cores had greatly reduced recovery of limestones. Three lithological units are recognized at Site 965:

Unit I (0-23 mbsf) comprises 23 m of unconsolidated, extensively bioturbated nannofossil muds and nannofossil oozes, with sporadic sapropels and sapropelic layers. Bedding ranges from horizontal to subhorizontal and locally tilted. Microfaults range from moderately to steeply inclined, with measurable throws of up to 15 cm. Unit I is dated as Pleistocene to late early Pliocene. Two hiatus are present. The first hiatus representing foraminifer Zone MPL6 and nannofossil zones ranging from uppermost MNN18 to MNN19c. This bank has an estimated duration of 0.95 m.y. A second hiatus (20.2 mbsf), having an estimated duration of 0.75 m.y., extends from the middle Pliocene to the late early Pliocene (foraminifer Zone MPL4b is missing). Sediments below 23 mbsf are only sparsely fossiliferous and are provisionally dated as no older than 6 Ma (late Miocene), based on calcareous nannofossils. Reworked benthic foraminifers were locally observed in the lower part of the succession. Preliminary paleomagnetic data (incompletely demagnetized) indicate a reversed polarity interval from 8 to 10 mbsf, immediately above the first paleontologically determined hiatus, during the middle Matuyama Chron. Geochemical data from Unit I indicate slightly less than seawater chlorinity values, as also noted in piston cores taken farther south on the Eratosthenes Seamount (i.e., at the KC 20 site). Organic carbon determinations range from 2%-5%, and C/N ratios are suggestive of mixed marine and terrestrial origins for the organic matter.

Unit II (23-29.3 mbsf) comprises ca. 6 m of greenish and brownish sticky to firm clays, with scattered small (centimeter-sized), angular carbonate clasts. There is abundant evidence of soft-sediment deformation and reworking by gravity processes (e.g., as debris flows). Microscopy and X-ray diffraction (XRD) revealed significant occurrences of aragonite and dolomite, as well as locally abundant ostracode carapaces.

Unit III (29.3-250.4 mbsf) is a 200-m-thick interval in which the lithologies that were recovered range from medium- to coarse-grained, parallel- to cross-laminated packstones and grainstones (i.e., limestones), with common well-preserved calcareous algae (including oncolites and intact rhodoliths), ooids, echinoderm remains, pelecypods, benthic foraminifers, gastropods, and rare coral of poritid type. The oolitic lithofacies are mainly in the upper part of the section. High porosity and permeability reflect the dissolution of aragonitic constituents. Interstitial and voidfilling sparry calcite cement is sparse to well developed. Some limestones grade into poorly cemented gray marls, possibly indicative of the lithology of non-recovered intervals. The limestones are cut by sporadic carbonate veins, suggestive of tectonic disruption. The final core showed evidence of penecontemporaneous tectonic brecciation and reworking of clasts.

An excellent suite of logs was obtained over 186 m. Interpretation of the formation microscanner (FMS) records, combined with other logs, reveals that (1) dips are nearly horizontal throughout; (2) the lower part of the succession includes apparent cross-lamination, whereas the upper part is more planar bedded; (3) A mainly muddy succession is interbedded with thin intervals, interpreted as the cored limestones); (4) scattered high-angle faults are present.

The preserved stratigraphic record at Site 695 began in the early Pliocene (possibly late Miocene), with accumulation of shallow-water carbonates in a muddy, current-influenced, probably lagoonal setting, adjacent to reef buildups and subject to tectonic instability. This was followed by accumulation of calcareous clays in possibly low-salinity to hypersaline settings (Messinian?). Concomitantly with, or immediately following, deposition the muds were redeposited downslope into an open-marine setting (younger than 6 Ma). Subsequent, Plio-Quaternary deep-marine sedimentation took place on a tectonically unstable slope, subject to slumping, nondeposition, and/or reworking.

In summary, at Site 965 on the Eratosthenes Seamount, a mainly shallow-water carbonate succession has subsided during the last 5 Ma, accompanied by tectonic instability and faulting. Later faulting has produced the present fault-controlled bathymetry of the site. We hope that post-cruise studies will clarify the age of the shallow-water limestones and the rate of tectonic subsidence. Drilling at Site 965 was clearly successful and constituted an important part of the test of the collision-related hypothesis for the evolution of the Eratosthenes Seamount.

Site 966

Site 966, the second of the transect holes drilled across the Eratosthenes Seamount to the Cyprus margin, is located on a broad high on the fault-bounded northern margin of the seamount plateau area (Fig. 6). Objectives here were (1) to recover a Plio-Quaternary succession with abundant sapropels, (2) to determine the nature of the Miocene-Pliocene paleo-environments and tectonic setting, (3) to elucidate the earlier history of the Eratosthenes Seamount, and (4) to infer the subsidence history of the site in relation to the Eratosthenes collision hypothesis. Seismic data show that a distinct (but complex) reflector at the base of the Plio-Quaternary succession is underlain by several deeper, westward-inclined reflectors, of which the uppermost was penetrated by drilling. Four lithologic units were recognized in the recovered sequence, within Holes 966A-966F, as follows:

Unit I (0-66 mbsf) is composed of greenish-gray to olive-green nannofossil ooze, which is clay-rich toward the top and increasingly foraminifer rich in the lower part of the section. The clay-rich intervals show sedimentary structures indicative of deposition as mud turbidites (e.g., subtle grading and fine parallel lamination). Volcanic ash is disseminated through the entire interval, which is mainly intensely bioturbated. The succession includes scattered evidence of both high-angle normal and reverse faulting, together with isolated small (<3 cm) clasts of limestone.

Within Unit I, more than 90 discrete sapropels and sapropelic layers were identified. These are dark olive green to black in color, a few centimeters to 60 cm thick, and are mostly strongly bioturbated; in a few intervals, only the tops of the sapropels are slightly bioturbated with *Chondrite*s. The number of sapropels increases dramatically toward the base of the section, where as many as 26 were found within one core. The sapropels vary in organic carbon concentrations from 2% to 11% and show moderately high to low hydrogen indices coupled to the extent of secondary alteration (bioturbation). The source of the organic matter is assumed to be mainly marine, based on shipboard organic geochemical data. The preliminary assessment of paleo sea-surface temperatures, based on alkenone ratios in lipids from sapropel extracts, indicates a fairly stable and warm climate in the Pliocene.

From five individual APC holes, a composite section was compiled by means of high-resolution physical property measurements and sedimentological correlation. Coring gaps were identified between individual cores at each hole, and slight differences in sediment thickness were recognized between individual holes (Fig. 7). Micropaleontological studies have established 18 datum levels in the composite section; these represent the time from the early Pliocene (MPL2 for planktonic foraminifers, and MNN12 for calcareous nannofossils) to the Holocene (sapropel S1 was found near the sediment surface). They imply deposition at nearly uniform rates of around 15 m/m.y. Paleomagnetic measurements reveal extensive diagenetic modifications and neoformation of magnetic carriers in sapropel-bearing intervals; these effects have overprinted the magnetic signal in the sediments and preclude recognition of a coherent shipboard magnetic stratigraphy.

Unit II was reached at markedly different depths in the five holes drilled (Hole 966A, 65 mbsf; Hole 966B, 120 mbsf; Hole 966C, 95 mbsf; Hole 966D, 125 mbsf; Hole 966F, 105 mbsf). The top of the unit is marked by some debris flows and evidence of faulting. The remainder of the unit is mainly matrix-supported breccia, mostly composed of angular, soft carbonate, or well-cemented limestone clasts (up to 5 cm in size) in a matrix of green and brownish micrite. The uppermost breccia contains well-rounded clasts, indicative of reworking under high-energy conditions. Breccias lower in the section are locally cemented by sparry calcite. A few mud clasts yielded calcareous nannofossils of early Pliocene age (MNN12 for nannofossils and MPL2 for planktonic foraminifers), while one of the clasts is provisionally dated as late Miocene. Numerous small high-angle faults with normal offsets were observed. A few limestone clasts show evidence of shearing and cataclastic deformation. Formation microscanner (FMS) data show alternations of clast-rich and clast-poor fine-grained sediment and confirm that the breccia was not the result of drilling disturbance. In addition, the five holes drilled into Unit II at this site allowed an irregular paleotopography to be inferred beneath the Plio-Quaternary succession.

Unit III (105-298.5 mbsf in Hole 966F) contains well-cemented packstones and grainstones, showing cyclical variations in grain size and sedimentary structures. Individual zones include variable abundances of red and green calcareous algae, coral, benthic foraminifers, bivalves, and bryozoans. Benthic foraminifers are locally abundant and suggest a Miocene age. Coarser and thicker bedded intervals have high moldic porosity (e.g., from the dissolution of bivalves) that is locally infilled with brown opaline silica. Several limestone zones are strongly cemented by sparry calcite. Minor dolomitization was also noted.Various trends in the log data (e.g., uranium spikes and other features) correlate with primary sedimentary variations (e.g., grain size), or diagenesis (e.g., secondary porosity and cementation). A relatively small number of high-angle faults and fractures were noted in the cores and FMS data. The base of Unit III is marked by a sharp discontinuity in the log data at 304 mbsf.

Unit IV (298.5-356.0 mbsf) comprises an interval of finely laminated, highly burrowed, well-cemented chalky limestones rich in planktonic foraminifers of middle Eocene age. The limestones contain scattered nodules of black vitreous chert, mainly composed of finely crystalline chalcedonic quartz. There are also several intervals (each tens of centimeters thick) that are composed of finely laminated bituminous limestone, which is thermally immature. The organic matter is hydrogen rich, has a low sulfur content, and is mainly marine in origin. The lowermost four cores exhibit a well-developed tectonic fabric, defined by mainly low-angle veins and shear planes, that are cut by later high-angle normal faults and fractures. Individual burrows within the limestone are “plastically deformed,” indicating shear displacement prior to complete lithification.

The preserved sedimentation history of Site 966 began in the middle Eocene with accumulation of deep-water pelagic carbonates (Unit I), similar to the coeval Lefkara Formation of southern Cyprus. Both these units experienced silica diagenesis and chert formation. The black, laminated sediments, in which organic matter is of mainly marine origin, reflect an interval of enhanced organic-matter deposition under low-oxygen conditions. Deep-water sedimentation was terminated by regression (dominantly driven by tectonic uplift), followed unconformably by accumulation of Unit III as a shallow-water coralgal facies, in an inferred near-reef setting of probable Miocene age. Lithologically similar limestones were cored at Site 965. After a second unconformity, matrix-supported breccias were shed from a rugged (fault-controlled) paleotopography into an open-marine setting in the lowermost Pliocene. The local existence of this mass-wasted unit may explain the irregular and rather diffuse nature of the seismic reflectors directly below the semi transparent Plio-Quaternary at this site. Marine nannofossil ooze and sapropel deposition followed, with local evidence of minor syn-depositional faulting, and derivation of limestone clasts from inferred active faults. Bioturbation and partial oxidation of the sapropels is in keeping with the relatively condensed nature and shallow setting (<1000 m) of sedimentation on the Eratosthenes Seamount plateau area. Fine-grained mud turbidite deposition increased upward, possibly reflecting redeposition processes. This, together with the evidence of a hiatus in the early Pleistocene, may record tectonic disturbances of the Eratosthenes seamount plateau area.

In summary, drilling at Site 966 was clearly successful: we retrieved an extensive record of Pliocene sapropels, identified the nature of the upper Miocene-Pliocene transition at this locality, and shed light on the earlier, Tertiary history of the Eratosthenes Seamount. Tectonically induced collapse of the seamount, inferred from evidence at Site 965, was identified to have occurred, in part, in the early Pliocene.

Site 967

Site 967 is located on a small ridge near the foot of the northern slope of the Eratosthenes Seamount (Figs. 1 and 6). The ridge had been inferred to be a compressional feature related to thrusting beneath the Cyprus active margin to the north. Drilling results support this hypothesis; coring at Site 967 further provided a Plio-Pleistocene sapropel record, and a remarkable window into the history of the Mediterranean Sea as far back as the Late Cretaceous.

Five lithological units were recognized in the sequence recovered from five APC holes and a single RCB hole cored at Site 967 (Fig. 6).

Unit I (0-100 mbsf) is composed of intercalations of bioturbated nannofossil ooze, nannofossil clay, mud turbidites, and sapropels. An important interval of slumping with an overlying debris-flow unit (1-7 m thick) was noted in all holes between 50 and 60 mbsf. Bedding of the host sediment is horizontal to subhorizontal throughout, and is cut by sporadic high-angle faults. Eighty discrete sapropels were identified, in which organic carbon values typically range from 3%-10% (maximum 17%). Sapropels were also imaged in the highest part of the section logged, using the FMS. Many of the sapropels are finely laminated; in the upper three cores, some occur with intercalated mud turbidites. Carbon/nitrogen ratios of the organic matter are relatively high (around 20); hydrogen indices of the organic matter are relatively low (200 to 400 mg hc/g organic carbon) and are positively correlated with organic carbon concentrations. The source of the organic matter may be dominantly marine, but the material appears to be degraded. Optical microscopy shows that fine plant material can be seen in some sapropels, while in others the organic matter is present as amorphous matter and dark brown aggregates. Estimates of paleo sea-surface temperatures (Fig. 8) based on alkenone indices indicate cyclic variations in the Pleistocene between 21˚ and 25˚C, and average temperatures that are 2˚-3˚C higher in the Pliocene, but with less pronounced fluctuations.

Sediment sequences recovered from the five APC holes were correlated by means of continuously logged physical properties, color, and sedimentological features, from which a composite section was constructed. Over several intervals in the Pliocene, the pattern of sapropel occurrence and lithological and physical properties resemble those encountered at Site 966 on the top of Eratosthenes Seamount. Comparisons of the depositional history of the sites of greatly different water depths will be a high-priority objective of post-cruise work.

Paleontological studies recognized 15 datum levels within the Pleistocene and Pliocene and include the lowermost Pliocene zones MNN12 and MPL1. A possible hiatus was identified from 1.75 to 2.0 Ma in Hole 967A (but not in Hole 967C), coinciding with the debris flow and slump. The average sedimentation rate over the entire Unit I is 26 m/m.y., ranging from 5 to 57 m/m.y. The preliminary study of benthic foraminifers indicates forms typical of middle mesobathyal depths (i.e., 1800-2500 m) in the late Pliocene, which give way to an assemblage of possibly lower mesobathyal (2500-3000 m) character, indicative of somewhat deeper water, in the Pleistocene.

Paleomagnetic measurements reveal a complex directional signature that is not easily reconciled with standard paleomagnetic reversal stratigraphy. However, several polarity zones were recognized by measuring discrete samples, and these zones compare well with the biostratigraphic data. Problems with the paleomagnetic measurements arise from magnetic mineral diagenesis and

magnetic overprinting of sequences that contain abundant sapropels and where organic matter degradation results in redox changes during burial. It appears that strong gradients in magnetic intensity (over three orders of magnitude on a scale of centimeters) between the sapropels and the surrounding sediments are introducing artifacts that cannot be resolved with the shipboard cryogenic magnetometer.

Unit II (100-125 mbsf in Hole 967A, and 109.5-125 mbsf in Hole 967E) consists of intercalations of well-consolidated reddish colored nannofossil mud and nannofossil ooze, with both micritic and recrystallized carbonate rock fragments. A mixed microfossil assemblage was noted at ca. 130 mbsf in Hole 967A and Hole 967E, including reworked planktonic foraminifers and nannofossils of middle Eocene, Oligocene, Miocene, and late Miocene-early Pliocene age. Pore-water calcium, sulfate, and strontium data indicate the presence of gypsum at around 120-130 mbsf. Trends of soluble potassium and rubidium are indicative of uptake by clay minerals. Preliminary analysis of FMS and other log data reveal the presence of a highly resistive interval from 120 to 124 mbsf that is thought to be gypsum. Heat-flow measurements indicate increased values at the boundary with Unit I that may result from upward flow of relatively warm water through limestones at depth, possibly along fault conduits; flow was then constrained by relatively impermeable Plio-Pleistocene clay-rich sediments above.

Unit III (125-446 mbsf) is composed of well-lithified bioturbated nannofossil chalk, with several thin (tens of centimeter-thick) intervals of dark organic-matter-rich, laminated calcilutite. Glauconite, pyrite, mollusk shells, and replacement chert concretions were also noted. Deformation structures include both a small (cm-offsets), relatively shallow-dipping suite of normal and reverse faults, and a pervasive fabric of steeply-dipping normal faults with slickensided fault planes. Paleontological studies indicate that the upper part of Unit III is middle Eocene in age, while the lower part is Late Cretaceous (late Santonian-late Maastrichtian), based on well-preserved planktonic foraminifers (*A. mayaroensis-D. asymetrica* Zones) and less well-preserved calcareous nannofossils (NC23 to CC15?). The Cretaceous-Tertiary transition is estimated to lie at ca. 170 mbsf, and although it was probably not recovered, it appears to have some expression in the log data. The FMS and other log data allow the Eocene and Cretaceous pelagic intervals to be distinguished (together with subunits) and also reveal bands of highly resistive material in the Eocene succession, inferred to be chert. FMS data indicate a large number of deformed intervals of

both low and high angle, interpreted as representing several generations of faulting, within which marked conductivity variations are indicative of rheology contrasts (e.g., open vs. cemented fault zones).

Unit IV (446-504 mbsf) consists of well-cemented shallow-water limestones (calcarenites), with calcareous algae, shell fragments, and peloids. Recrystallization and secondary porosity development have destroyed much of the depositional fabric, except within scattered chert nodules. Fossils have not been identified. The limestone is fractured, with an interstitial brown clay-bearing matrix and a finely crystalline carbonate cement. Both calcite and chalcedonic quartz occur as vein fill.

Unit V (504-600.3 mbsf) is restricted to recovery of a small number of clasts of calcarenite, calcilutite, and breccia that are cut by well-developed slickensides. Individual clasts show a gradation from massive to pervasively brecciated, and are composed of mainly angular clasts, showing evidence of shearing, pressure solution, and several generations of cement (i.e., carbonate, then chalcedonic quartz). The FMS and other log data reveal evidence of a breccia-like tectonic fabric, in addition to other features (e.g., bedding).

In summary, Site 967 exhibits a long and diverse geologic history. The site once formed part of a shallow-water carbonate platform, as exposed on land around the Mediterranean Sea. The platform was later inundated, ushering in a 40-m.y. period of deep-water pelagic carbonate deposition, punctuated by low-oxygen episodes in the Late Cretaceous, and times of high-silica accumulation, both in the Late Cretaceous and in the middle Eocene (represented by chert). The earliest Pliocene was the next time interval that is definitely recorded at Site 967. However, the presence of derived microfossils of middle Eocene, Oligocene, Miocene, and late Miocene-early Pliocene age shows that some open-marine sedimentation took place at, or in the vicinity of, Site 967 during the intervening middle Eocene-early Pliocene time interval. Sediments of this time interval may have been deposited and then eroded, perhaps in response to tectonic uplift. Evaporites apparently accumulated in the late Miocene (i.e., Messinian). This was followed by erosion of carbonate clasts and deposition of well-oxidized muds and carbonates, largely by turbidity currents in a open-marine setting, followed my open-marine sedimentation and sapropel deposition. Water depths increased after the late Pliocene in response to dominantly tectonic subsidence, allowing the accumulation of deep-sea nannofossil-rich sediments, interspersed with sapropels and fine-grained mud turbidites.

Interpretation of the site-survey seismic data support the interpretation of Site 967 as a dominantly south-verging thrust structure. In addition, trends in pore-water chloride concentration indicate the presence of a brine at depth, which can be explained by the presence of overthrust Messinian evaporites beneath. However, the shipboard structural data indicate one or more phases of extensional faulting. The site appears to have experienced mainly extensional deformation prior to the late Pliocene, followed by reverse faulting and minor uplift to form the present raised ridge in a compressional setting at the base of the Eratosthenes Seamount slope. This uplift possibly began in the late Pliocene-early Pleistocene at the time of the inferred depositional hiatus and slumping.

In conclusion, drilling at Site 967 has charted the kinematic history of a collision-related structure and revealed part of the Mesozoic history of the Eratosthenes Seamount.

Site 968

Site 968 is located on the crest of a small ridge that projects southward from the base of the Cyprus slope at a depth of 2000 m (Fig. 6). Based on the interpretation of seismic profiles, the site is assumed to lie on the upper plate over a downgoing slab that includes the Eratosthenes Seamount. The site geophysical survey confirmed that the ridge at Site 968 is an intact block relative to adjacent parts of the Cyprus slope that are more deformed. Three units were recognized based on lithological criteria.

Unit I (0-143 mbsf) comprises calcareous nannofossil ooze and nannofossil clay, with some thin ash layers (above 55 mbsf). In total, more than 80 sapropels were recovered (Fig. 9). The upper portion represents the most complete record of upper Pleistocene sapropels so far cored during Leg 160. Mainly below 30 mbsf, many of the individual sapropels are expanded by the deposition of thin (millimeter to centimeter thick) mud and clay turbidites. Sedimentary structures within the fine-grained turbidites (e.g., grading) are well preserved within sapropels, while those in nannofossil oozes and nannofossil clays are mainly highly bioturbated. Two additional APC mud-line cores were taken, allowing the sapropels in three APC cores to be correlated using continuously logged physical properties, color (Fig. 9), and sedimentological features, which will permit shore-based high-resolution study. Carbonate contents are mainly between 20% and 40%. The sapropels contain up to 12% organic carbon, but in general are not as rich in organic matter as at other Leg 160 sites. The Pliocene sapropels are consistently richer in organic carbon and exhibit better preservation of marine organic matter than the Pleistocene sapropels.

Unit II (143-167 mbsf) comprises nannofossil clay, clayey nannofossil ooze, clay, and calcareous silty clay, and was recognized as a discrete unit mainly based on the abundance of clay, mainly kaolinite and smectite. Lower in this unit, X-ray diffraction revealed calcite, quartz, feldspars, clay minerals, dolomite, amphibole, and serpentine minerals. In addition, smear slides contain 27%-45% inorganic calcite (with unusual “rice grain” texture).

Unit III (167-301 mbsf) is composed of calcareous silty clay, silt, and sand, with carbonate typically close to 30%. The unit is dominated by interbeds of silty clay, silt, and fine sand (up to tens of centimeters thick), with relatively low clay content (ca. 30%) and some dolomite. The presence of grading and erosional bases indicates a turbiditic origin. Gypsum is present at ca. 215 mbsf, as millimeter- to centimeter-thick layers (i.e., gypsarenite) within muddy sediments; a 13-cm-thick interval of fine-grained (alabastrine) gypsum is also present. A 5-m-thick gypsum interval was recognized on the resistivity, sonic, and gamma-ray logs (212.5-217.5 mbsf); some additional gypsum may also be present around 182.5 mbsf. The logs also reveal cyclical variation that is interpreted as possible sedimentary grading. XRD and smear slide analysis reveal minerals and lithoclasts, including calcite, quartz, feldspar, dolomite, clay, amphibole, serpentine, opaque minerals, common pelagic carbonate, and rare altered basalt.

Paleontological studies show that extensive reworking of microfossils has taken place throughout all three units. However, 10 datums could be recognized from the Holocene to the lower/middle Pliocene boundary, corresponding to the last appearance of *G. puncticulata* (ca. 3.57 Ma). A hiatus was identified during the late Pliocene to the earliest Pleistocene time interval. A further hiatus may be present around 145 mbsf. The oldest zones recognized are MPL2 for planktonic foraminifers and MNN12 for nannofossils, at 150-153 mbsf. Sedimentation rates increased from relatively low values of 3.5 m/m.y. in the Pleistocene, to ca. 80 m/m.y. in the early Pliocene. No age-diagnostic fossils were found in Units II and III. However, ostracodes possibly related to a brackish environment, and some specimens of the *A. beccarii* group, were noted from 180 mbsf to near the bottom of the hole.

Paleomagnetic studies were limited to the uppermost 110 m of the section that was cored with the APC. Preliminary studies reveal a complex directional signature that is dominated by normal polarity overprinting, and which is probably also influenced by chemical diagenesis. Useful structural observations were also restricted to the APC cores, where a suite of high-angle faults was observed around 30 and 70 mbsf, together with a few small, low-angle faults especially within sapropels (at 30 mbsf). In addition, discrete small-scale (several centimeters) low-angle features around 30 mbsf were probably caused by downslope sediment motion in the early to middle Pleistocene.

A greater than usual number (30) of pore-water samples was taken at Site 968. Salinity rises to four times seawater values at the bottom of the hole; this trend, together with corresponding increases of chloride and sodium, suggests the existence of halite at relatively shallow depths (beneath approximately 600 mbsf). Sulfate decreases in the upper 80 m at this site, probably due to bacterial sulfate reduction. Sulfate then increases to 200 mbsf in the part of the section where detrital gypsum was observed. The absence of any corresponding substantial change in calcium and strontium at this level suggests that equilibria may exist with calcium- and strontium-bearing solid phases at depth. In addition, potassium and rubidium concentrations increase progressively downhole, probably reflecting diagenetic uptake into (expandable) clay minerals within the numerous clay-rich intervals observed.

The section recorded at Site 968 (of Messinian age?) began with accumulation of calcareous turbidites and fine-grained sediments that locally include brackish ostracodes that may have accumulated in a lacustrine setting (of "Lago-mare" type?). The provenance of the thick calcareous turbidites was apparently mainly from the Miocene Pakhna Formation, and the Troodos Ophiolite of southern Cyprus following its initial stages of uplift. Detrital gypsum could also have been derived from up-paleoslope, where gypsum is locally developed in small silled basins. Smectite and kaolinite are abundant in Unit II, possibly derived by erosion of an adjacent landmass under hot, humid conditions. Deep-marine deposition ensued in the early Pliocene. The inferred hiatus in the late Pliocene-earliest Pleistocene corresponds to the time when land-based evidence indicates that southern Cyprus was experiencing intense tectonic uplift. The subsequent demise of all but the thinnest bedded mud turbidites could reflect tectonic uplift of Site 968 from a deep basinal setting in the Messinian/early Pliocene to its present position on the lower slope of the Cyprus margin.

Site 969

Sedimentary Unit I of the sequence at Site 969 (Fig. 1) consists of nannofossil ooze and nannofossil clay with sapropels of early Pliocene to Holocene age (Fig. 10). It unconformably overlies calcareous silty clay of indeterminate age (Unit II) of which a total of 5.45 m was recovered. Holes 969A, 969B, and 969C contain locally faulted and thinned sedimentary sequences. However, some sedimentological markers and physical properties in these holes could be unambiguously correlated. Hole 969D recovered a tilted sequence containing small reverse faults. This hole appears to have yielded a more complete sedimentary sequence than the others, which contain numerous normal faults.

Over 80 sapropel beds were recovered from the lower Pliocene through Holocene section at Site 969 (Fig. 10). The sapropels clearly stand out in a number of continuously logged physical properties: their density is lower (1.4 g/cm^3) than that of carbonate oozes; their water content is higher, and their natural gamma-ray emission is distinctly higher and correlates with organic carbon concentrations. The sapropels occur in five distinct groups, separated by intervals of sediment that are commonly oxidized, yellowish brown in color, and have no preserved sapropels. The lowermost sapropel occurs near the transition of Units I and II, presumably directly after the establishment of marine conditions. The darkest black sapropels, of middle Pliocene age, possess a fine, bedding-parallel parting, which may be a primary lamination. Their organic carbon content reaches 30%. Based on the amount of hydrocarbons liberated by pyrolysis, the organic matter is interpreted as degraded marine material with admixtures of terrigenous origin. The organic matter has unusually high carbon to nitrogen ratios; the high organic carbon concentrations are associated with high sulfur concentrations of up to 12%. Preliminary assessment of paleo sea-surface temperatures (SST) suggest that the surface mixed layer was significantly warmer during the Pliocene as compared to the Pleistocene.

A total of 18 biostratigraphic events were recognized in Hole 969A, ranging from the earliest Pliocene (MPL 1) to the late Pleistocene. The clay-rich unit at the base of the recovered sequence contained no age-diagnostic taxa and yielded only reworked marine specimens and ostracodes indicative of brackish water. The age vs. depth relationship reveals that the sedimentation rate in Hole 969A averaged 22 m/m.y. (range 6 to 86 m/m.y.) since the early Pliocene (Fig. 11). Several polarity zones were recognized by measuring discrete samples, and these zones compare well with the biostratigraphic data. The magnetic intensity is found to be much higher in the sapropels than in the surrounding sediment. A significant increase in intensity appears to be a general feature of sapropels and may be related to post-depositional magnetic enhancement by mineral formation during diagenesis.

Pore-water concentrations of dissolved ions imply that solutions characteristic of late-stage brine, possibly derived from dissolving evaporites at depth, are present below the cored sediment interval. The ratios of ammonia and alkalinity show that some carbonate diagenesis occurs in the sediment.

As was expected, Site 969 yielded a sedimentary sequence that includes the uppermost Messinian(?), a well-developed basal Pliocene, and a Pliocene to Holocene section with abundant and extraordinarily organic-rich sapropels. Tectonic overprinting has resulted in considerable variation between holes that are within a few hundred meters distance. Detailed post-cruise inter-hole correlation will have to establish if the sequence is complete and if a composite section can be constructed for high-resolution studies.

Site 970

An east-northeast - west-southwest transect of four holes was drilled from the flank to the crest of the Milano mud volcano, within the Olimpi mud diapir field (Figs. 1 and 12). This is located on the northern part of the Mediterranean Ridge (150 km south of Crete). Hole 970A (to 200 mbsf) sampled the mud volcano’s outer flank. Hole 970B (to 50 mbsf), ca. 600 m farther from the volcano, examined the most distal effects of mud volcanism; Hole 970C (50 m) characterized the nature of the upper flank of the mud volcano; and, finally, Hole 970D (to 30 mbsf) examined the crestal area.

At the outermost hole (Hole 970B), the sediments comprise interbedded nannofossil oozes, nannofossil clays, and sapropels, typical of the regional hemipelagic sedimentation. There are also poorly consolidated thin- to medium-bedded sands and silts. Some intervals are tilted, and small normal and reverse faults were noted. This section is dated as early-late Pleistocene.

The outer flank hole (Hole 970A) comprises alternations of mud debris flows and normal hemipelagic sediment (Fig. 12). The section begins with pebbly mudstone with a thin (<1 m) pelagic interval dated as younger than 0.26 Ma. This is underlain by thick clast-rich mud debris flows (7.6-134 mbsf), and then by a thin interval of pelagic sediment (155-234 mbsf), dated as slightly older than 1.5 Ma to slightly younger than 0.99 Ma. This is turn is followed by layered coarse-grained turbidites with mud clasts at the base, together with minor graded sands and silts (155-192 mbsf), and then finally by normal pelagic sediments (l92-201 mbsf) dated at 1.75 Ma. Downhole logs, including the FMS, clearly define the main intervals and show that the mud debris flows include numerous clasts of various lithologies, up to 0.5 m in diameter.

The inner flank and crestal holes (Hole 970C and the top of Hole 970D) recovered mainly “mousse-like” muddy and silty sediments, with evidence of gas hydrates (see below).

Overall, a number of different mud volcanic facies are present. The clast-supported facies in the lower part of Hole 970A are interpreted as turbidites and minor debris flows. The predominant extrusive sediment type, however, is well-consolidated, matrix-supported, clast-rich debris flows (the well-known “mud breccias”), in which the matrix ranges from silty clay to rare sandy silt, with nannofossils, foraminifers, clay, quartz, and rock fragments. Clasts vary in shape from mainly subangular to subrounded and less commonly angular or rounded. The clast lithologies include poorly consolidated sandstone and siltstone, weakly to well-consolidated calcareous claystone and mudstone, together with calcite (or locally quartz)-cemented sandstone and siltstone.

Numerous sandstone clasts are mostly litharenites, derived from mainly plutonic igneous and metamorphic source terrains, admixed with shallow-water carbonate (e.g., calcareous algae and polyzoans and pelagic carbonate). Lithoclasts of pelagic carbonate include foraminifers of middle Miocene (Burdigalian-Langhian) age. In addition, some clasts contain nannofossils and planktonic foraminifers of Eocene and Oligocene age, and rare nannofossils of Cretaceous age again within clasts of Miocene pelagic limestone; brackish-water ostracodes (Messinian or early Pliocene?) were also observed in a few clasts.

Pore-water salinities in Holes 970A and 970B show a linear increase with depth to approximately twofold seawater values. By contrast, in Holes 970C and 970D, pore-water salinities decrease with depth, which is explicable by the decomposition of clathrates (methane hydrates). Very low sulfate levels in this hole may relate to intense bacterial sulfate reduction.

In Hole 970D, bubbles generated in the mud by decompression contained pure methane in the upper 30 m, but with several orders of magnitude lower concentrations beneath this (to 50 m). Levels of higher hydrocarbons relative to methane increase toward the bottom of the hole, so that the methane/ethane ratio decreased from about 4300 in the top core to 18 in the lowest part (40-50 m). Carbonate contents range from 40% to 60% in the pelagic intervals, to typically 15% within the matrix of the mud breccias, and 20%-30% within the stratified clastic sediments in the lower part of Hole 970A. Organic carbon values in the mud matrix are low (ca. 0.5%).

The Milano mud volcano became active around 1.75 Ma, or earlier. Stratified debris flows and turbidites record relatively early mud volcanism. Mudflows were localized around the eruptive center on the transect studied. Seismic reflectors around the mud volcano dip inward and imply progressive subsidence, perhaps resulting in ponding of the mud debris flows. Normal pelagic sediments accumulated around the mud volcano during the Pleistocene, interbedded with turbiditic silts and sands, possibly shed from the crestal area. Hemipelagic sediments interdigitate with mud debris flows on the flanks, while more silty and mousse-like sediments with clathrates characterize the crestal area.

Site 971

The Napoli mud volcano was drilled in the Olimpi field south of Crete (Figs. 1 and 13). Site survey data confirm that the mud dome is an asymmetrical flat-topped mound structure, with a well-defined peripheral moat and underlying inward-dipping reflectors. Hole 971A (106 m) was drilled just beyond the moat to investigate the margin of the mud volcano; Hole 971B (203 m) was drilled within the moat; Hole 971C (17 m) was drilled at the same site to recover unusual diatomaceous muds; while Holes 971D (46 m) and 971E (29 m) were drilled to investigate the crestal area (Fig. 13).

In Hole 971A the sediments comprise interbedded nannofossil oozes, nannofossil clays, and turbidites, in which 11 combined nannofossil and planktonic foraminifer datums were noted, ranging from middle-late Pleistocene to middle Pliocene in age. This sediment is underlain by clast-rich, matrix-supported mud debris flows (16.5-71.0 mbsf). The clasts (15-25 vol%) are mainly calcareous and range from several millimeters to a few centimeters in size. The matrix of the mud debris flows contains Pleistocene, middle Miocene, Oligocene, and Eocene nannofossils. The pelagic sediment above the mud debris flow is dated at more than 0.46 Ma, while that beneath the mud debris flow is younger than 1.5 Ma. In addition, the lower part of the debris flow is within the *Gephyrocapsa* Zone of 1.25-1.5 Ma. Clasts in the mud debris flows were dated as Burdigalian to Langhian in age. In addition, the Miocene clasts rarely contain nannofossils and planktonic foraminifers of Oligocene, Eocene, and Cretaceous age. The section ends with hemipelagic sediments.

Within the moat (Hole 971B) an upper unit of hemipelagic sediments with sapropels (0-20 mbsf) is underlain by mud debris flows that are older than 0.26 Ma, but younger than 0.46 Ma. Clast-poor mud debris flows alternate with more homogeneous silty clay. The matrix and the clasts in the mud debris flows are similar to those in Hole 971A; however, Pleistocene species are more abundant in Hole 971B.

Downhole logs (especially natural gamma and resistivity) indicate the presence of a number of thin layers that correspond to relatively sandy cored intervals. Intervals with unusual compaction trends may correspond to recovery of soupy sediment. The logs also distinguish clast-rich and clast-poor intervals.

Hole 971C recovered an expanded section. A 3.3-m-thick S5 sapropel is composed of laminated diatom ooze, with well-preserved diatom species characteristic of upwelling, as well as mat-forming varieties. Some radiolarians are also present.

Hole 971D recovered mousse-like silty clay with scattered small (<5 cm) clasts of mudstone and siltstone. In addition, angular fragments of coarsely crystalline halite (up to 3 cm in size) are concentrated in thin, more silty layers, together with a small number of subrounded halite-cemented mudstone clasts (<5 cm in size). The matrix contains dominantly reworked middle Miocene nannofossils, with rare late Pleistocene forms in the upper part of the section.

Hole 971E comprises mousse-like silty and sandy clays with a few small (<3 cm) clasts of mudstone and fine-grained carbonate. Rare nannofossils of late Pleistocene age are present in the upper part of the section, while reworked Miocene nannofossils dominate beneath this.

Gas is much more abundant in the Napoli mud volcano than in the Milano mud volcano. The methane/ethane ratios in Holes 971B, 971D, and 971E vary from 10-40 overall, but in individual holes values remain constant with depth. In contrast to the Milano mud volcano, methane hydrates (clathrates) were not observed. The gas also contains several higher hydrocarbons up to hexane and a number of hydrocarbons that could not be identified on the ship. Measured organic carbon is in the range typical of Pleistocene (ca. 2%-6%) and Pliocene (up to 24%) sapropels. Again in contrast to the Milano mud volcano, pore waters from the crestal holes are saturated with respect to halite in all five holes (Fig. 14). Brines in the lower part of Hole 971A are unusually rich in potassium (Fig. 14), suggesting that brine of more than one source may be present. Very high alkalinity throughout (ca. 80 mmol/L in Holes 971D and 971E) probably formed by microbial consumption of methane. A sharp downward decrease in sulfate was observed in Hole 971B, probably indicating high bacterial sulfate reduction rates and an organic-matter-rich substrate. A single ADARA temperature measurement obtained in Hole 970D at 45 mbsf gave a temperature of 16.1˚C, which is 2˚C above normal bottom-water levels.

The sediments cored from the Napoli mud dome all show clear evidence of sedimentary layering, and an origin by intrusion of mud sills can be excluded. The well-developed moat contains layered muddy debris flows with few clasts, compared to the thick clast-rich mud debris flows recovered at the Milano mud volcano (Hole 970A). More clast-rich mud debris flows interfinger with hemipelagic sediment on the flanks, as observed in the Milano mud volcano. The presence of more silty sediment in the crestal holes may relate to a contrasting mode of eruption, or the effects of current winnowing. Solid halite in the crestal holes (Hole 971D) was introduced both as crystalline aggregates and as halite-cemented clasts. Hydrocarbon gas is continuously flowing to the surface in the Napoli mud volcano, and clathrates are absent (both in contrast to the Milano mud volcano), perhaps because of the effects of higher pore-fluid temperatures and salinities of up to 300 g/kg. The Napoli mud volcano apparently first erupted between 1.5 and 1.25 Ma and has been episodically active to the present time, in contrast to the Milano mud volcano, which is probably now dormant.

Site 972

Site 972 is located on a small topographic high on the lower slope of the Hellenic accretionary prism (Fig. 1). Seismic data indicate that the section is folded and faulted. The main objective of drilling was to infer the structural history of the toe of the accretionary wedge, in particular any evidence of subduction/accretion processes, or vertical tectonics. Drilling reached only 100 m due to mechanical problems, and was unable to achieve all its objectives.

Only one lithological unit was recognized, composed of alternations of nannofossil clay, clayey nannofossil ooze, and nannofossil ooze (Fig. 15). Carbonate values range from 15% to 86%. Minor components of the background sediments include quartz, volcanic glass, inorganic calcite, and authigenic minerals, including calcite and pyrite. In addition, minor ash layers are present in the upper part of the section. Organic carbon values range from 0.2% to 1% in the nannofossil-rich sediments. There are also sporadic thicker beds of turbidites up to a meter or more, with thin (1-2-cm) graded silt layers at their base, composed of quartz, mica, inorganic calcite, and foraminifers. Sporadic intervals of fine sand up to 50 cm in thickness are visible. Based on color and compositional variation, three main types of turbidites are recognized: (1) white nannofossil ooze, (2) green-yellow clayey nannofossil ooze, and (3) silt or fine sand, fining upward to gray-green nannofossil clay. In addition, 24 discrete sapropels were noted, all of which are enriched in pyrite, amorphous organic matter, volcanic glass, quartz, and fragments of higher plant material. Carbonate contents in the sapropels range from 3% to 40%, and organic carbon values are between 2% and 14%. Measurements of corrected bedding orientation indicate shallow to moderate dips (1˚ to 57˚), mainly toward the southwest and to a lesser extent toward the northeast, broadly parallel to the trend of the Mediterranean Ridge. Three small reverse faults in one core dip to the northwest.

Micropaleontological studies reveal a large degree of reworking and poor preservation of assemblages. Only 4 first-occurrence datums and 1 last-occurrence datum could be recognized, indicative of a late Pleistocene to latest Pliocene age.

Pore-fluid analysis indicates that salinity increases up to 7 times normal seawater values from the top of the hole downward. The pore-water data point to the existence of a late-stage evaporite at depth, of presumed Messinian age.

In summary, drilling at Site 972 confirmed that turbidites of heterogeneous origin are present on the toe of the Hellenic accretionary complex. There is some evidence of tilting and reverse faulting. Also, evaporites are assumed to exist at depth, and brines have permeated upward.

Site 973

The objective of drilling at Site 973 was to investigate the structure, sedimentation, and geochemical environment of the lower toe of the Hellenic accretionary prism. The site is located on a broad high slightly higher on the slope relative to Site 972. Two units were recognized.

Unit I comprises 84 m of nannofossil ooze and nannofossil clay of late Pliocene to Holocene age with more than 27 intercalated sapropels. There are also interbeds of sands, silts, and nannofossil clays, and a single 14-m-thick interval of sand, grading upward into nannofossil clay. The provenance of the sand was mainly foraminiferal lime mudstones. The turbidite-rich interval is distinguished on the downhole gamma-ray logs by progressive changes in radioactivity. Three thin ash layers are present in the upper part of the section. Pleistocene planktonic foraminifers are generally common to abundant, while Pliocene forms are less diverse and moderately to poorly preserved. Reworking is common throughout.

Unit II is made up of ca. 68-m reddish-colored, clayey nannofossil ooze and an underlying calcareous silty claystone with a thin black layer almost completely replaced by gypsum that is interpreted as a relict sapropel. The unit is paleontologically dated as early to late Pliocene. Planktonic foraminifers are rare or absent. Downhole logs of this poorly recovered interval suggest the presence of alternations of relatively coarse- and fine-grained sediments. High uranium levels in the downhole logs may indicate the presence of organic-rich layers (e.g., sapropels) above 112 mbsf.

The upper part of the section cored by APC was correlated between holes based on the nature and occurrence of sapropels, turbidites, and distinctive ash beds. High-resolution color reflectance data were used to check visual correlations. Incomplete stratigraphic records were attributed to coring gaps, and erosion and removal of some sapropels, possibly by the turbidity currents responsible for sand deposition.

Bedding in the upper part of the section recovered by APC generally dips shallowly to the south or southwest. Some steeply inclined normal faults occur locally with small offsets. Elsewhere, sub-vertical faults with offsets of up to 44 cm in length were noted. Between 140 and 152.6 mbsf, microveins and small-scale reverse faults are infilled with fibrous gypsum. Several generations of cross-cutting gypsum veins can be observed. The gypsum was also deformed by tension gashes, linked with small-scale en-echelon fractures. In addition, discrete beds of angular to subangular clasts were noted near the base of the recovered section. The veins and tension gashes indicate that these rocks have been affected by shear, possibly in more than one orientation. The structural features and changes in bedding dips within the section indicate a downward increase in deformation toward a décollement beneath the toe of the Mediterranean Ridge accretionary complex.

Pore-water analyses record a sharp increase in salinity with depth, to a maximum level of 370‰ at the base of the recovered interval. Chloride parallels this increase, together with magnesium, but sodium decreases; this suggests that a magnesium-rich (>40 times seawater) brine with a low sodium content may be present at depth. Calcium increases steeply down to the level where gypsum is present, then decreases. Trends in sulfate, calcium, and alkalinity indicate upward diffusion of sulfate, carbonate dissolution or dolomitization reactions at depth, and gypsum precipitation below 100 mbsf. All the gypsum present in Unit II is interpreted as a secondary precipitate from sulfate-rich pore waters, based on the textural evidence in the cores. Methane concentrations increase slightly downhole, and an alkalinity buildup at depth may in part be related to bacterial methane consumption. High levels of magnesium near the base of the recovered section (>40 times seawater concentration) imply that a magnesium-rich brine is located at this depth. Bromide concentrations also increase steeply with depth, suggesting the existence of a late-stage evaporite brine.

CONCLUSIONS

Leg 160 included the study of geological responses to collisional processes in three contrasting tectonic settings. The first of these settings, in the east, is the collision of an inferred continental fragment, the Eratosthenes Seamount, with the Eurasian continental margin to the north, represented by the Cyprus active margin. A north-south transect of four holes was made from the Eratosthenes Seamount to the Cyprus slope. The second objective concerned processes related to the formation of mud domes, resulting from both mud diapirism and mud volcanism on the Mediterranean Ridge, within the Olimpi area south of Crete. Four holes were drilled on the Milano mud dome, one on the crest and three on the flanks, while a further five holes were drilled on the Napoli mud dome: one on the flanks, two near the base of the dome, and two in the crestal area. In addition, the eastern flank of the Milano Dome in the Olimpi Field was also drilled, as there the seismic character of the flank facies was more clearly imaged. Some additional information on the regional tectono-sedimentary setting of the Plio-Pleistocene of the Mediterranean Ridge was obtained by drilling nearby for sapropels at Site 969. The third objective, in the west, was the Ionian deformation front, where a transect of three holes was drilled, one on the abyssal plain and two on the lower and middle slopes of the accretionary prism, respectively. The aim here was to sample the incoming sediments and then to compare them with the accreted material, in which fluids may have been affected by salt tectonics associated with the Messinian desiccation event.

In conclusion, the tectonic component of Leg 160 was conceived as a contribution to the understanding of incipient collision-related processes in the Eastern Mediterranean, with a major focus on the tectonic history of the Eratosthenes Seamount and the mud volcanoes of the Mediterranean Ridge. The aim in both cases was to shed light on fundamental processes that operate on a global basis.

In the sediments recovered from the Pliocene to Holocene hemipelagic sequence, more than 80 individual sapropels were found. Preliminary shipboard investigations suggest that the pattern of sapropel occurrences marks periods when the Mediterranean catchment area experienced increased humidity and high average temperatures. These conditions resulted in cyclical and dramatic changes of conditions both in the biologically active surface layer and at the seafloor. A general dependence on global climate is evident in the pattern of sapropel frequency during the Pliocene: before the onset of glaciations in the northern hemisphere (at approximately 2.5 Ma), sapropels occurred frequently, simultaneously, and irrespective of paleo water depth at all sites. After the onset of glaciations, their occurrence was less frequent, the concentrations of organic carbon vary with water depth, and periods of sapropel deposition are separated by well-oxygenated reddish sediment intervals. When sapropel bundles occurred during this later interval, they coincided with times when the global climatic background was warm and ice volume was at a minimum. The initial interpretation from shipboard study is that anoxic conditions in the deep water were a primary contributor to sapropel formation. The link to the climatic background implies a dependence on deep-water formation rates, which may be amplified by simultaneous changes in physical water-mass structure and characteristics, and processes in the biologically active surface layer.

Aside from their paleoceanographic significance, the sapropels recovered during Leg 160 represent a rare and excellent opportunity to study the mechanisms and conditions of organic-carbon-rich sediment formation in the marine environment. Together with detailed stratigraphic work, questions concerning the nature of the environment during sapropel events will be the focus of land-based research.

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Prahl, F.G., and Wakeham, S.G., 1987. Calibration of unsaturation patterns in long-chain ketone composition for paleotemperature assessment. *Nature*, 330:367-369.

Sikes, E.L., and Volkman, J.K., 1993. Calibration of alkenone unsaturation ratios ($U_{37}^{k'}$) for paleotemperature estimation in cold polar waters. *Geochim. Cosmochim. Acta*, 57:1883-1889.

FIGURES

Figure 1. Location of Leg 160 sites in the Eastern Mediterranean. Bathymetry in meters.

Figure 2. Lithostratigraphic profiles, age, and sapropel occurrences of the paleoceanographic transect drilled during Leg 160.

Figure 3. Recovery, lithostratigraphic profile, magnetostratigraphy, and nannofossil and foraminiferal bioevents at Site 963.

Figure 4. Age vs. depth (meters composite depth, mcd) diagram showing selected calcareous nannofossil datums and paleomagnetic reversals with corresponding sedimentation rates. The core level and depth (mcd) data shown below each fossil datum represent the last sample where the marker species was not found for corresponding first-occurrence datums and the first sample where the marker species was not found for corresponding last-occurrence datums.

Figure 5. Core recovery, lithostratigraphy, and nannofossil and foraminiferal bioevents at Site 964.

Figure 6. Eratosthenes Seamount transect. A. Location of Sites 965 through 968. B. Lithostratigraphic profiles, age, and location of Sites 965 through 968. C. Tectonic model.

Figure 7. Percentage color reflection (550-nm wavelength) from Site 966 on the mcd (meters composite depth) scale. Holes 966A through 966E are vertically offset from each other by a constant (30 instrument units). Cores from each hole are shown (e.g., B3 = Core 160-966B-3H).

Figure 8. Variation of paleo sea-surface temperatures (SST) during times of sapropel deposition as a function of depth at Site 967. Temperatures were calculated from the alkenone unsaturation index according to the calibrations of (a) Sikes and Volkman (1993), (b) Prahl and Wakeham (1987), and (c) Brassell (1993).

Figure 9. Lithostratigraphic profile, sapropel occurrences, age, and color reflectance (550 nm) at Site 968.

Figure 10. Lithostratigraphic profile and description, recovery, age, and sapropel occurrence at Site 969. A= ash layers

Figure 11. Age vs. depth (meters composite depth, mcd) diagram for Site 969, showing selected calcareous nannofossil datums with corresponding sedimentation rates. The core level

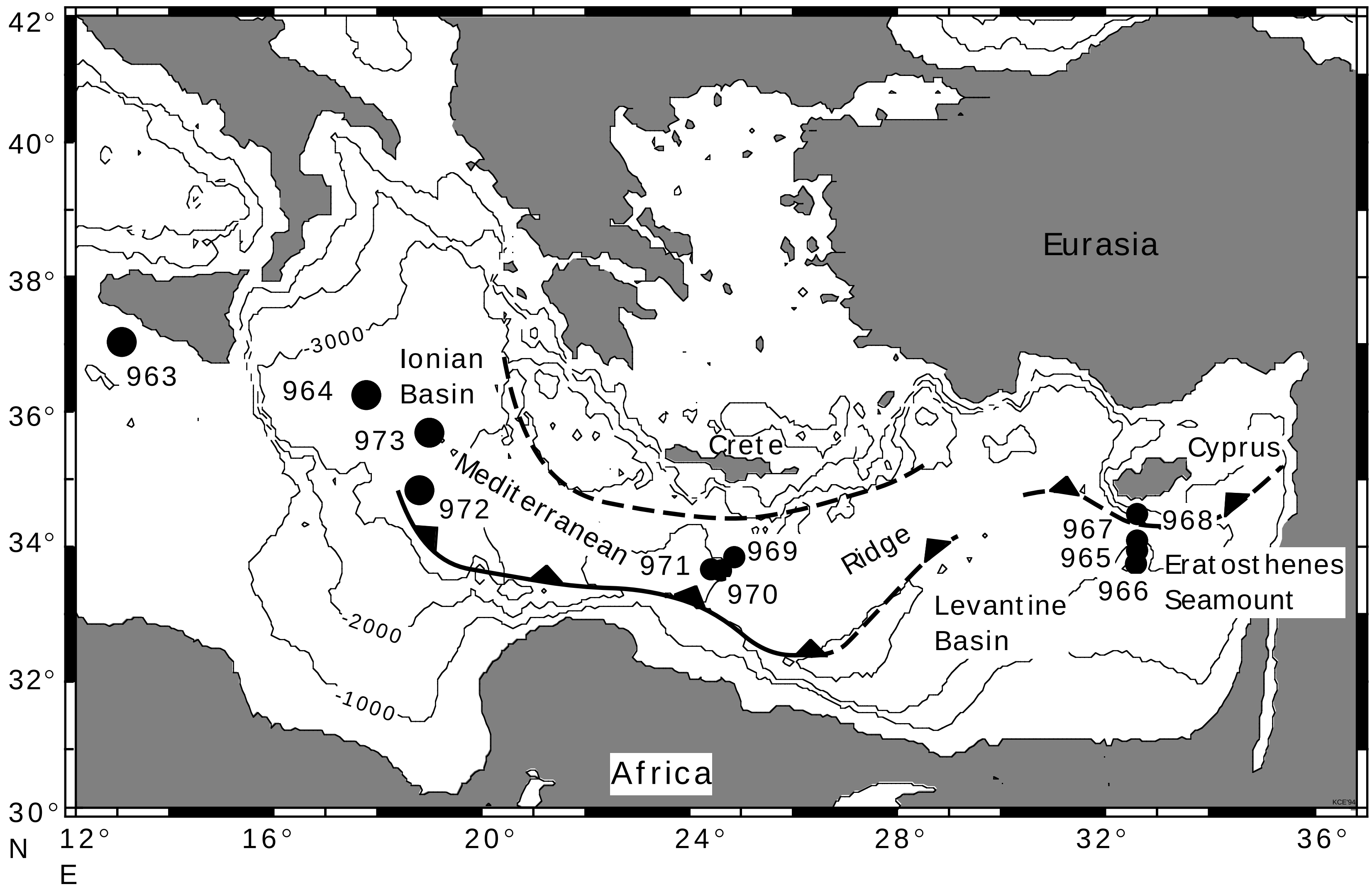
and depth (mcd) data shown next to each fossil datum represent the last sample where the marker species was not found for corresponding first-occurrence datums and the first sample where the marker species was not found for corresponding last-occurrence datums.

Figure 12. Lithostratigraphic profiles of Holes 970A through 970D at the Milano mud volcano. The location of each hole is shown on a simplified seismic profile.

Figure 13. Lithostratigraphic profiles of Holes 971A through 971E at the Napoli mud volcano. The location of each hole is shown on a simplified seismic profile.

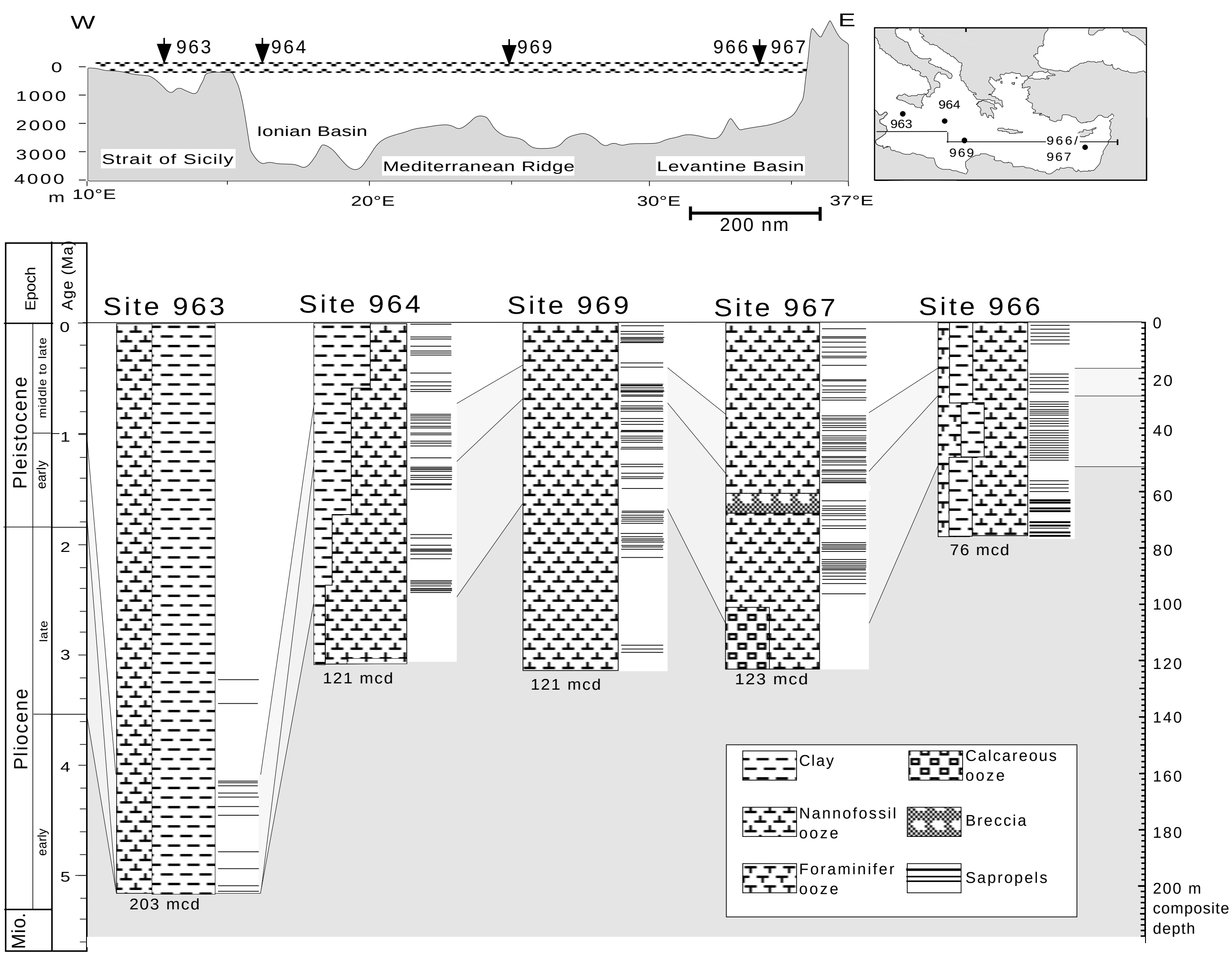
Figure 14. Pore-water salinity, chloride, and potassium concentrations vs. depth for Holes 971A through 971E.

Figure 15. Lithostratigraphic profile and description, recovery, age, and sapropel occurrence at Site 972.



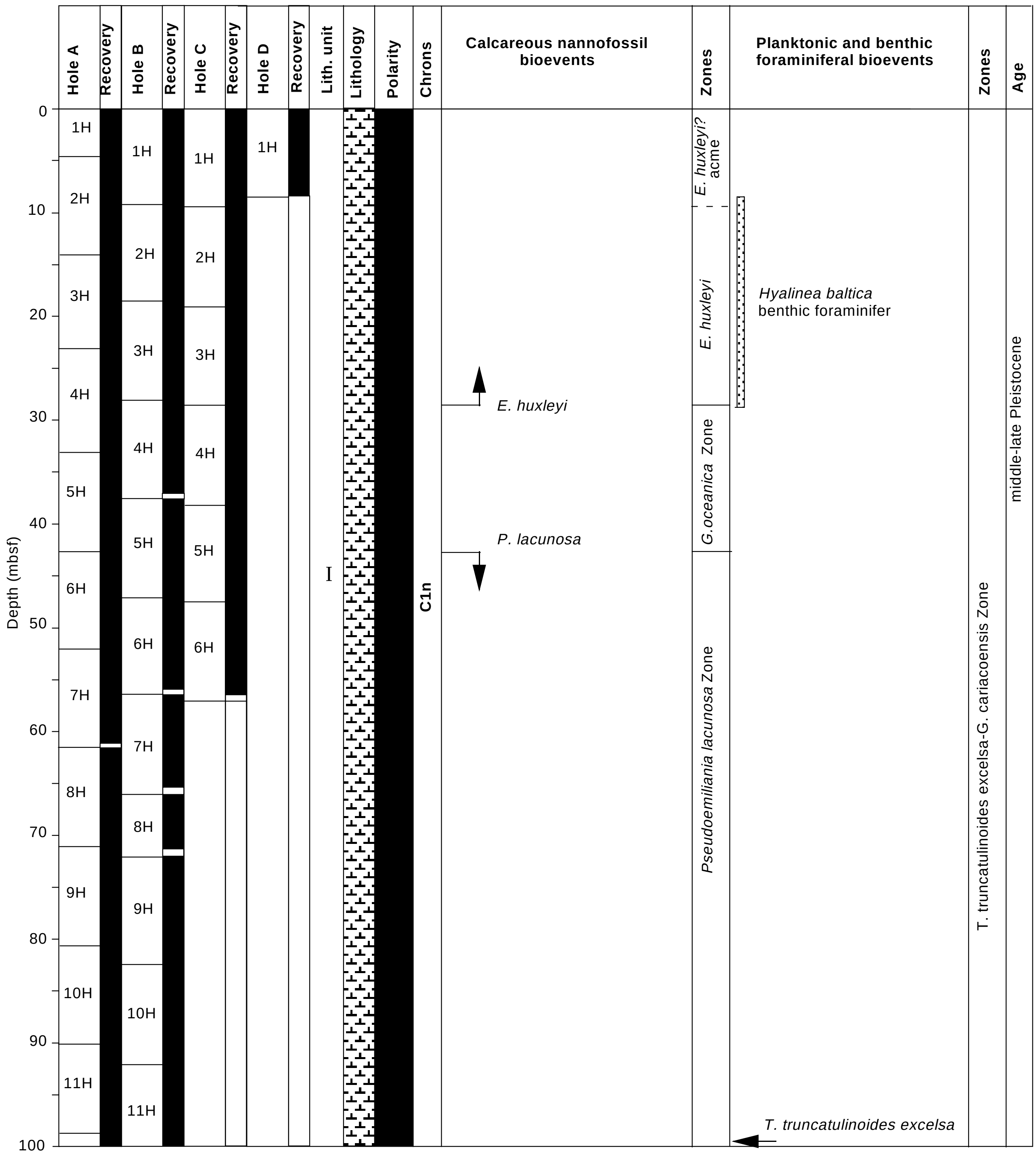
42°
40°
38°
36°
34°
32°
30°
N
12°
E
16°
20°
24°
28°
32°
36°
Eurasia
963
964
Ionian
Basin
973
-3000
972
Mediterranean
Crete
971
969
970
Ridge
Levantine
Basin
Cyprus
967
968
965
966
Eratosthenes
Seamount
-2000
-1000
Africa

Figure 1



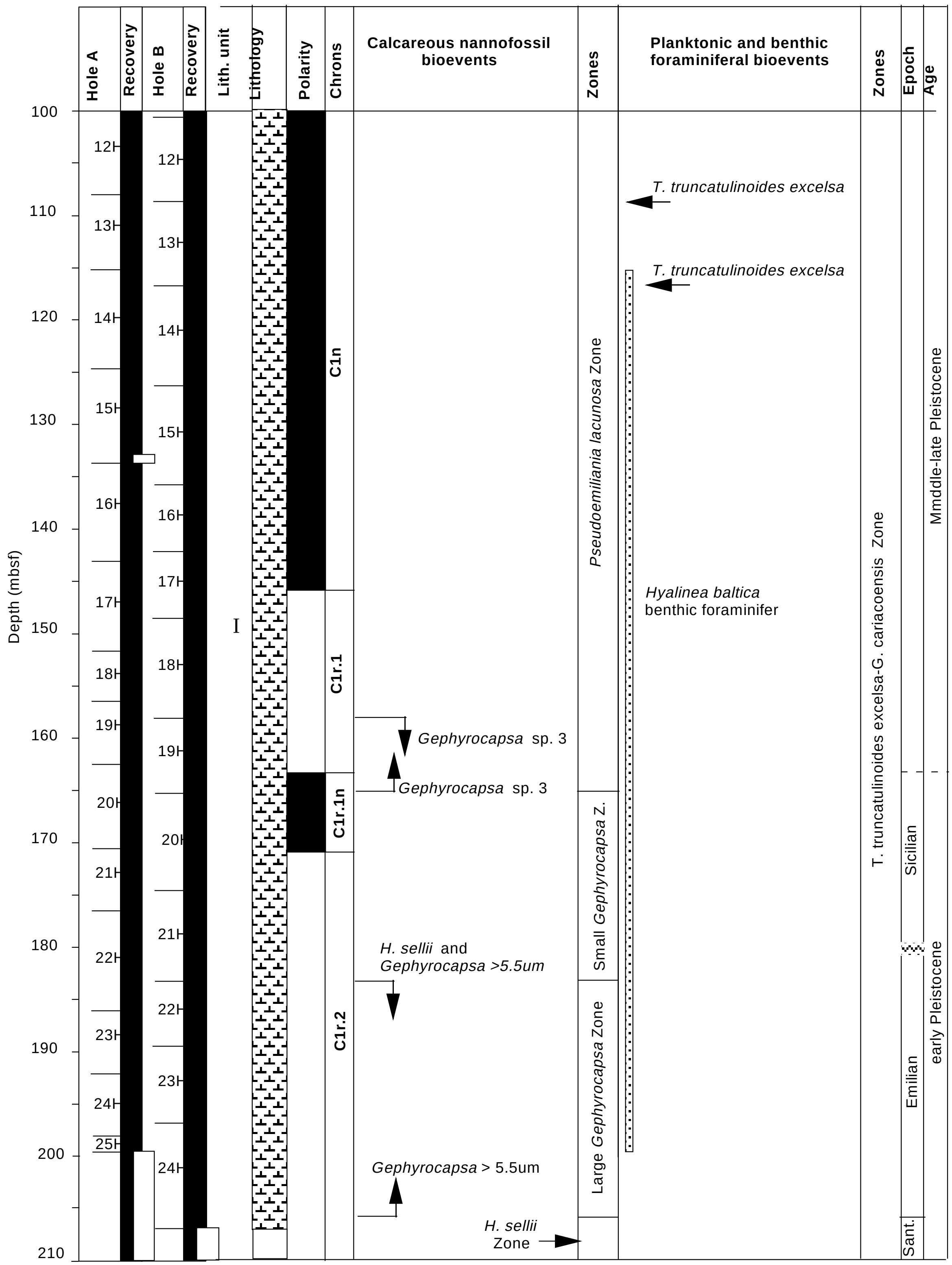
W
E
963
964
969
966
967
0
1000
2000
3000
4000
m
10°E
20°E
30°E
37°E
200 nm
Strait of Sicily
Ionian Basin
Mediterranean Ridge
Levantine Basin
963
964
969
966/
967
Epoch
Age (Ma)
Pleistocene
middle to late
early
Pliocene
late
early
Mio.
Site 963
Site 964
Site 969
Site 967
Site 966
203 mcd
121 mcd
121 mcd
123 mcd
76 mcd
200 m
composite
depth
Clay
Nannofossil
ooze
Foraminifer
ooze
Calcareous
ooze
Breccia
Sapropels

Figure 2



Hole A
Recovery
Hole B
Recovery
Hole C
Recovery
Hole D
Recovery
Lith. unit
Lithology
Polarity
Chrons
Calcareous nannofossil bioevents
Zones
Planktonic and benthic foraminiferal bioevents
Zones
Age
Depth (mbsf)
0
10
20
30
40
50
60
70
80
90
100
1H
2H
3H
4H
5H
6H
7H
8H
9H
10H
11H
I
C1n
E. huxleyi
P. lacunosa
E. huxleyi? acme
E. huxleyi
G.oceanica Zone
Pseudoemiliania lacunosa Zone
Hyalinea baltica
benthic foraminifer
T. truncatulinoides excelsa
T. truncatulinoides excelsa-G. cariacoensis Zone
middle-late Pleistocene

Figure 3a



Hole A
Recovery
Hole B
Recovery
Lith. unit
Lithology
Polarity
Chrons
Calcareous nannofossil bioevents
Zones
Planktonic and benthic foraminiferal bioevents
Zones
Epoch
Age
Depth (mbsf)
100
110
120
130
140
150
160
170
180
190
200
210
I
C1n
C1r.1
C1r.1n
C1r.2
Gephyrocapsa sp. 3
Gephyrocapsa sp. 3
H. sellii and Gephyrocapsa >5.5um
Gephyrocapsa > 5.5um
H. sellii Zone
Pseudoemiliania lacunosa Zone
Small Gephyrocapsa Z.
Large Gephyrocapsa Zone
T. truncatulinoides excelsa
T. truncatulinoides excelsa
Hyalinea baltica benthic foraminifer
T. truncatulinoides excelsa-G. cariacoensis Zone
Sicilian
Emilian
Sant.
Mmddle-late Pleistocene
early Pleistocene

Figure 3b

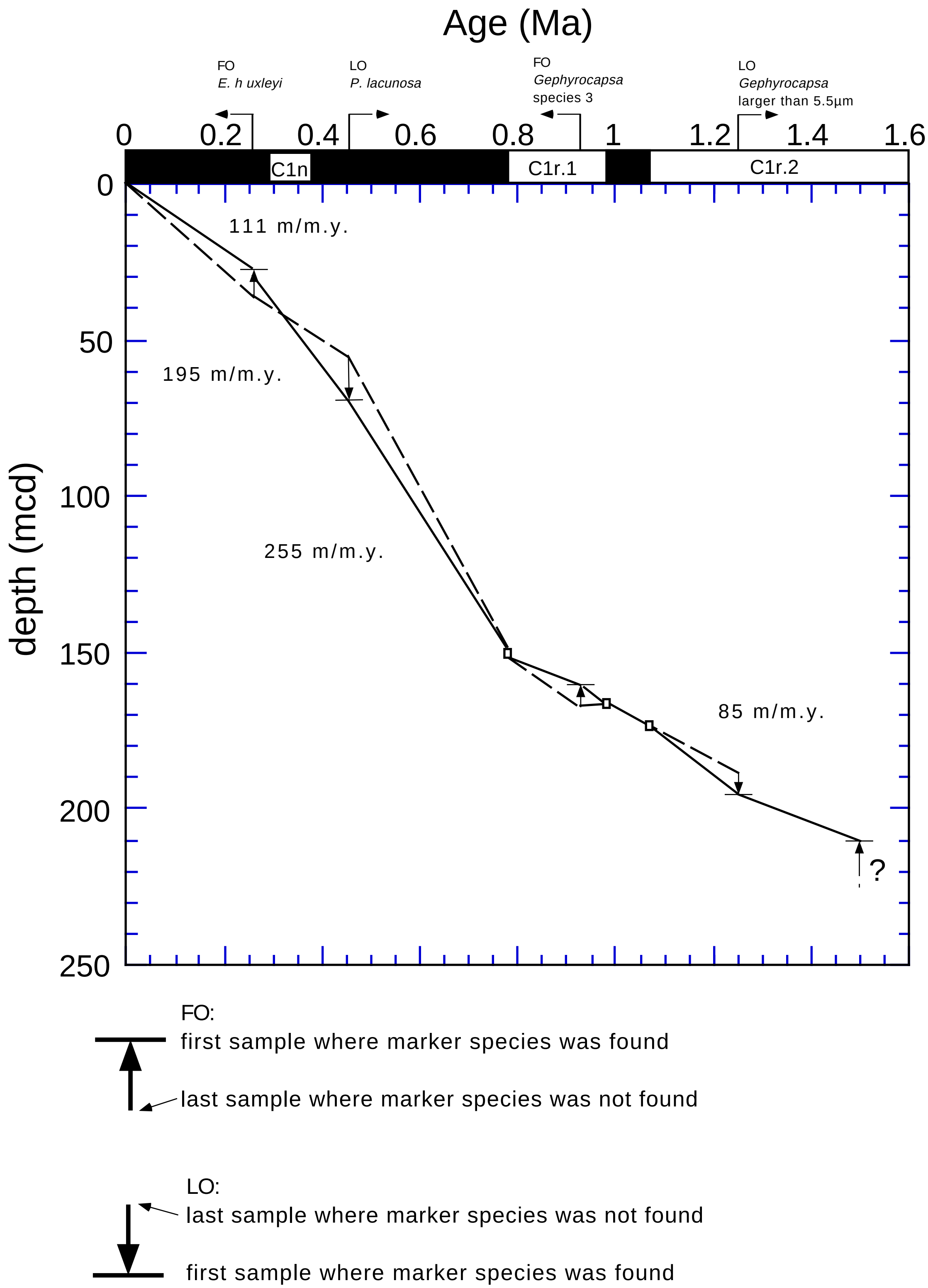

Age (Ma)
FO
E. h uxleyi
LO
P. lacunosa
FO
Gephyrocapsa
species 3
LO
Gephyrocapsa
larger than 5.5µm
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
C1n
C1r.1
C1r.2
0
50
100
150
200
250
depth (mcd)
111 m/m.y.
195 m/m.y.
255 m/m.y.
85 m/m.y.
?
FO:
first sample where marker species was found
last sample where marker species was not found
LO:
last sample where marker species was not found
first sample where marker species was found

Figure 4

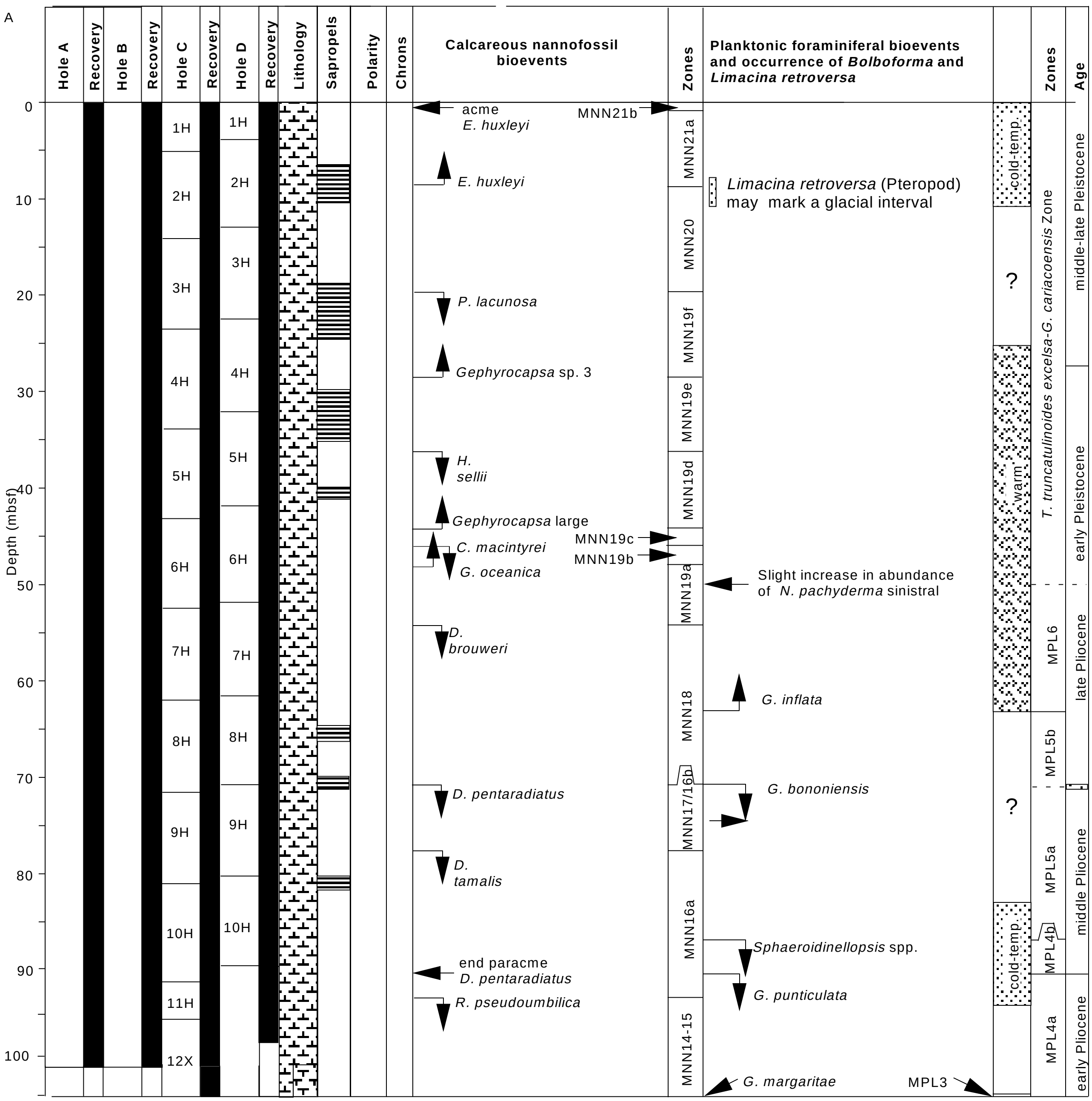
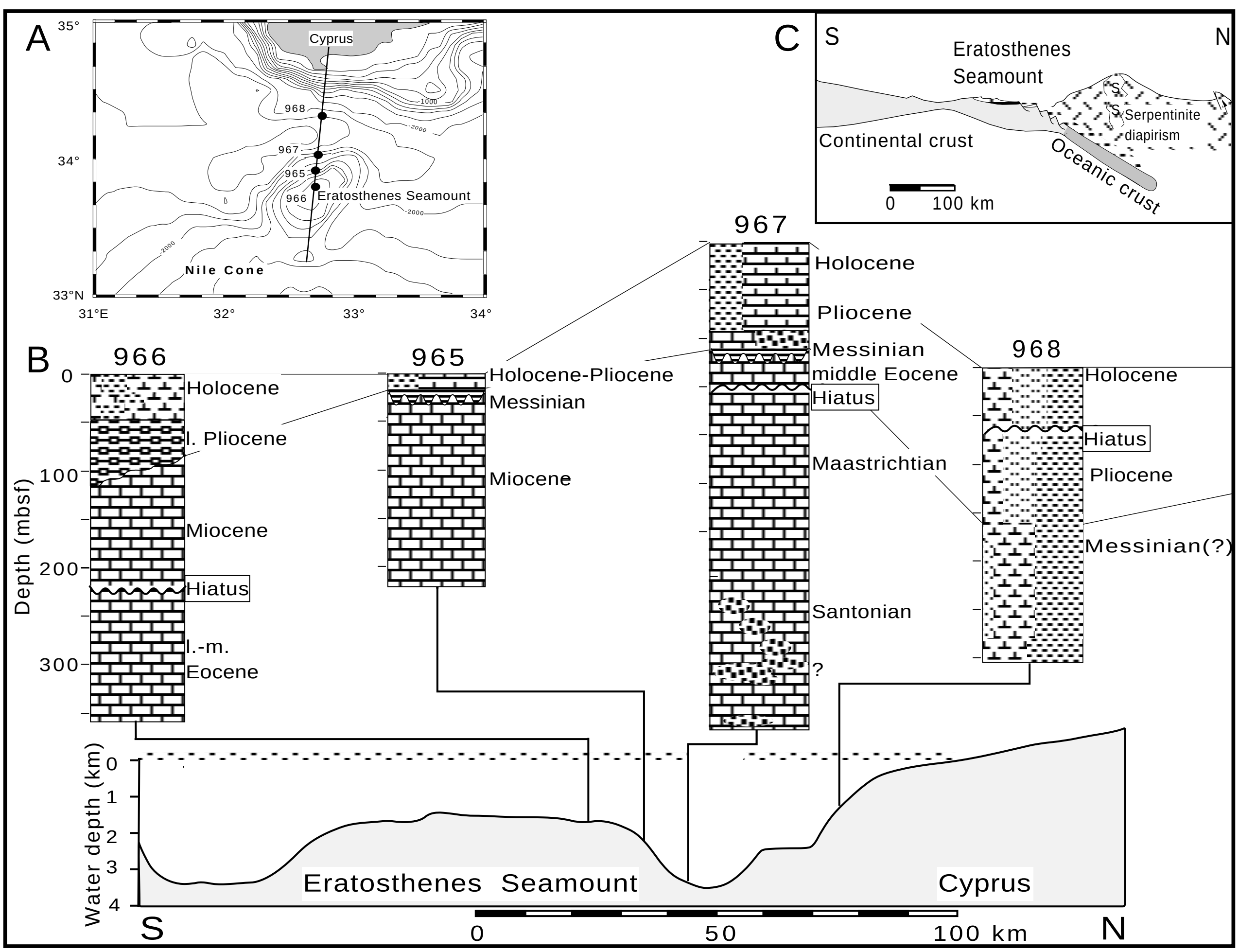
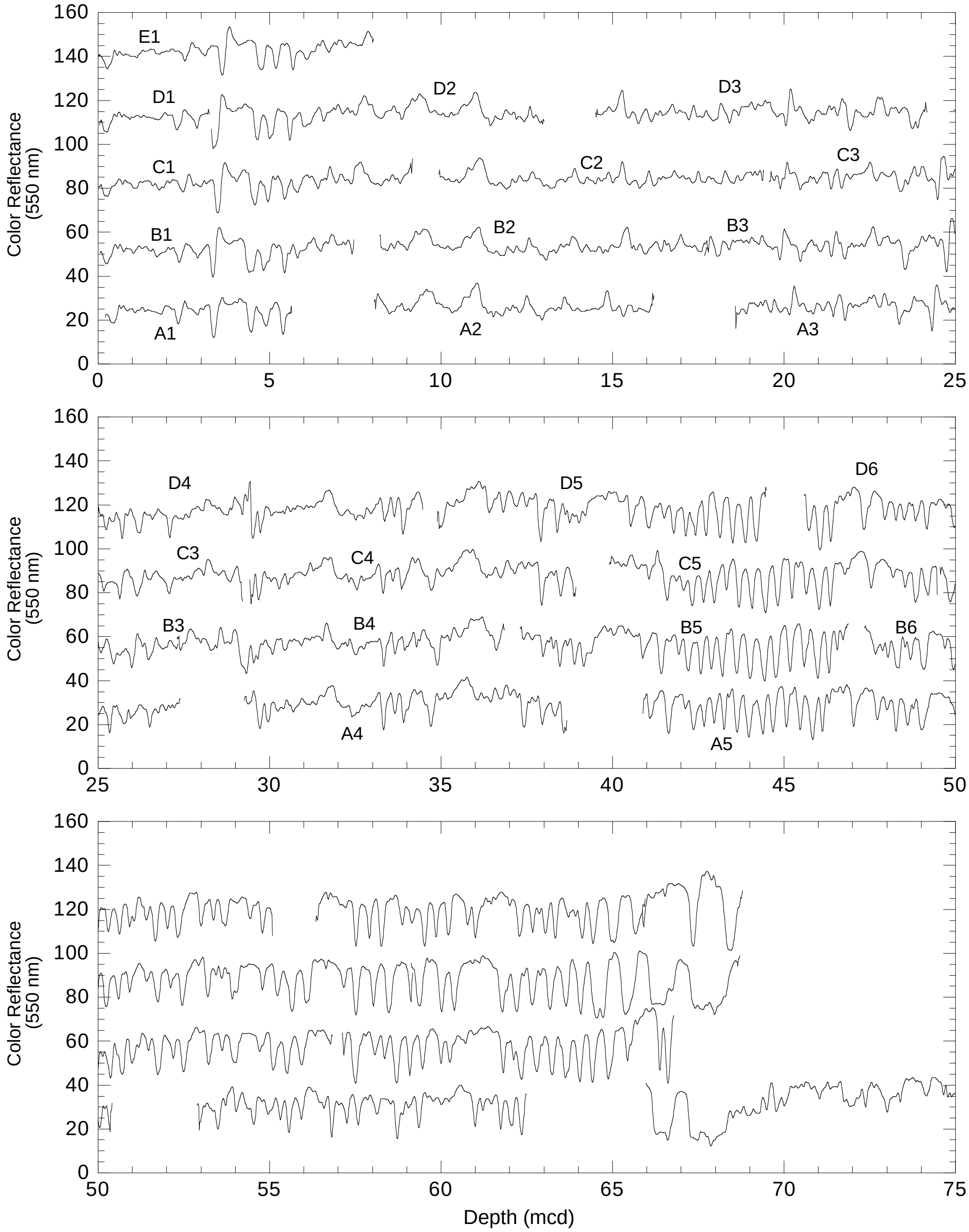

A
Hole A
Recovery
Hole B
Recovery
Hole C
Recovery
Hole D
Recovery
Lithology
Sapropels
Polarity
Chrons
Calcareous nannofossil bioevents
Zones
Planktonic foraminiferal bioevents and occurrence of Bolboforma and Limacina retroversa
Zones
Age
Depth (mbsf)
acme E. huxleyi
MNN21b
E. huxleyi
P. lacunosa
Gephyrocapsa sp. 3
H. sellii
Gephyrocapsa large
C. macintyrei
G. oceanica
MNN19c
MNN19b
D. brouweri
D. pentaradiatus
D. tamalis
end paracme D. pentaradiatus
R. pseudoumbilica
MNN21a
MNN20
MNN19f
MNN19e
MNN19d
MNN19a
MNN18
MNN17/16b
MNN16a
MNN14-15
Limacina retroversa (Pteropod) may mark a glacial interval
Slight increase in abundance of N. pachyderma sinistral
G. inflata
G. bononiensis
Sphaeroidinellopsis spp.
G. punticulata
G. margaritae
MPL3
cold-temp.
warm
T. truncatulinoides excelsa-G. cariacoensis Zone
MPL6
MPL5b
MPL5a
MPL4b
MPL4a
middle-late Pleistocene
early Pleistocene
late Pliocene
middle Pliocene
early Pliocene

Figure 5



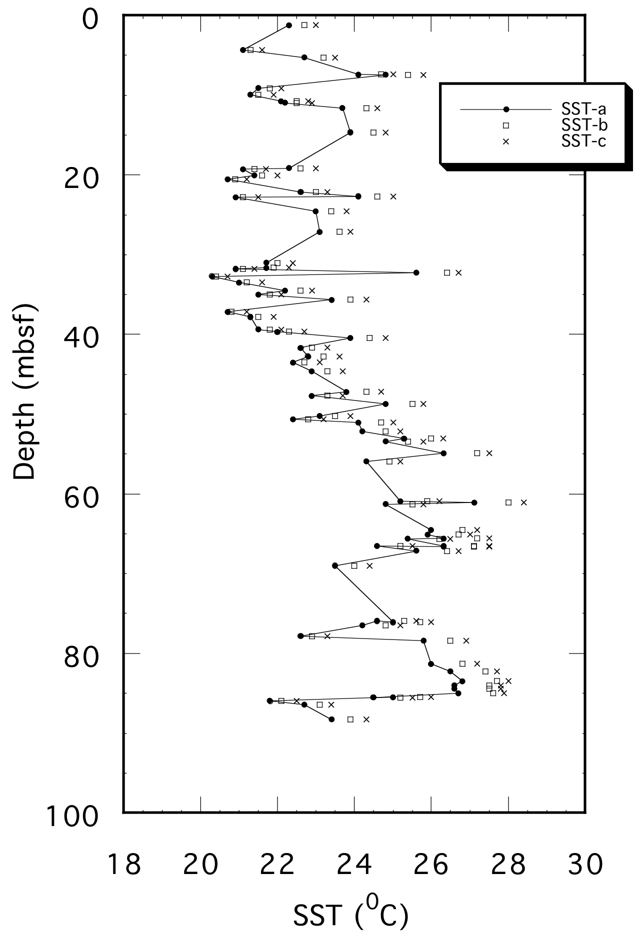
A
Cyprus
968
967
965
966
Eratosthenes Seamount
Nile Cone
35°
34°
33°N
31°E
32°
33°
34°
C
S
N
Eratosthenes Seamount
Serpentinite diapirism
Continental crust
Oceanic crust
0
100 km
B
966
965
967
968
Depth (mbsf)
0
100
200
300
Holocene
l. Pliocene
Miocene
Hiatus
l.-m. Eocene
Holocene-Pliocene
Messinian
Miocene
Holocene
Pliocene
Messinian
middle Eocene
Hiatus
Maastrichtian
Santonian
?
Holocene
Hiatus
Pliocene
Messinian(?)
Water depth (km)
0
1
2
3
4
Eratosthenes Seamount
Cyprus
S
N
0
50
100 km

Figure 6



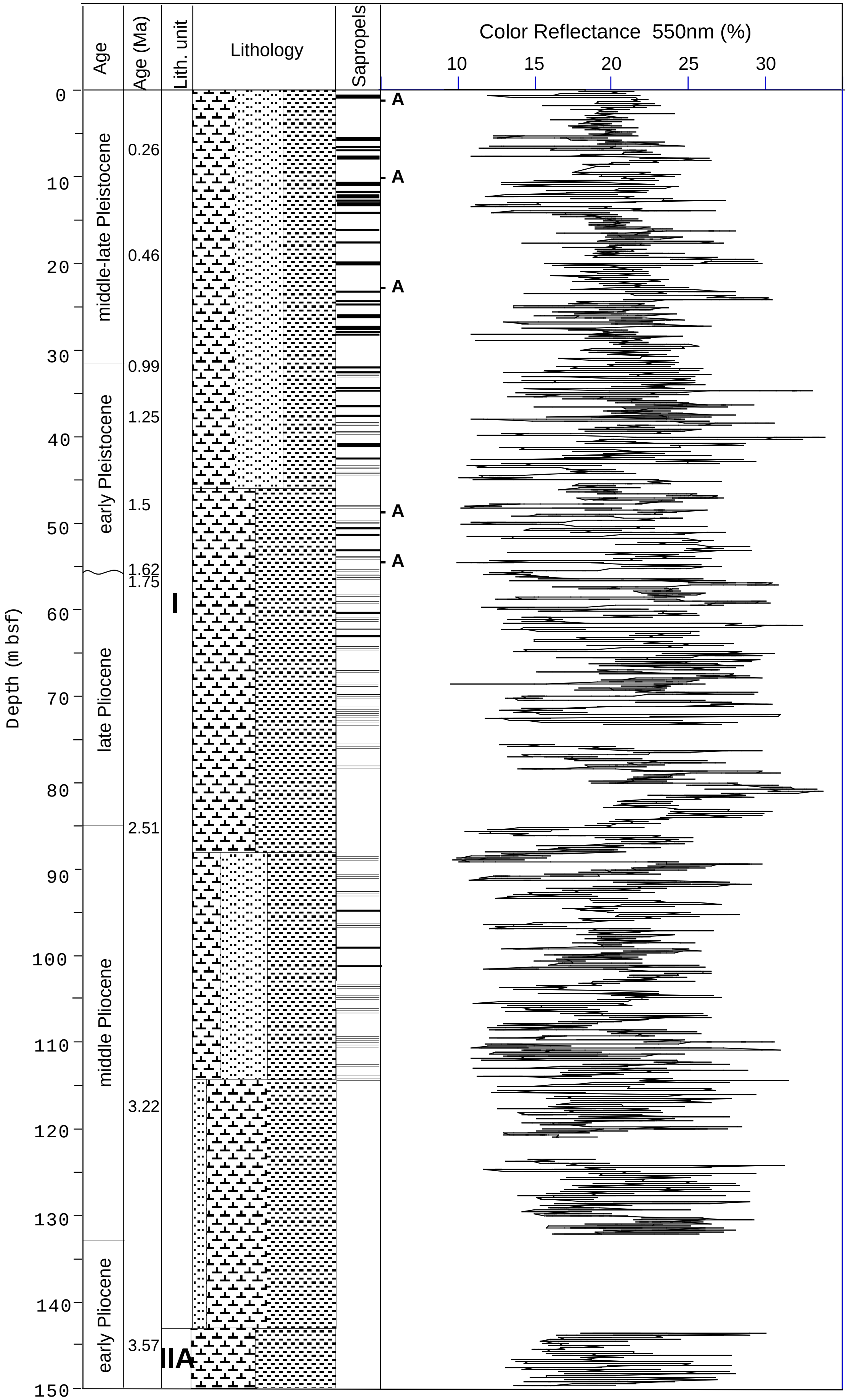
E1
D1
D2
D3
C1
C2
C3
B1
B2
B3
A1
A2
A3
D4
D5
D6
C3
C4
C5
B3
B4
B5
B6
A4
A5
Color Reflectance
(550 nm)
Depth (mcd)

Figure 7



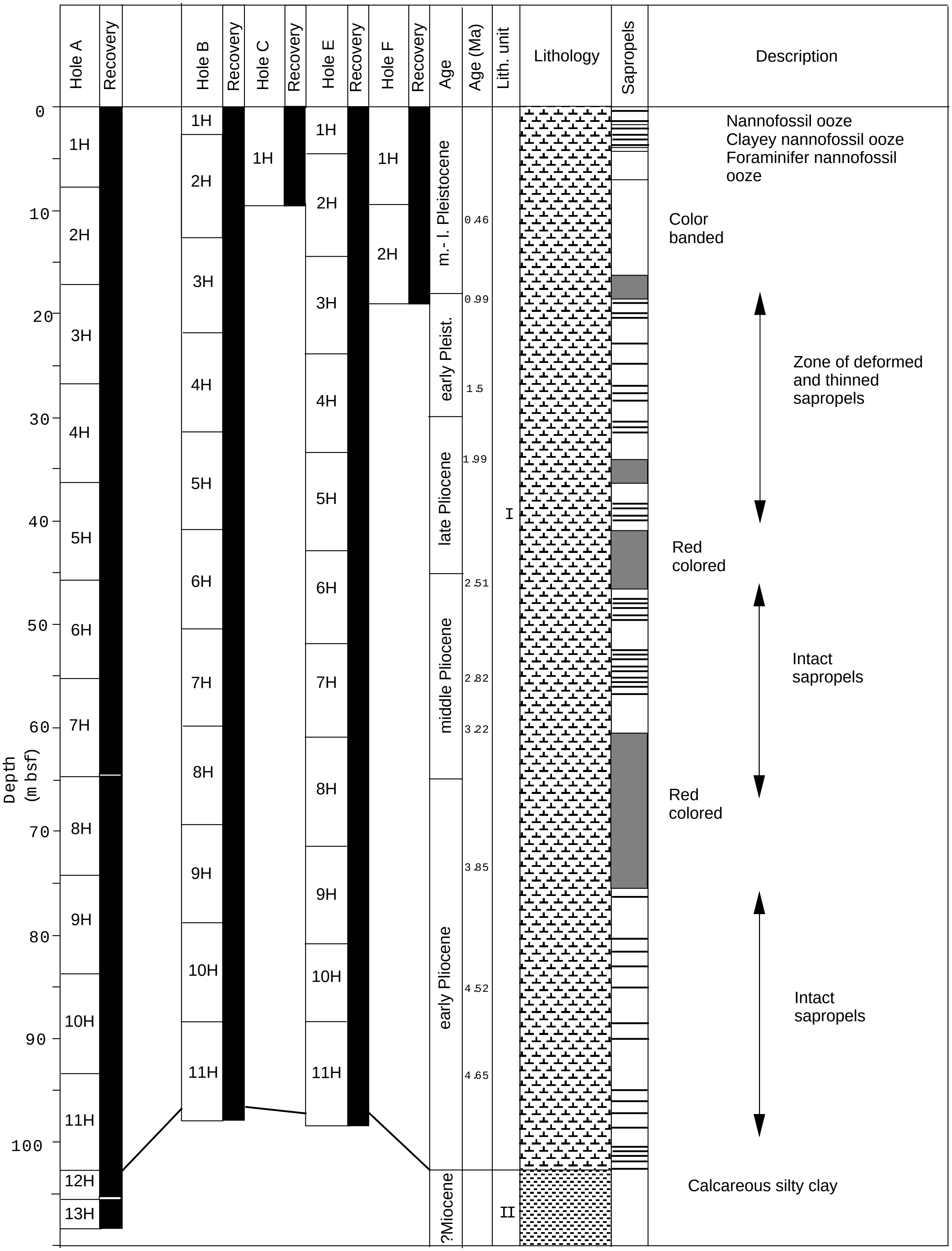
0
20
40
60
80
100
Depth (mbsf)
18
20
22
24
26
28
30
SST (0C)
SST-a
SST-b
SST-c

Figure 8



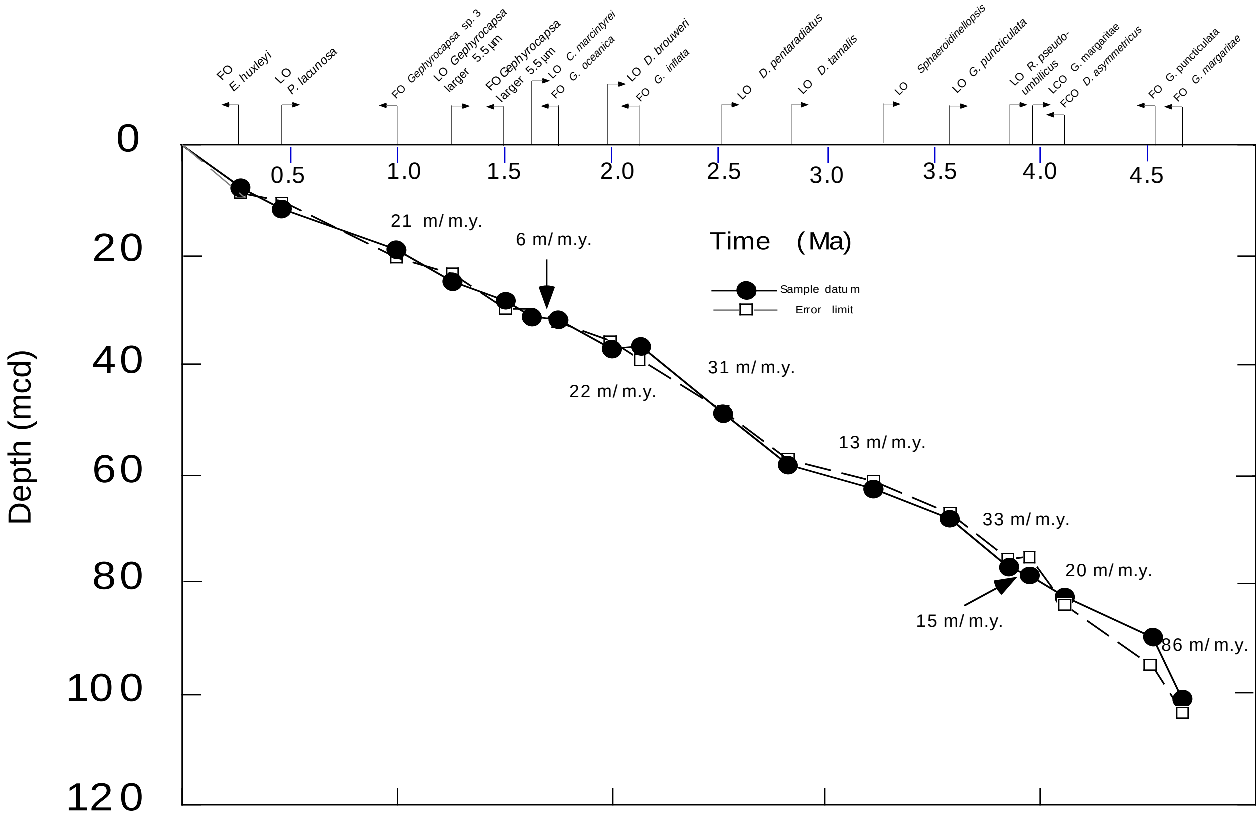
Age
Age (Ma)
Lith. unit
Lithology
Sapropels
Color Reflectance 550nm (%)
10
15
20
25
30
Depth (m bsf)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
middle-late Pleistocene
early Pleistocene
late Pliocene
middle Pliocene
early Pliocene
0.26
0.46
0.99
1.25
1.5
1.62
1.75
2.51
3.22
3.57
I
IIA
A
A
A
A
A

Figure 9



Hole A
Recovery
Hole B
Recovery
Hole C
Recovery
Hole E
Recovery
Hole F
Recovery
Age
Age (Ma)
Lith. unit
Lithology
Sapropels
Description
Depth (m bsf)
0
10
20
30
40
50
60
70
80
90
100
1H
2H
3H
4H
5H
6H
7H
8H
9H
10H
11H
12H
13H
m.- l. Pleistocene
early Pleist.
late Pliocene
middle Pliocene
early Pliocene
?Miocene
0.46
0.99
1.5
1.99
2.51
2.82
3.22
3.85
4.52
4.65
I
II
Nannofossil ooze
Clayey nannofossil ooze
Foraminifer nannofossil ooze
Color banded
Zone of deformed and thinned sapropels
Red colored
Intact sapropels
Red colored
Intact sapropels
Calcareous silty clay

Figure 10



FO E. huxleyi
LO P. lacunosa
FO Gephyrocapsa sp. 3
LO Gephyrocapsa larger 5.5 µm
FO Gephyrocapsa larger 5.5 µm
LO C. marcintyrei
FO G. oceanica
LO D. brouweri
FO G. inflata
LO D. pentaradiatus
LO D. tamalis
LO Sphaeroidinellopsis
LO G. puncticulata
LO R. pseudo-umbilicus
LCO G. margaritae
FCO D. asymmetricus
FO G. puncticulata
FO G. margaritae
0
20
40
60
80
100
120
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Depth (mcd)
Time (Ma)
Sample datum
Error limit
21 m/m.y.
6 m/m.y.
22 m/m.y.
31 m/m.y.
13 m/m.y.
33 m/m.y.
20 m/m.y.
15 m/m.y.
86 m/m.y.

Figure 11

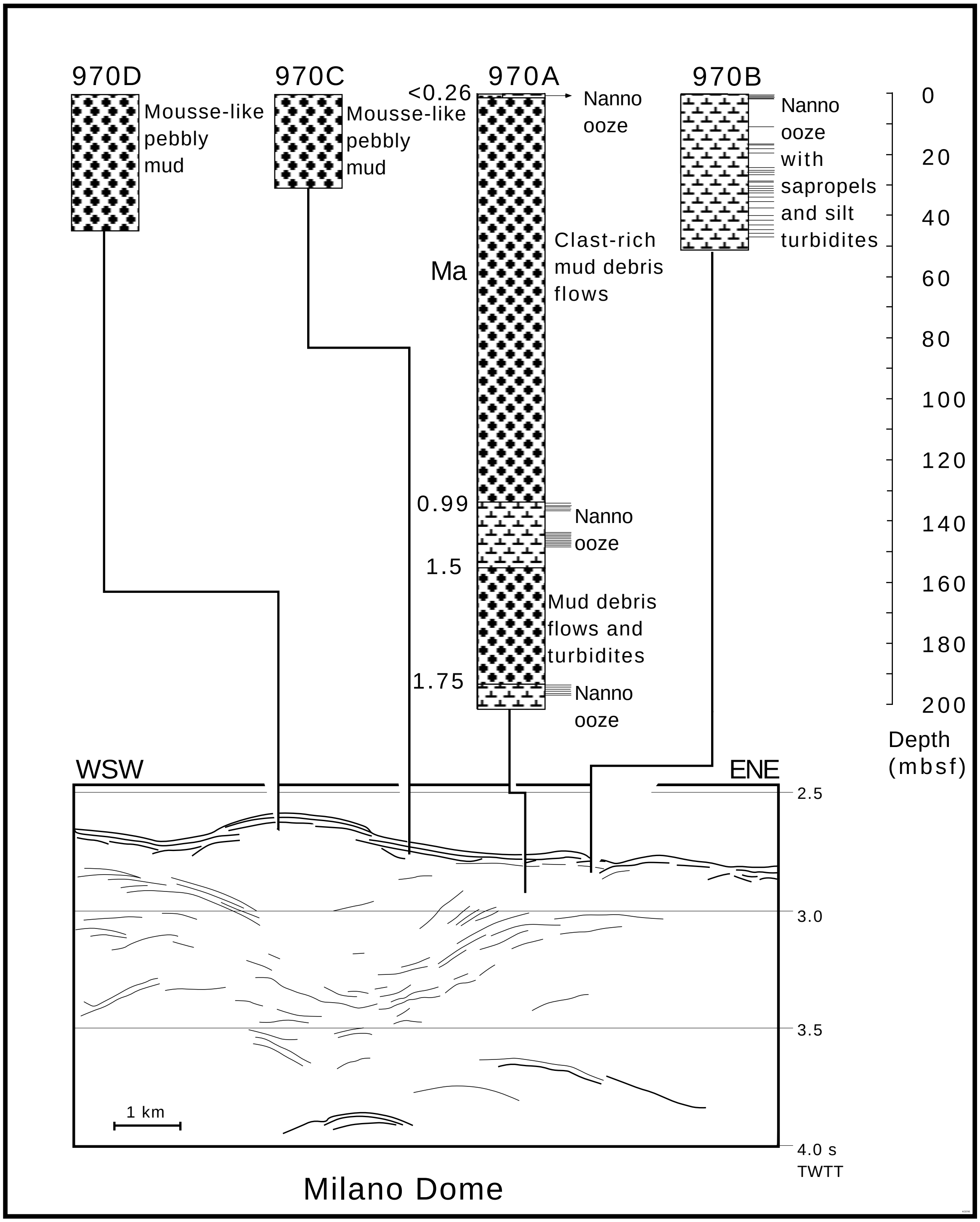
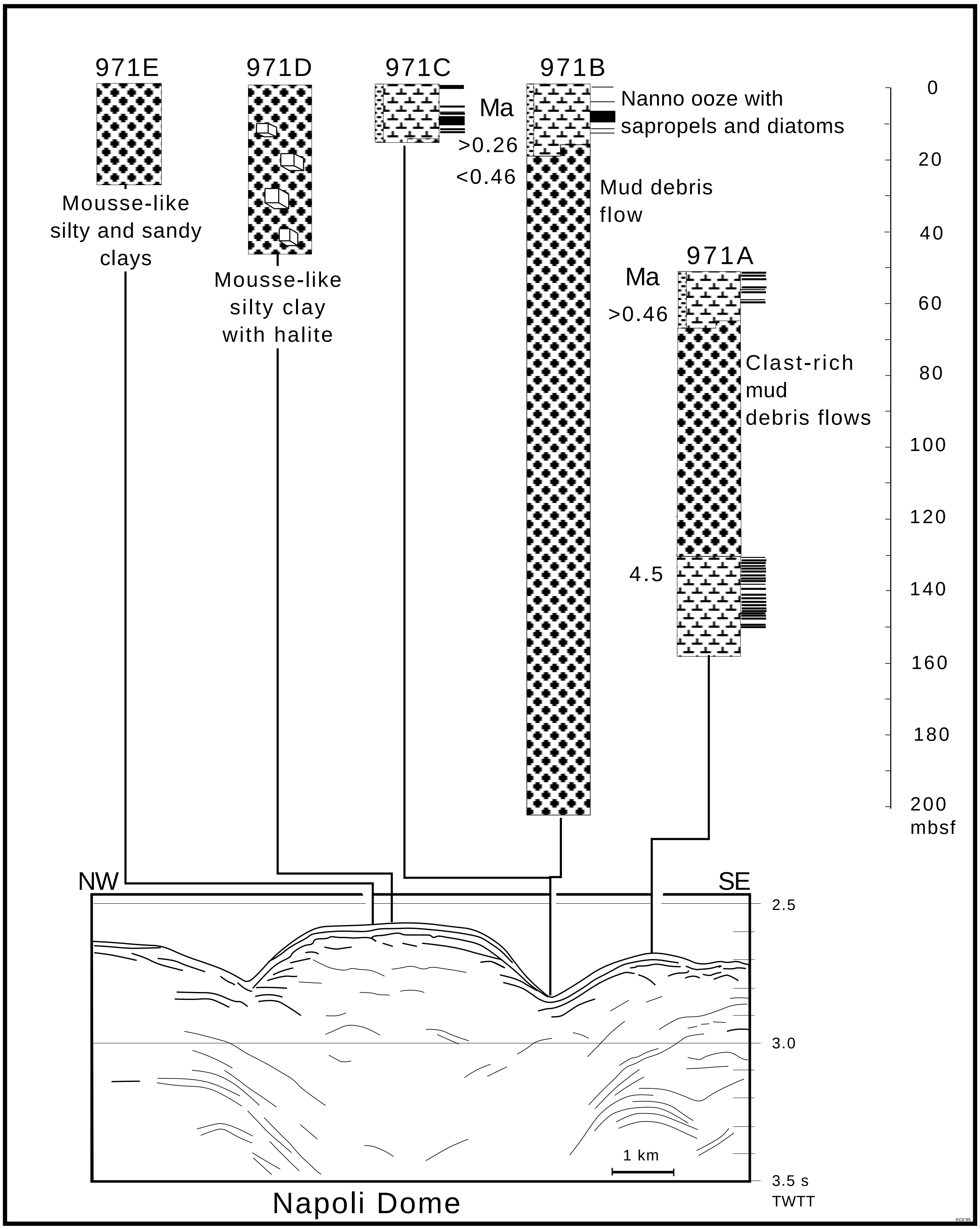

970D
Mousse-like pebbly mud
970C
Mousse-like pebbly mud
970A
<0.26
Nanno ooze
Ma
Clast-rich mud debris flows
0.99
Nanno ooze
1.5
Mud debris flows and turbidites
1.75
Nanno ooze
970B
Nanno ooze with sapropels and silt turbidites
0
20
40
60
80
100
120
140
160
180
200
Depth (mbsf)
WSW
ENE
2.5
3.0
3.5
4.0 s TWTT
1 km
Milano Dome

Figure 12



971E
971D
971C
971B
971A
Ma
>0.26
<0.46
Nanno ooze with
sapropels and diatoms
Mud debris
flow
Mousse-like
silty and sandy
clays
Mousse-like
silty clay
with halite
Ma
>0.46
Clast-rich
mud
debris flows
4.5
0
20
40
60
80
100
120
140
160
180
200
mbsf
NW
SE
2.5
3.0
3.5 s
TWTT
1 km
Napoli Dome

Figure 13

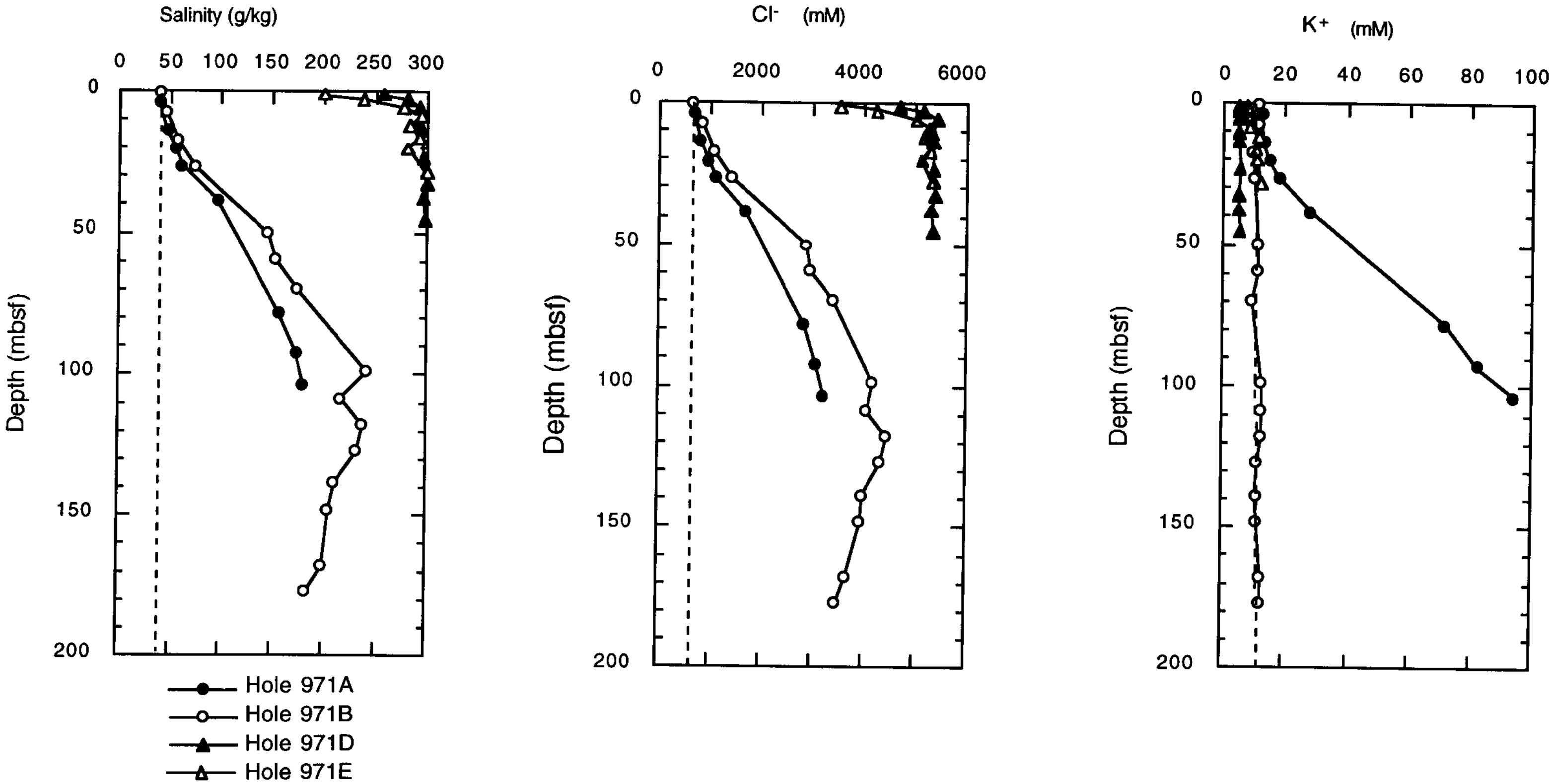
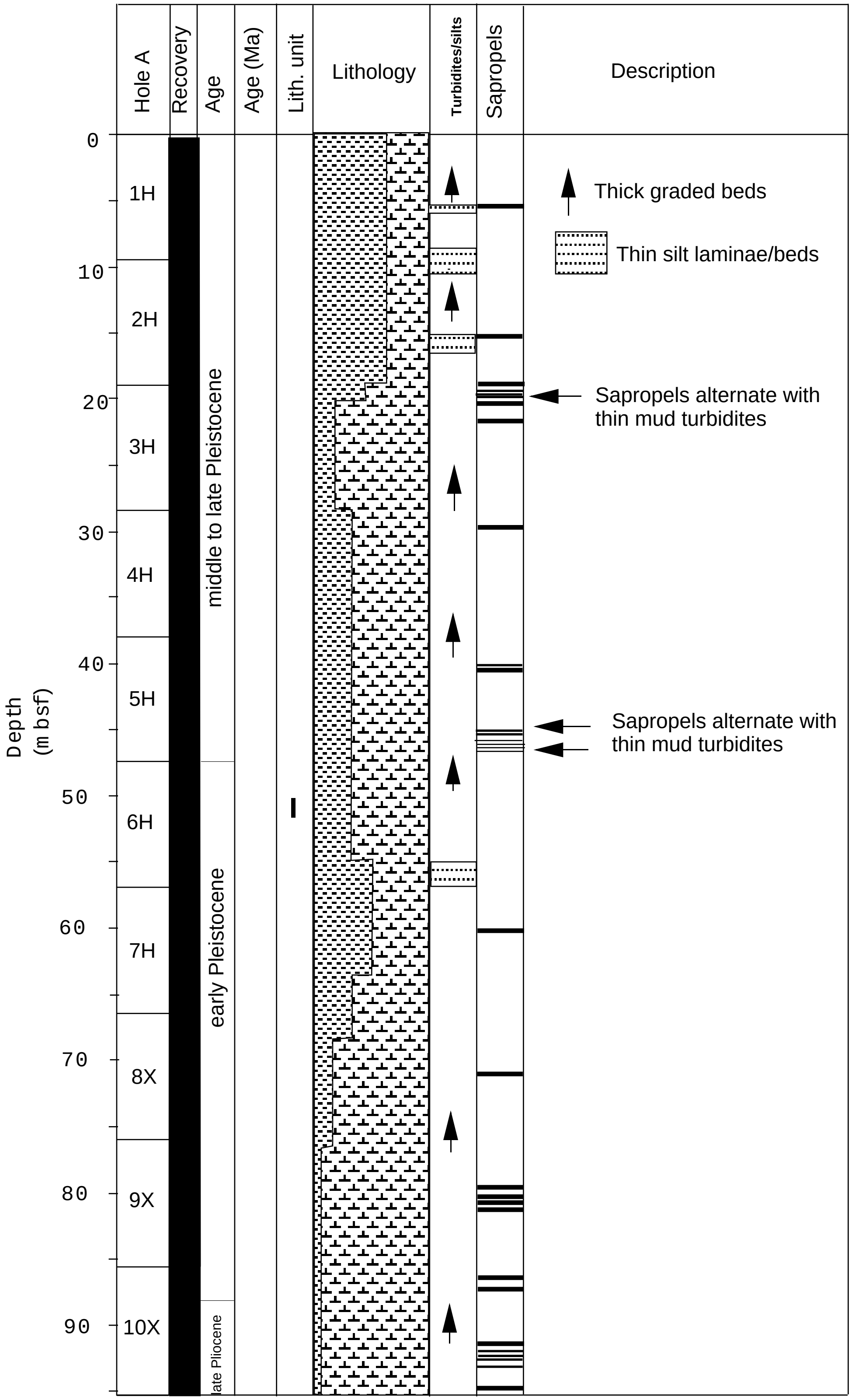

Salinity (g/kg)
0 50 100 150 200 250 300
Depth (mbsf)
0 50 100 150 200
Hole 971A
Hole 971B
Hole 971D
Hole 971E
Cl- (mM)
0 2000 4000 6000
Depth (mbsf)
0 50 100 150 200
K+ (mM)
0 20 40 60 80 100
Depth (mbsf)
0 50 100 150 200

Figure 14



Hole A
Recovery
Age
Age (Ma)
Lith. unit
Lithology
Turbidites/silts
Sapropels
Description
Depth (mbsf)
0
10
20
30
40
50
60
70
80
90
1H
2H
3H
4H
5H
6H
7H
8X
9X
10X
middle to late Pleistocene
early Pleistocene
late Pliocene
I
Thick graded beds
Thin silt laminae/beds
Sapropels alternate with thin mud turbidites
Sapropels alternate with thin mud turbidites

Figure 15

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 160 were:

Operations Manager:	Gene Pollard
Schlumberger Engineer:	Steve Kittredge

TRANSIT CREW CHANGE IN LAS PALMAS

Leg 160 began with the first line ashore in Las Palmas, Gran Canaria, at 0700 hr on 2 March 1995 for a short crew change. The Leg 159 crew was discharged, and the Leg 160 SEDCO and ODP transit crew came on board. The ship departed Las Palmas at 1600 hr on 2 March for the voyage to Marseille, France.

MARSEILLE, PORT CALL

The 1391-nmi sea voyage from Las Palmas to Marseille required 123.3 hr at an average speed of 11.2 kt. The first line ashore at Leon Gourret/Marseille was at 2130 hr (local time) on 7 March. The pacing port call item was to change out the drill pipe. A total of 108 stands of 5-in. drill pipe and 87 stands of 5-1/2-in. drill pipe were laid down. One stand of 5-1/2-in. drill pipe would not break down even with 100,000 ft-lb force and heat; therefore, it was cut up. A total of 100 stands and a single of 5-in. drill pipe and 52 stands and a double of 5-1/2-in. drill pipe were loaded on board and made up. Three joints of 5-in. drill pipe with short boxes were scrapped. An attempt to coat 128 joints of reconditioned 5-in. drill pipe was only partially successful because of an existing black (phosphate?) coating. The Lebus grooving from the TV coaxial winch drum was removed on the transit. A new Lebus grooving plate for a new larger diameter coaxial cable could not be installed; therefore, after cutting off 550 m of damaged cable, 6165 m of the larger cable was spooled directly on the drum. The 4690-m-long aft coring wireline was spooled off the drum, the drum was inspected with die-penetrant (no failures noted), and the CWL was spooled back on the drum. Personnel for Zeiss microscopes and Fisons XRF performed service calls. Tours were conducted for over 200 persons.

SEDCO inspected the elevating cylinder in thruster pod no. 3 and started cleaning mud pits nos. 5 and 6, and salt-water ballast tanks no. 7 port and starboard in preparation to reinforce them per ABS requirements. The work on the mud pits was completed on 25 March.

TRANSIT FROM MARSEILLE TO SITE 963

The last line ashore in Marseille cleared the dock at 1309 hr local time (UTC+1) on 12 March 1995. The ship took 1-1/2 hr to stop in the harbor, hold a lifeboat drill, and lowered all four boats to meed Liberian regulations. The 535-nmi sea voyage to Site 963 required 50.7 hr at an average speed of 11.1 kt. A force 8 storm slowed progress to 7 kt at times with winds to 38 kt, 12-ft seas, and 15-ft swells. After a 20-nmi survey in 3.0 hr at 6.6 kt, a Datasonics 354M beacon (S/N 1240, 14.5 kHz) was deployed at 2150 hr on 14 March at 37°01.940'N, 13°10.892'E.

SITE 963

Hole 963A

Hole 963A (proposed site MedSap-4A) was spudded at 0435 hr on 15 March. The precision depth recorder (PDR) indicated a water depth of 481.4 m, and the first core indicated a water depth of 481.0 meters below rig floor (mbrf) by drill-pipe measurement (DPM). APC Cores 160-963A-1H to -25H were taken from 0 to 199.4 meters below seafloor (mbsf) with 199.4 m cored and 203.17 m recovered (101.9% recovery). Cores were oriented from Core 160-963A-4H to -25H. To improve recovery for high-resolution studies, the APC coring system was pushed beyond 150 m into stiffer formation than normal. There was no bleed-off after Core 160-963A-5H, and overpull was 20,000 to 50,000 lb after Core 160-963A-6H. A total of 12 liners imploded, and one burst from the stiff clay. Advance by recovery was used from Core 160-963A-11H (90.0 mbsf). There was no indication of suck-in. The maximum gas recorded was 270 ppm methane at Core 160-963A-9H (71.0 mbsf). Torque (to 400 amps) and overpull (to 40,000 lb) increased when the bit and bottom-hole assembly (BHA) balled-up with clay. Coring was terminated a short time later while the string was rotated at 120 rpm and the pump rate increased, which reduced the problem. The bit cleared the seafloor at 2154 hr on 15 March, ending Hole 963A.

Hole 963B

The ship was moved 10 m to the northwest, and Hole 963B was spudded at 2235 hr on 15 March. The first core indicated a water depth of 480.5 mbrf DPM. APC Cores 160-963B-1H to -24H were taken from 0 to 207.0 mbsf, with 208.0 m cored and 205.9 m recovered (98.9% recovery). Adara heat-flow measurements were taken from Cores 160-963B-5H, -8H, and -11H. The lithology was the same as in Hole 963A, and the bit and BHA again had to be cleaned to reduce torque (to 700 amps) and overpull (to 50,000 lb). Five core liners imploded at the top, and two liners had to be pumped out. The bit cleared the seafloor at 1231 hr on 16 March, ending Hole 963B.

Hole 963C

The ship was moved 10 m to the northwest, and Hole 963C was spudded at 1340 hr on 16 March. The first core indicated a water depth of 480.0 mbrf DPM. APC Cores 160-963C-1H to -6H were taken from 480.0 to 537.0 m (0 to 57.0 mbsf), with 57.0 m cored and 57.93 m recovered (101.6% recovery).

Hole 963D

The ship was moved another 10 m to the northwest, and Hole 963D was spudded at 1705 hr on 16 March. A single mud-line core was taken, which indicated a water depth of 480.1 mbrf. Core 160-963D-1H was taken from 0 to 8.4 mbsf, with 8.39 m recovered. The BHA was secured for transit at 2200 hr on 16 March, ending Hole 963D. The drill collars were caked with about 7 cm of clay, proving that they were balled up. The beacon was recalled and recovered.

SITE 964

The 217-nmi sea voyage to Site 964 (proposed site MEDSAP-3A) required 18.5 hr at an average speed of 11.7 kt. A seismic survey of 21 nmi was run over target site MEDSAP-3A in 3.2 hr at 6.3 kt. A Datasonics 354M beacon (S/N 772, 15.0 kHz) was deployed at 2014 hr on 17 March 1995 at 36°15.612'N, 17°44.990'E.

Hole 964A

The first attempt at coring produced a water core with mud inside the shoe. The bit was lowered 5 m, and a 6.80-m core was recovered, indicating a seafloor depth of 3657.7 m. APC Cores 160-964A-1H to -11H were taken from 0 to 101.8 mbsf with 101.8 m cored and 106.12 m recovered (104.2% recovery). Cores were oriented from Core 160-964A-3H. The last two cores (160-964A-10H and -11H) were partial strokes with full recovery. The maximum gas detected was 4 ppm methane. There were no coring problems.

Hole 964B

The ship was offset 10 m to the east, where a seafloor depth of 3658.3 m was indicated by Core 160-964B-1H. APC Cores 160-964B-1H to -11H were taken from 0 to 102.0 mbsf, with 102.0 m cored and 105.26 m recovered (103.2% recovery). Adara heat-flow readings were taken from

Core 160-964B-5H and -8H (a third-heat flow reading was canceled due to high overpull on Core 160-964B-8H). Two liners imploded, and the last two cores were partial strokes.

Hole 964C

The ship was offset 10 m to the east, and Hole 964C was spudded at 1110 hr on 19 March. A seafloor depth of 3660.3 m was indicated by Core 160-964C-1H. APC Cores 160-964D-1H to -11H were taken from 0 to 95.6 mbsf, with 95.6 m cored and 99.00 m recovered (103.6% recovery). Cores were oriented from Core 160-964C-3H. Core 160-964C-1H was a partial stroke with a collapsed liner, which had to be pumped out. An XCB Core 160-964C-12X was taken from 95.6 to 105.1 mbsf and recovered 7.48 m (79% recovery) of foraminifer sand. The foraminifer sands were apparently the reason for the APC refusal.

Hole 964D

The ship was offset 10 m to the north, and Hole 964D was spudded at 0240 hr on 20 March. A seafloor depth of 3660.3 m was indicated by Core 160-964D-1H. APC Cores 160-964D-1H to -12H were taken from 0 to 108.6 mbsf, with 108.6 m cored and 112.2 m recovered (103.3% recovery). Cores were oriented from Core 160-964D-7H. A WSTP temperature measurement was taken after Core 160-964D-11H, but the temperature did not stabilize, possibly because the probe may have been in foraminifer sands with some permeability and flow. Cores 160-964D-10H to -12H were partial strokes with 40,000-50,000 lb overpull. Core 160-964D-9H had an imploded liner on the bottom.

Hole 964E

The ship was offset 10 m to the west, and Hole 964E was spudded at 1735 hr on 20 March. A seafloor depth of 3660.9 m was indicated by Core 160-964E-1H. APC Cores 160-964E-1H to -3H were taken from 0 to 24.5 mbsf. The hole was washed from 24.5 to 57.0 mbsf. APC Cores 160-964E-4H to -6H were taken from 57.0 to 85.5 mbsf to recover a section that had core breaks at nearly the same depth in offset holes. Cores 160-964E-1H to -6H had 53.0 m cored and 54.32 m recovered (102.5% recovery).

Hole 964F

The ship was offset 10 m to the west, and Hole 964F was spudded at 0140 hr on 21 March. A seafloor depth of 3657.3 m was indicated by Core 160-964F-1H. APC Cores 160-964F-1H to -3H were taken from 0 to 28.1 mbsf, with 28.1 m cored and 27.94 m recovered (99.4%

recovery). The pipe was pulled out of the hole, and the BHA was secured for sea voyage at 1224 hr on 21 March, and the beacon was retrieved, ending Site 964.

SITE 965

The 749-nmi sea voyage to the proposed ESM sites required 59.9 hr at an average speed of 12.6 kt. Shipboard clocks were advanced 1 hr (0000-0100 hr) on 23 March to match European (Italian) daylight savings time. A 115-nmi seismic survey was run from south to north over proposed sites ESM-1A, -2A, -3A, and -4A in 16.4 hr at 7.0 kt. The *Resolution* returned to site ESM-2A, and a Datasonics 354M beacon (S/N 1240, 14.5 kHz) was deployed at 1828 hr on 24 March.

Hole 965A

Proposed site ESM-2A was the first site to be drilled on the Eratosthenes Seamount as required by safety considerations. The same APC/XCB BHA used at Sites 963 and 964 was used on ESM-2A: a 10-1/8-in. RBI PDC bit, APC/XCB BHA with a nonmagnetic drill collar (NMDC).

The precision depth recorder (PDR) indicated a seafloor depth of 1505.4 meters below rig floor (mbrf). The first APC core from 1501.0 mbrf was a water core. The bit was lowered 8 m, and Hole 965A was spudded at 0035 hr on 25 March. A 0.76-m core was recovered, indicating a seafloor depth of 1506.6 m. APC Cores 160-965A-1H to -4H were taken from 0 to 29.3 mbsf, with 29.3 m cored and 29.87 m recovered (101.9% recovery). Core 160-965A-4H was oriented and had a partial stroke that bottomed in a hard clay and limestone. The maximum gas detected was 6 ppm methane.

XCB Cores 160-965A-5X to -27X were taken from 29.3 to 250.4 mbsf, with 221.1 m cored and 12.92 m recovered (5.8% recovery). XCB recovery was poor in limestones and carbonate breccia. Erratic torque indicated extensive fracturing, and 25-bbl high-viscosity gel mud sweeps were pumped each core. The last two cores jammed in the shoe.

Logging operations in Hole 965A

The hole was conditioned for logging with a short trip. No drag and only 1 m of fill indicated good hole conditions for logging. The hole was displaced with 120 bbl of 9.0 ppg sepiolite/seawater mud. The bit was positioned at 89.2 mbsf to log. Sonic, density neutron, and FMS logs were run to 1768.2 m total depth with no fill. Logging was finished at 0100 hr on 27 March, and the bit was pulled, clearing the rotary table at 0425 hr. The beacon was recovered, and the transit to Site 966 began at 0430 hr.

SITE 966

The 8-nmi sea voyage to Site 966 (proposed site ESM-1A) required 0.7 hr at an average speed of 11.4 kt. A Datasonics 354M beacon (S/N 783, 15.0 kHz) was deployed at 0558 hr on 27 March.

Hole 966A

The same APC/XCB BHA used at the previous sites was used at Site 966: a 10-1/8-in. RBI PDC bit, APC/XCB BHA with a nonmagnetic drill collar (NMDC) and the subs required to run the motor driven core barrel (MDCB).

Hole 966A was spudded at 0940 hr on 27 March. A 5.84-m core was recovered, indicating a seafloor depth of 926.6 m. APC Cores 160-966A-1H to -9H were taken from 0 to 68.3 mbsf with 68.3 m cored and 8.81 m recovered (12.9% recovery). Cores were oriented from Core 160-966A-4H. Adara heat-flow measurements were taken on Cores 160-966A-5H, -7H, and -9H. Core 160-966A-9H was a partial stroke that bottomed in a hard limestone. The maximum gas detected was 4 ppm methane.

XCB Cores 160-966A-10X to -13X were taken from 68.3 to 106.8 mbsf with 38.5 m cored and 4.38 m recovered (11.4% recovery). XCB recovery was poor in limestones and carbonate debris using a standard shoe and an 8- and 9-finger core catcher. All four cores jammed in the shoe. Overall recovery was 68.5%. The bit cleared the seafloor at 2146 hr on 27 March.

Hole 966B

The ship was offset 78 m to the south. Hole 966B was spudded at 2345 hr on 27 March. Core 160-966B-1H indicated a seafloor depth of 926.6 m. APC Cores 160-966B-1H to -10H were taken from 0 to 90.3 mbsf, with 90.3 m cored and 90.32 m recovered (100% recovery). Cores were oriented from Core 160-966B-3H. Cores 160-966B-8H to -10H had partial strokes, but piston coring continued because the XCB had poor recovery, and suck-in disturbance in the APC cores could be detected. The maximum gas detected was 3 ppm methane. Core 160-966B-10H bottomed in hard limestone reef debris.

XCB Cores 160-966B-11X to -16X were taken from 90.3 to 146.0 mbsf, with 55.7 m cored and

6.14 m recovered (11% recovery). XCB recovery was poor in limestones and carbonate breccia using a hard formation tungsten carbide shoe and 8- and 9-finger core catchers. All four XCB cores jammed in the shoe. Overall recovery was 66%. The bit cleared the seafloor at 1312 hr on 28 March.

Hole 966C

The ship was offset 20 m to the north. Hole 966C was spudded at 1400 hr on 28 March. Core 160-966C-1H indicated a seafloor depth of 925.9 m. APC Cores 160-966C-1H to -11H were taken from 0 to 95.1 mbsf, with 95.1 m cored and 99.13 m recovered (104.2% recovery). Cores were oriented from Core 160-966C-3H. The formation was a nannofossil ooze with numerous sapropels. Cores 160-966C-9H to -10H had partial strokes, but piston coring continued because the XCB had very poor recovery, and suck-in disturbance in the APC cores could be detected. Core 160-966C-11H failed to penetrate and there was no pull out.

XCB Cores 160-966C-12X to -17X were taken from 95.1 to 127.0 mbsf, with 31.9 m cored and 2.47 m recovered (7.7% recovery). XCB recovery was poor in nannofossil ooze using a hard-formation tungsten carbide shoe and 8- and 9-finger core catchers. Half of the XCB cores jammed in the shoe. Overall recovery was 80%. The bit cleared the seafloor at 0320 hr on 29 March.

Hole 966D

The ship was offset 10 m to the north. Hole 966D was spudded at 0350 hr on 29 March. Core 160-966D-1H indicated a seafloor depth of 926.3 m. APC Cores 160-966D-1H to -10H were taken from 0 to 84.5 mbsf, with 84.5 m cored and 91.80 m recovered (108.6% recovery). Cores were oriented from Core 160-966D-3H. The liner shattered on Core 160-966D-9H. Core 160-966D-10H hit a large cobble and bottomed in a well-compacted carbonate debris flow with scattered cobbles.

XCB (half-cores) 160-966D-11X to -20X were taken from 88.5 to 136.5 mbsf, with 52.0 m cored and 14.14 m recovered (27.2% recovery). XCB recovery was poor in nannofossil ooze with scattered cobbles, which jammed the liner and shoe, acting as center bits. A short-extension hard-formation tungsten carbide shoe was used with an 8- and 9-finger core catcher. All but one of the XCB cores jammed in the shoe. Overall recovery was 80%. The bit cleared the seafloor at 1838 hr on 29 March.

Hole 966E

The ship was offset 10 m to the north. Hole 966E was spudded at 1900 hr on 29 March. A single mud-line core was taken, which indicated a seafloor depth of 926.3 m. APC Core 160-966D-1H was taken from 0 to 8.5 mbsf, with 8.5 m cored and 8.48 m recovered (99.9% recovery). The APC/XCB BHA was pulled out of the hole, and the bit cleared the rotary at 2345 hr on 29 March.

Hole 966F

An RCB bottom-hole assembly was assembled, and Hole 966F was spudded at 0550 hr on 30 March. The hole was drilled to 59.0 mbsf. RCB Cores 160-966F-1R to -31R were taken from 0 to 356.0 mbsf, with 297.0 m cored and 65.85 m recovered (22.1% recovery). The rotary stalled, and the pipe stuck with 65,000 lb overpull at 1074.0 mbrf. The McCullough jars were hit down one time to free the string. A 15-bbl high-viscosity gel sweep was pumped every other core from Core 106-966-9R.

Logging operations in Hole 966F

A short trip was made to condition the hole for logs. No drag and 2.5 m of light fill at the bottom indicated good hole conditions for logging. The hole was displaced with 9.0 ppg sepiolite/seawater mud, the bit was released with the mechanical bit release, and the sleeve was shifted shut. The pipe was pulled back to 87.9 mbsf for logging. Quad-Combo, FMS, and GHMT logs were run to 355 mbsf with no fill. Logging was finished at 0700 hr on 1 April, and the bit was pulled, clearing the rotary table at 0955 hr on 1 April. The beacon was recovered, and the transit to Site 967 began at 1150 hr.

SITE 967

The 17-nmi sea voyage to Site 967 (proposed site ESM-3A) required 1.5 hr at an average speed of 11.3 kt. A Datasonics 354M beacon (S/N 1240, 14.5 kHz) was deployed at 1150 hr on 1 April.

Hole 967A

The same APC/XCB bottom hole assembly used at the previous sites was used on ESM-3A: a 10-1/8-in. RBI PDC bit, APC/XCB BHA with a nonmagnetic drill collar (NMDC). Hole 967A was spudded at 1905 hr on 1 April. A seafloor depth of 2553.0 m was indicated. APC Cores 160-967A-1H to -13H were taken from 0 to 123.3 mbsf, with 123.3 m cored and 127.63 m recovered

(103.5% recovery). Cores were oriented from Core 160-967A-3H. Adara heat-flow measurements were taken on Cores 160-967A-5H, -7H, and -9H. The top and bottom of the liner imploded on Core 160-967A-12H. The maximum gas detected was 5 ppm methane. XCB Cores 160-967A-14X to -16X were taken from 123.3 to 141.3 mbsf, with 18.0 m cored and 14.51 m recovered (80.6% recovery). XCB recovery was poor in the stiff nannofossil ooze using a standard shoe and an -8 and 9-finger core catcher. The last two cores jammed in the shoe. Overall recovery was 100.5%. The bit cleared the seafloor at 1140 hr on 2 April.

Hole 967B

The ship was offset 10 m to the south. Hole 967B was spudded at 1241 hr on 2 April. Core 160-967B-1H indicated a seafloor depth of 2555.0 m. APC Cores 160-967B-1H to -14H were taken from 0 to 121.5 mbsf, with 121.5 m cored and 126.61 m recovered (104.2% recovery). Cores were oriented from Core 160-967B-3H. Cores 160-968B-12H to -14H had partial strokes, but piston coring continued because the XCB had very poor recovery, and suck-in disturbance in the APC cores could be detected. The bit cleared the seafloor at 0040 hr on 3 April.

Hole 967C

The ship was offset 326 m to the north of Hole 967B and Hole 967C was spudded at 0210 hr on 3 April. Core 160-967C-1H indicated a seafloor depth of 2552.8 m. APC Cores 160-967C-1H to -13H were taken from 0 to 114.4 mbsf, with 114.4 m cored and 119.55 m recovered (104.5% recovery). Cores were oriented from Core 160-967C-3H. Cores 160-967C-12H and -13H had partial strokes, and Core 160-967C-13H was mostly suck-in. The bit cleared the seafloor at 1150 hr on 3 April.

Hole 967D

The ship was offset 20 m to the south of Hole 967C. The first mud-line core attempt recovered 9.86 m, and there was doubt that it was a good mud-line core; therefore, it was kept for later lab instruction and not archived. Hole 967D was spudded at 1415 hr on 3 April. Core 160-967D-1H indicated a seafloor depth of 2551.5 m. APC Cores 160-967D-1H to -2H were taken from 0 to 16.2 mbsf, with 16.2 m cored and 16.89 m recovered (104.3% recovery). The bit cleared the rotary table at 2115 hr on 3 April.

Hole 967E

The ship was offset south back to 20 m north of Hole 967A. An RCB bottom hole assembly was assembled consisting of: a 9-7/8" RBI C-4 bit (S/N BF744), MBR, Head Sub, Control Length

Drill Collar (CLDC), Long Top Sub, Head Sub, 8 X 8-1/4" drill collar (DC), McCullough Drilling Jars, 2 X 8-1/4" DC, XO, 7-1/4" DC, XO, 5 joints of 5-1/2" drill pipe (DP), XO, 5" DP to the ship, XO, 5-1/2" DP through the moonpool. The bit indicated a seafloor depth of 2552.7 m. Hole 967E was spudded at 0320 hr on 4 April. The hole was drilled to 109.5 mbsf. RCB Cores 160-967E-1R to -51R were taken from 0 to 600.3 mbsf with 111.5 m drilled, 488.8 m cored and 72.32 m recovered (14.8% recovery). Following 6 cores with negligible recovery, the hole was drilled with a center bit from 561.8-563.8 mbsf in an attempt to clean out the bit throat and remove rollers and rubble from the bottom of the hole. The center bit was marked by the bit teeth, indicating that the bit bearings might be failing. Coring continued to 600.3 mbsf with negligible recovery.

Logging operations in Hole 967E

A short trip was made to condition the hole for logs. No drag and 10 m of light fill on bottom indicated average hole conditions for logging. The hole was displaced with 9.0 ppg sepiolite/seawater mud, the bit was released with the mechanical bit release (MBR), and the sleeve was shifted shut. The pipe was pulled back to 91.3 mbsf for logging. The Quad-Combo log was run to 3162 m, the GST to 3145 m, the FMS to 3144 m, and the GHMT log to 3148 m. Logging was finished at 0200 hr on 9 April, and the bit was pulled. The entire BHA was inspected on the trip out. The MBR cleared the rotary table at 1040 hr. The beacon was recovered, and the transit to Site 968 began.

Hole 967F

The bit cleared the seafloor at Hole 967C at 1150 hr on 3 April, and the ship was offset 20 m to the south of Hole 967C. A mud-line core attempt was made at 1200 hr, which recovered 9.86 m; however, there was doubt that it was a good mud-line core, and it was kept for later lab inspection and not archived initially. Later, the core liner was split and revealed two sapropels that were needed to complete the upper section: therefore, it was archived as Core 160-967F-1H, taken from 0 to 9.5 mbsf, with 9.5 m cored and 9.86 m recovered.

SITE 968

The 13-nmi sea voyage to Site 968 (proposed site ESM-4A) required 1.0 hr at an average speed of 13.0 kt. A Datasonics 354M beacon (S/N 1240, 14.5 kHz) was deployed at 1213 hr on 9 April.

Hole 968A

Hole 968A was spudded at 1730 hr on 9 April. A seafloor depth of 1961.0 m was indicated. APC Cores 160-968A-1H to -9H were taken from 0 to 85.0 mbsf, with 103.5% recovery. Cores were oriented from Core 160-968A-3H. Adara heat-flow measurements were taken on Cores 160-968A-5H, -7H, and -9H. Cores 160-968A-7H to -9H were partial strokes, the core liner collapsed on Core 160-968A-8H, and suck-in was evident in the bottom 2 m of Core 160-968A-9H. The maximum gas detected was 5 ppm methane.

XCB Cores 160-968A-10X to -34X were taken from 85.0 to 302.7 mbsf, with 70.0% recovery. XCB recovery was very good in hard clay using a hard formation shoe and an 8- and 9-finger core catcher. Nine of the last 14 cores jammed in the shoe. Overall recovery was 79.4%. The bit cleared the seafloor at 1702 hr on 12 April.

Logging operations in Hole 968A

A short trip was made to condition the hole for logs. No drag and 14.2 m of light fill on bottom indicated poor hole conditions for logging. The hole was displaced with 100 bbl of 9.0 ppg sepiolite/seawater mud, and the go-devil was dropped. The pipe was pulled back to 90.4 mbsf for logging. The Quad-Combo log was run to 2270 m (5.2 m off bottom). The caliper was not working; therefore, the logging tool was pulled. The bit was run back in, and a tight spot was reamed at 2198 m. The Quad-Combo was rerun to 2263 m (12.2 m of fill). The formation microscanner (FMS) log was run but would not pass 156.2 mbsf. Logging was finished at 1630 hr on 12 April. The bit cleared the seafloor at 1702 hr on 12 April.

Hole 968B

The ship was offset 20 m to the north, and Hole 968B was spudded at 1825 hr on 12 April. A seafloor depth of 1962.6 m was indicated. APC Cores 160-968B-1H to -2H were taken from 0 to 14.9 mbsf, with 103.7% recovery. The bit cleared the seafloor at 1915 hr on 12 April.

Hole 968C

The ship was moved 20 m to the north, and Hole 968C was spudded at 1953 hr on 12 April. A seafloor depth of 1964.2 m was indicated. APC cores 160-968C-1H to -2H were taken from 0 to 15.4 mbsf, with 102.3% recovery. The bit cleared the seafloor at 2110 hr on 12 April, cleared the rotary table, and was secured for sea at 0215 hr on 13 April. The beacon could not be recalled.

SITE 969

The 385-nmi transit to Site 969 (proposed site MEDSAP-2D) required 31.8 hr at an average speed of 12.1 kt. A 15.6-nmi seismic survey was run over Site 969 in 2.6 hr at 6.0 kt. A Datasonics 354M beacon (S/N 799, 15.0 kHz) was deployed at 1300 hr on 14 April.

Hole 969A

The same APC/XCB bottom-hole assembly used at previous sites was run, and Hole 969A was spudded at 1800 hr on 14 April. The estimated seafloor depth was at 2200.3 m. APC Cores 160-969A-1H to -13H were taken from 0 to 108.3 mbsf, with 108.3 m cored and 111.43 m recovered (102.9% recovery). Cores were oriented from Core 160-969A-3H. Adara heat-flow measurements were taken on Cores 160-969A-5H, -7H, and -9H. Six of the last 7 cores were partial strokes, coring was terminated when Core 160-969A-11H had an imploded top, and the core liner had to be pumped out on Core 160-969A-12H. The maximum gas detected was 4 ppm methane. Some core separation from gas expansion occurred.

Hole 969B

The ship was moved 190 m to the northwest of the beacon, and Hole 969B was spudded at 0620 hr on 15 April. A seafloor depth of 2202.1 m was indicated. APC Cores 160-969B-1H to -11H were taken from 0 to 97.9 mbsf, with 97.9 m cored and 100.46 m recovered (102.6% recovery). The bit cleared the seafloor at 1540 hr on 15 April.

Hole 969C

The ship was moved 175 m southwest of the beacon, and Hole 969C was spudded at 1720 hr on 15 April. A seafloor depth of 2195.5 m was indicated. APC Core 160-969C-1H was taken from 0 to 9.5 mbsf, with 9.5 m cored and 9.98 m recovered (105.1% recovery). The top of the core appeared to be about 3 m below the seafloor, and the hole was abandoned for that reason. The bit cleared the seafloor at 1745 hr on 15 April.

Hole 969D

Hole 969C was spudded in the same position as Hole 969C at 1720 hr on 15 April. A seafloor depth of 2192.1 m was indicated. APC Cores 160-969D-1H to -13H were taken from 0 to 116.2

mbsf, with 116.2 m cored and 118.54 m recovered (102.0% recovery). The bit cleared the seafloor at 0555 hr on 15 April.

Hole 969E

The ship was moved 170 m north of the beacon (5 m south of Hole 969B), and Hole 969E was spudded at 0655 hr on 16 April. A seafloor depth of 2201.1 m was indicated. APC Cores 160-969E-1H to -11H were taken from 0 to 97.9 mbsf, with 97.9 m cored and 100.23 m recovered (102.4% recovery). The liner imploded or failed on 4 of the last 5 cores. Coring was terminated when the formation got extremely firm while drilling for Core 160-969-12H. The bit cleared the seafloor at 1520 hr on 16 April.

Hole 969F

The ship was moved 10 m south of Hole 969E, and Hole 969F was spudded at 1615 hr on 16 April. A seafloor depth of 2198.5 m was indicated. APC Cores 160-969F-1H to -2H were taken from 0 to 19.0 mbsf, with 19.0 m cored and 19.46 m recovered (102.4% recovery). The bit cleared the rotary table at 2306 hr, and the rig floor was secured for sea voyage at 2324 hr on 16 April. The beacon was recovered.

SITE 970

A 36-nmi seismic survey was run over Sites 970 and 971 (proposed sites MV-2 and MV-1/1,1/2) in 6.8 hr at 5.3 kt. A Datasonics 354M beacon (S/N 799, 15.0 kHz) was deployed on the lower flank of Site 970 at 0639 hr on 17 April.

Hole 970A

Hole 970A was spudded at 1120 hr on 17 April on the lower slope of the Milano mud volcano. A seafloor depth of 2077.0 m was indicated. APC Cores 160-970A-1H to -2H were taken from 0 to 10.2 mbsf, with 10.2 m cored and 10.24 m recovered (100.4% recovery). Core 160-970A-1H had 30,000 lb overpull off bottom (i.e., the core barrel did not penetrate fully), and Core -2H was rejected with a partial stroke and no overpull in stiff clay with rock debris; therefore, the XCB coring system was deployed. XCB Cores 160-970A-3X to -22X were taken from 10.2 to 201.4 mbsf, with 191.2 m cored and 40.28 m recovered (21.1% recovery). XCB recovery was reduced by scattered large angular pebbles in hard clay that jammed in the shoe using a short, hard formation shoe and an 8- and 9-finger core catcher. Nine of the first 11 cores jammed in the shoe.

A short trip was made to condition the hole for logs, with no drag and 12 m of light fill on bottom. The hole was displaced with 150 bbl of 8.9 ppg sepiolite/seawater mud, and the go-devil was dropped. The pipe was pulled back to 88.8 mbsf for logging. The Induction/Sonic log was run to 2288.4 m total depth (TD) in 3.08 hr. The Density/Neutron tool was run to 2288 m TD in 2.67 hr. The FMS log was run to 2288 m TD in 2.33 hr. Logging was finished at 0900 hr on 19 April. The bit cleared the seafloor at 0920 hr on 19 April.

Hole 970B

The ship was moved 800 m east to the distal edge of the Milano mud volcano, and a beacon was dropped at 1021 hr on 19 April. Hole 970B was spudded at 1425 hr on 19 April. The estimated seafloor was at 2078.6 m. Core 160-970A-1H was probably taken slightly below the seafloor. APC Cores 160-970B-1H to -5H were taken from 0 to 47.5 mbsf, with 47.5 m cored and 48.68 m recovered (102.5% recovery). Nannofossil ooze was recovered; therefore, the hole was terminated. The bit cleared the seafloor at 1920 hr on 19 April. The beacon was recovered.

Hole 970C

The ship was moved 1013 m west to the upper flank of the Milano mud volcano, and a Datasonics 354M beacon (S/N 779, 15.0 kHz) was dropped at 2059 hr on 19 April. Hole 970C was spudded at 2300 hr on 19 April. The estimated seafloor depth was 2036.9 m. APC Cores 160-970C-1H to -3H were taken from 0 to 16.5 mbsf, with 16.5 m cored and 16.54 m recovered (102.2% recovery). Core 160-970-1H was a partial stroke, which was caused by hitting a siltstone cobble.

XCB Cores 160-970C-4X to -5X were taken from 16.5 to 35.6 mbsf, with 19.1 m cored and 0.43 m recovered (2.3% recovery). XCB recovery was reduced by scattered large angular pebbles in hard clay that lodged in the shoe, acting as a center bit. The bit cleared the seafloor at 0350 hr on 20 April. The beacon was recovered.

Hole 970D

The ship was moved 720 m west to the crest of the Milano mud volcano, and a Datasonics 354M beacon (S/N 1243, 14.0 kHz) was dropped at 0448 hr on 20 April. Hole 970D was spudded at 0715 hr on 20 April. The estimated seafloor was at 1953.3 m. APC Cores 160-970D-1H to -5H were taken from 0 to 42.8 mbsf, with 42.8 m cored and 44.19 m recovered (103.2% recovery). The last four cores were partial strokes in hard clay with pebbles and gravel, and Core 160-970D-2H had a split liner. The bit cleared the seafloor at 1010 hr on 20 April. The beacon was recovered, and transit to Site 971 began.

SITE 971

The ship was moved in dynamic positioning (DP) mode 3.7 nmi west of Site 970 in 3.5 hr, and a Datasonics 354M beacon (S/N 779, 15.0 kHz) was dropped at 1401 hr on 20 April.

Hole 971A

Hole 971A (proposed site MV-1/1,1/2) was spudded at 1600 hr on 20 April on the distal flank of the Napoli mud volcano. The estimated seafloor depth was 2026.1 m. APC Cores 160-971A-1H to -4H were taken from 0 to 28.5 mbsf, with 28.5 m cored and 28.94 m recovered (101.5% recovery). The last two cores were partial strokes in hard clay with pebbles and gravel, and Core 160-971A-4H required 25 min to drill off in hard siltstone. XCB Cores 160-971A-5X to -12X were taken from 28.5 to 105.9 mbsf, with 77.4 m cored and 29.81 m recovered (38.5% recovery). A short hard-formation shoe and an 8- and 9-finger core catcher were used. Overall recovery was 55.4%. The bit cleared the seafloor at 0635 hr on 21 April, and the beacon was recovered.

Hole 971B

The ship was moved 0.87 nmi northwest to the flank moat of the Napoli mud volcano, and a Datasonics 354M beacon (S/N 1243, 14.0 kHz) was dropped at 0802 hr on 21 April. Special H_2S and hydrocarbon guidelines were approved by the safety panel for this site, which has active natural venting. Hole 971B was spudded at 1015 hr on 21 April. The seafloor depth was 2140.9 m. APC Cores 160-971B-1H to -4H were taken from 0 to 30.7 mbsf, with 30.7 m cored and 31.37 m recovered (102.2% recovery). XCB Cores 160-971B-5X to -22X were taken from 30.7 to 203.5 mbsf, with 172.8 m cored and 33.04 m recovered (19.1% recovery). A short hard-formation shoe and an 8- and 9-finger core catcher were used. Six of 18 cores jammed in the shoe. Overall recovery was 31.7%.

Logging operations in Hole 971B

A short trip was made to condition the hole for logs, with no drag and 20.8 m of light fill on bottom. The hole was displaced with 160 bbl of seawater with 2% KCl, and the go-devil was dropped. The pipe was pulled back to 84 mbsf for logging and spaced out to pick up 20 m to log the upper hole. The Induction/Sonic log was run to 2325 m total depth (TD) (30.8 m fill) in 2.92 hr. The Density/Neutron log was run to 2288 m TD (67.8 m fill) in 2.75 hr. The FMS log was run to 2280 m TD (75.8 m fill) in 2.25 hr. Logging was finished at 1500 hr on 23 April. The bit cleared the seafloor at 1533 hr on 23 April.

Hole 971C

A short APC hole was required to recover a rare diatom-rich sapropel section missing in the Hole 971B core overlap from 10.2 to 11.7 mbsf. The ship was moved 10 m to the north, and Hole 971C was spudded at 1635 hr on 23 April in the lower flank moat of the Napoli mud volcano. The estimated seafloor was at 2140.9 m. APC Cores 160-971B-1H to -2H were taken from 0 to 16.7 mbsf, with 16.7 m cored and 17.25 m recovered (103.3% recovery).The bit cleared the seafloor at 1743 hr on 23 April. The beacon was recovered at 1900 hr.

Hole 971D

The ship was moved in DP mode 0.935 nmi northwest to the crest of the Napoli mud volcano, and a beacon was dropped at 1943 hr on 23 April. The first spud attempt resulted in a full core barrel of very gassy clay. The bit was pulled up 5 m, and Hole 971D was spudded at 2235 hr on 23 April. The seafloor was at 1933.1 m. APC Cores 160-971D-1H to -5H were taken from 0 to 46.0 mbsf, with 46.0 m cored and 47.50 m recovered (103.3% recovery).

Core 160-971D-1H had 100-200 ppm H_2S in the top section. The H_2S concentration degassed rapidly to 10 ppm with negligible ambient level. In the bottom sections, the core was gassy and expanded (like a mousse) with a slight petroleum odor and 5-10 ppm H_2S. The liners were drilled and allowed to degas on the core platform until H_2S was 5 ppm or less. Lab personnel wore air packs in the lab while cutting the liners, and the liners were allowed to degas on the core deck with maximum H_2S ambient levels of 5 ppm.

The bit cleared the seafloor at 0240 hr on 24 April.

Hole 971E

The ship was moved in DP mode 0.525 nmi southwest to the crestal vent area of Napoli mud volcano, and a Datasonics 354M beacon (S/N 1243, 14.0 kHz) was dropped at 0347 hr on 24 April. Hole 971E was spudded at 0610 hr on 24 April. The seafloor was at 1943.6 m. APC Cores 971E-1H-3H were taken from 1955.0 to 1983.5 m (0 to 28.5 mbsf), with 28.5 m cored and 29.52 m recovered (103.6% recovery). Core 160-971E-1H was very gassy and had 200 ppm H_2S in the top two sections. On Core 160-971E-3H the core liner burst on the core deck while being drilled to vent gas. There were no injuries, but coring was terminated for crew safety. The bit cleared the seafloor at 0825 on 24 April, and the BHA was secured, ending Site 971. The beacon was recovered.

SITE 972

The 304-nmi transit to Site 972 (proposed site MR-2) required 25.0 hr at 12.2 kt. A 22-nmi seismic survey was run over Sites 972 and 973 in 3.25 hr at 6.8 kt. A Datasonics 354M beacon (S/N 1243, 14.0 kHz) was deployed at Site 972 at 1702 hr on 25 April.

Hole 972A

Hole 972A was spudded at 0150 hr on 26 April. The estimated seafloor was at 3930.6 m. APC Cores 160-972A-1H to -7H were taken from 0 to 66.5 mbsf, with 66.5 m cored and 66.70 m recovered (100.3% recovery). The last three cores were partial strokes with imploded liner bottoms, and Core 160-972A-7H had 70,000 lb pullout. The bottom 2-3 m of Cores 160-972A-6H and -7H were sucked in.

XCB Cores 160-972A-8X to -10X were taken from 66.5 to 95.3 mbsf, with 28.8 m cored and 26.84 m recovered (93.2% recovery). The XCB core barrel would not land properly for Core 160-972A-11X. When it was pulled, we found that the Spring-Hex Quick Release Adapter had backed off the spring shaft, leaving the XCB core barrel in the open hole below the Hex Drive. The spring shaft threads were undamaged and it was reused. The hole was terminated, and the BHA was pulled, clearing the seafloor at 1602 hr on 26 April.

Hole 972B

A new XCB latch assembly and core barrel were made up. Hole 972B was spudded at 1655 hr on 26 April in 3930.6 m water depth to continue coring. An XCB wash barrel was dropped, and a hole was drilled from 0 to 60.1 mbsf to obtain a missing APC core suck-in section. The wash barrel was pulled with about 2 m of wash core recovered. An APC core barrel was run, but it would not pressure up to shoot. On the assumption that some wash core had been dropped in the barrel, an XCB core barrel was pumped down as a deplugger. The XCB landed with low pump pressure and was worked without success. There was no visible damage to the core barrels; therefore, the BHA was pulled, clearing the seafloor at 2258 hr on 26 April. The beacon was recovered.

SITE 973

The ship was moved 11.4 nmi in dynamic positioning (DP) mode while the pipe was being pulled. The bottom-hole assembly cleared the rotary at 0600 hr on 27 April.

Hole 973A

A Datasonics 354M beacon (S/N 1248, 14.5 kHz) was deployed at 0938 hr on 27 April. A full core barrel was obtained on the first APC core attempt and initially discarded; however, it was archived later as core from Hole 973B. Hole 973A (proposed site MR-3) was spudded at 1520 hr on 27 April. The estimated seafloor was at 3695.0 m. APC Cores 160-973A-1H to -7H were taken to 65.0 mbsf, with 66.70 m recovered (100.3% recovery). Orientations were taken from Core 160-973A-3H. Adara heat-flow measurements were taken at Cores 160-973A-5H and -7H. XCB Cores 160-973A-8X through -16X were taken from 65.0 to 146.5 mbsf. The bit was balling, and the rate of penetration was slow. The XCB shoes were plugging, and 5 of 9 shoes jammed in stiff clay. The XCB shoe broke off on Core 160-973A-17X, junking the hole and terminating coring. The spacer sub was nearly cut in two by a loose bit cone, indicating bit failure. The 11-716-in. bit had lost the no. 2 cone and had severe shirttail abrasion wear.

Hole 973B

A Datasonics 354M beacon (S/N 1248, 14.5 kHz) was deployed at 0938 hr on 27 April.The first APC core attempt was from 3710 m, and 9.62 m was recovered. The core was not considered to be a valid mud-line and was not archived initially; however, it was sectioned for demonstration purposes later, and interesting sapropels were discovered and sampled. The core was archived as having been recovered from Hole 973B, but it was left on the ship. For the record, Hole 973B was spudded at 1415 hr on 27 April. APC Core 160-973B-1H was taken from 0 to 9.5 mbsf, with 9.62 m recovered (101.3% recovery). The seafloor depth (3695.0 m) and the location are the same as for Hole 973A. The bit cleared the seafloor on Hole 973B at 1500 hr on 27 April.

Hole 973C

The ship was moved 10 m to the north. The first mud-line core recovered only 1 m and was discarded as a water core. The second core was shot at 3695.4 m and recovered a full barrel, which was archived. Hole 973C was spudded at 1940 hr on 29 April. A seafloor depth of 3695.4.0 m was indicated. APC Core 160-973C-1H was taken to 9.5 mbsf, with 9.73 m recovered (102.4% recovery).

Hole 973D

The ship was not moved. The first mud-line core was shot at 3694 m and recovered 8.88 m. Hole 973D was spudded at 2100 hr on 29 April. APC cores were taken from 0 to 62.4 mbsf, with 62.14 m recovered (99.6% recovery). Four of 7 cores were partial strokes in clay and sand, and 4 of 7 liners imploded or burst and had to be pumped out.

The hole was drilled ahead with a center bit from 62.4 to 140.0 mbsf in 5.5 rotating hr. XCB Cores 160-973-8X through -9X were taken from 140.0 to 152.6 mbsf. The rate of penetration was slow. The XCB shoes were jammed in stiff clay. A hole-cleaning sweep was circulated on the last core.

Logging operations in Hole 973D

Coring was terminated due to time constraints, a go-devil was pumped, and the bit was pulled to 71.5 mbsf (without a conditioning trip) for a short logging program. An Induction/Sonic log was run to 3858.2 m total depth (no fill) in 4.66 hr. Time was not available to run another log, so the bit was pulled and cleared the seafloor at 0155 hr on 1 May.

Hole 973E

Additional cores were needed to cover a coring gap at around 17.5 mbsf. The ship was not moved. Hole 973E was spudded at 0240 hr on 1 May. The seafloor depth was 3 m. An 11-7/16-in. hole was washed from 0 to 13.0 mbsf. APC Cores 160-973E-1H to -2H were taken from 13.0 to 32.0 mbsf, with 19.81 m recovered (104.2% recovery). The bit cleared the seafloor at 0525 hr on 1 May. The coring wirelines were coated with Compound L, and the drill pipe was inhibited with Coat 405. The 7-1/4-in. DC and XOs and NMDC were inspected (the DC had been inspected earlier). The bit cleared the rotary table at 1500 hr on 1 May. The *JOIDES Resolution* began the transit to Naples, Italy.

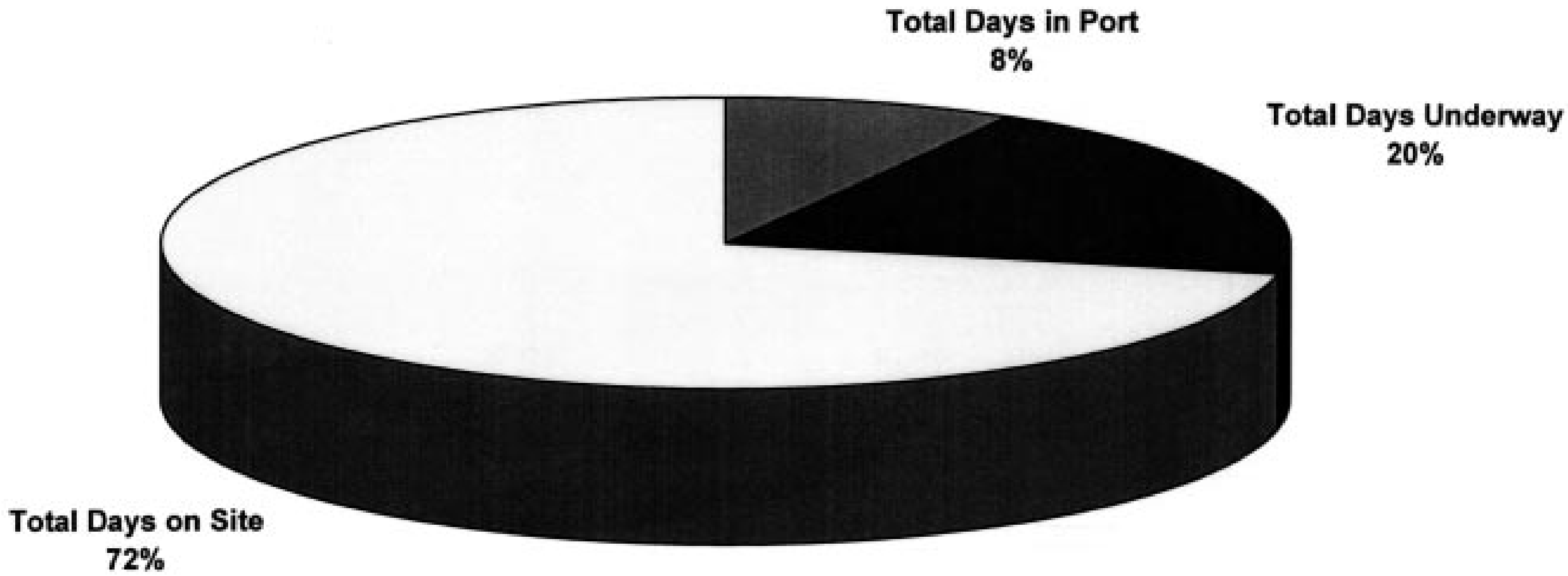
OCEAN DRILLING PROGRAM

TIME DISTRIBUTION

LEG 160

OCEAN DRILLING PROGRAM LEG 160 OPERATIONS RESUME		
Total Days (7-Mar-95 to 3-May-95)		56.3
Total Days in Port		4.7
Total Days Underway		11.3
Total Days on Site		40.3
Stuck Pipe/Downhole Trouble	0.0	
Tripping	8.4	
Other	0.1	
Drilling	0.6	
Coring	25.9	
Re-Entry	0.0	
Logging/Downhole Science	5.2	
Fishing & Remedial	0.0	
Repair Time (ODP)	0.1	
Development Engineering	0.0	
Repair Time (Contractor)	0.0	
W.O.W.	0.0	
Casing and Cementing	0.0	
Total Distance Traveled (nautical miles)		4048.0
Total Miles Transited:		350.6
Average Speed Transit (knots):		11.6
Total Miles Surveyed:		230.0
Average Speed Survey (knots):		6.5
Number of Sites		11.0
Number of Holes		48.0
Total Interval Cored (m)		4801.8
Total Core Recovery (m)		3362.2
% Core Recovery		70.0
Total Interval Drilled (m)		353.7
Total Penetration		5155.5
Maximum Penetration (m)		600.3
Maximum Water Depth (m from drilling datum)		3942.0
Minimum Water Depth (m from drilling datum)		480.0

LEG 160
TIME DISTRIBUTION



Total Days 56.3

OCEAN DRILLING PROGRAM

SITE SUMMARY

LEG 160

HOLE	LATITUDE	LONGITUDE	WATER DEPTH (meters)	NUMBER OF CORES	INTERVAL CORED (meters)	CORE RECOVERED (meters)	PERCENT RECOVERED (percent)	DRILLED (meters)	TOTAL PENETRATION (meters)	TIME ON HOLE (hours)	TIME ON SITE (days)
963A	37°01.938'N	13°10.896'E	481.0	25	199.4	203.17	101.9%	0.0	199.4	24.25	1.01
963B	37°02.004'N	13°10.830'E	480.5	24	208.0	206.00	99.0%	0.0	208.0	14.50	0.60
963C	37°02.076'N	13°10.758'E	480.0	6	57.0	57.93	101.6%	0.0	57.0	4.25	0.18
963D	37°02.148'N	13°10.686'E	480.1	1	8.4	8.39	99.9%	0.0	8.4	5.25	0.22
MEDSAP-4A TOTALS:				**56**	**472.8**	**475.49**	**100.6%**	**0.0**	**472.8**	**48.25**	**2.01**
964A	36°15.623'N	17°44.990'E	3668.3	11	101.8	106.12	104.2%	0.0	101.8	25.25	1.05
964B	36°15.623'N	17°45.000'E	3669.4	11	102.0	105.26	103.2%	0.0	102.0	13.00	0.54
964C	36°15.627'N	17°45.007'E	3671.4	12	105.1	106.48	101.3%	0.0	105.1	15.50	0.65
964D	36°15.632'N	17°45.000'E	3671.4	12	108.6	112.20	103.3%	0.0	108.6	14.75	0.61
964E	36°15.647'N	17°44.999'E	3672.0	6	53.0	54.32	102.5%	32.5	85.5	8.00	0.33
964F	36°15.638'N	17°45.025'E	3668.4	3	28.1	27.94	99.4%	0.0	28.1	11.75	0.49
MEDSAP-3A TOTALS:				**55**	**498.6**	**512.32**	**102.8%**	**32.5**	**531.1**	**88.25**	**3.68**
965A	33° 55.080'	32°42.785'E	1517.7	27	250.4	42.79	17.1%	0.0	250.4	58.00	2.42
ESM-2A TOTALS:				**27**	**250.4**	**42.79**	**17.1%**	**0.0**	**250.4**	**58.00**	**2.42**
966A	33° 47.799'	32°42.095'E	937.7	13	106.8	73.21	68.5%	0.0	106.8	15.75	0.66
966B	33° 47.765'	32°42.090'E	937.8	16	146.0	96.46	66.1%	0.0	146.0	15.50	0.65
966C	33° 47.779'	32°42.089'E	937.0	17	127.0	101.60	80.0%	0.0	127.0	14.00	0.58
966D	33° 47.790'	32°42.048'E	937.5	20	136.5	105.94	77.6%	0.0	136.5	15.50	0.65
966E	33° 47.800'	32°42.048'E	937.5	1	8.5	8.48	99.8%	0.0	8.5	5.00	0.21
966F	33° 47.858'	32°42.093'E	934.0	31	297.0	65.85	22.2%	59.0	356.0	58.25	2.43
ESM-1A TOTALS:				**98**	**821.8**	**451.54**	**54.9%**	**59.0**	**880.8**	**124.00**	**5.17**
967A	34° 04.098'	32°43.523'E	2564.2	16	141.3	142.14	100.6%	0.0	141.3	24.00	1.00
967B	34° 04.094'	32°43.526'E	2566.2	14	121.5	126.61	104.2%	0.0	121.5	13.00	0.54
967C	34° 04.270'	32°43.528'E	2564.0	13	114.4	119.55	104.5%	0.0	114.4	11.00	0.46

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967D	34° 04.253'	32°43.531'E	2562.8	2	16.2	16.88	104.2%	0.0	16.2	7.50	0.31
967E	34° 04.106'	32°43.525'E	2564.0	51	488.8	72.32	14.8%	111.5	600.3	133.50	5.56
967F	34° 04.106'	32°43.525'E	2563.0	1	9.5	9.86	103.8%	0.0	9.5	2.00	0.08
		ESM-3A TOTALS:		**97**	**891.7**	**487.36**	**54.7%**	**111.5**	**1003.2**	**191.00**	**7.96**
968A	34° 19.900'	32°45.065'E	1972.5	34	302.7	240.37	79.4%	0.0	302.7	76.75	3.20
968B	34° 19.919'	32°45.070'E	1974.1	2	14.9	15.45	103.7%	0.0	14.9	2.25	0.09
968C	34° 19.976'	32°45.211'E	1975.6	2	15.4	15.75	102.3%	0.0	15.4	7.00	0.29
		ESM-4A TOTALS:		**38**	**333.0**	**271.57**	**81.6%**	**0.0**	**333.0**	**86.00**	**3.58**
969A	33° 50.399'	24°53.065'E	2211.8	13	108.3	111.43	102.9%	0.0	108.3	16.25	0.68
969B	33° 50.469'	24°52.978'E	2213.6	11	97.9	100.46	102.6%	0.0	97.9	10.50	0.44
969C	33° 50.323'	24°53.005'E	2207.0	1	9.5	9.98	105.1%	0.0	9.5	2.00	0.08
969D	33° 50.319'	24°53.000'E	2203.6	14	116.2	118.54	102.0%	0.0	116.2	12.25	0.51
969E	33° 50.462'	24°52.981'E	2212.6	11	97.9	100.23	102.4%	0.0	97.9	9.25	0.39
969F	33° 50.475'	24°52.962'E	2210.0	2	19.0	19.46	102.4%	0.0	19.0	8.25	0.34
		MEDSAP-2D TOTALS:		**52**	**448.8**	**460.10**	**102.5%**	**0.0**	**448.8**	**58.50**	**2.44**
970A	33° 44.194'	24°48.120'E	2086.9	22	201.4	50.52	25.1%	0.0	201.4	50.50	2.10
970B	33° 44.214'	24°48.694'E	2099.0	5	47.5	48.68	102.5%	0.0	47.5	10.00	0.42
970C	33° 44.134'	24°47.457'E	2048.3	5	35.6	16.97	47.7%	0.0	35.6	8.50	0.35
970D	33° 44.042'	24°46.613'E	1964.7	5	42.8	44.19	103.2%	0.0	42.8	6.50	0.27
		MV-2 TOTALS:		**37**	**327.3**	**160.36**	**49.0%**	**0.0**	**327.3**	**75.50**	**3.15**
971A	33° 42.190'	24°42.814'E	2037.5	12	105.9	58.75	55.5%	0.0	105.9	16.50	0.69
971B	33° 42.817'	24°42.108'E	2152.3	22	203.5	64.41	31.7%	0.0	203.5	57.00	2.38
971C	33° 42.818'	24°42.108'E	2152.3	2	16.7	17.25	103.3%	0.0	16.7	2.25	0.09
971D	33° 43.437'	24°41.276'E	1944.5	5	46.0	47.50	103.3%	0.0	46.0	9.00	0.38
971E	33° 43.621'	24°40.839'E	1955.0	3	28.5	29.52	103.6%	0.0	28.5	10.00	0.42
		MV-1 /1,1 /2 TOTALS:		**44**	**400.6**	**217.43**	**54.3%**	**0.0**	**400.6**	**94.75**	**3.95**

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972A	35° 46.797'	18°43.515'E	3942.0	10	95.3	93.54	98.2%	0.0	95.3	23.00	0.96
972B	35° 46.802'	18°43.524'E	3942.0	0	0.0	0.00	0.0%	60.1	60.1	14.00	0.58
		MR-2 TOTALS:		**10**	**95.3**	**93.54**	**98.2%**	**60.1**	**155.4**	**37.00**	**1.54**
973A	35° 46.820'	18°56.889'E	3706.5	17	148.5	86.42	58.2%	0.0	148.5	44.50	1.85
973B	35° 46.813'	18°56.889'E	3710.0	1	9.5	9.59	100.9%	0.0	9.5	5.25	0.22
973C	35° 46.822'	18°56.889'E	3707.0	1	9.5	9.73	102.4%	0.0	9.5	8.75	0.36
973D	35° 46.821'	18°56.892'E	3705.6	9	75.0	64.13	85.5%	77.6	152.6	29.75	1.24
973E	35° 46.822'	18°56.881'E	3705.6	2	19.0	19.81	104.3%	13.0	32.0	13.00	0.54
		MR-3 TOTALS:		**30**	**261.5**	**189.68**	**72.5%**	**90.6**	**352.1**	**101.25**	**4.22**
		LEG 160 TOTAL		**544**	**4801.8**	**3362.18**	**70.0%**	**353.7**	**5155.5**	**962.50**	**40.10**

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 160 were:

Randy Ball	Marine Lab Specialist (Photographer)
Tim Bronk	Marine Lab Specialist (Downhole Tools, Thin Section Lab, Storekeeper)
Cesar Flores	Marine Computer Specialist
Margaret Hastedt	Assistant Lab Officer (Paleomagnetics)
Robert Kemp	Marine Lab Specialist (Chemistry)
Kuro Kuroki	Assistant Lab Officer (X-ray)
Monty Lawyer	Marine Lab Specialist (Underway Geophysics)
Jaque Ledbetter	Marine Lab Specialist (X-ray)
Greg Lovelace	Marine Lab Specialist (Physical Properties)
Erinn McCarty	Marine Lab Specialist (Curator)
Bill Mills	Lab Officer
Anne Pimmel	Marine Lab Specialist (Chemistry)
Jo Ribbens	Marine Lab Specialist (Yeoperson)
Bill Stevens	Marine Electronics Specialist
Mark Watson	Marine Electronics Specialist
Barry Weber	Marine Computer Specialist
Alex Wülbers	Marine Lab Specialist (Curatorial Asst.)

PORT CALL, MARSEILLE

The *JOIDES Resolution* departed Las Palmas on 2 March 1995, with a crew of 85 (21 technicians). We proceeded directly to Marseille (France) to pick up freight and the science party. The ship docked in Marseille on 8 March. Major PR activities were jointly conducted by ODP and the French science community. These activities included tours, news broadcasts, and social events. After a 5-day port call, we departed on 12 March with a crew of a 114 (50 scientists and technicians).

Two rendezvous occurred during the leg while drilling off the southern coast of Cyprus. The first boat delivered Schlumberger logging equipment, and the second involved the delivery of welding supplies, mail, and food, and the transfer of personnel. A fourth welder joined the ship at this time to assist with critical repairs to the ship's tanks. Leg 160 ended in Napoli, Italy, on 3 May 1995 for a total of 62 days (including the 5-day port call in Marseille).

UNDERWAY ACTIVITIES

Routine underway data were not collected on the transit from Las Palmas to Marseille.

After the Marseille port call, technicians routinely collected bathymetric, magnetic, and navigational data on all transits. Seismic surveys were conducted at each site using a single 80-$in.^3$ water gun.

During the transit from Las Palmas to Marseille, we installed a new version of our navigation software, WinFrog. Although usable, this new version is plagued with unexpected crashes, often occurring at critical times during a survey. Even with these difficulties, the seagoing staff feels that WinFrog will be an excellent program, once these problems are resolved. A new LabVIEW version of the "Site Fix" program was written to work with the WinFrog data files.

LABORATORY ACTIVITIES

Because of the mixed objectives of this leg, all labs were kept quite busy. The high recovery rates predicted for this leg did not come to pass, which provided time for core lab technicians to work in their secondary lab assignments. Other than the U/W lab's printer and navigation software, and a troublesome Dionex device in the chemistry lab, there were no major equipment failures to report.

On Hole 971E, the Core 3H liner ruptured suddenly as technicians were processing it on the core-receiving platform. The explosion scattered pieces of core liner and mud across the main deck and onto the core lab roof. Other than a few minor cuts and bruises, no one was seriously hurt.
The rupture was caused by gas pressure inside the core liner. Usually, such high gas pressure will extrude the core out of the liner, but this core contained a very sticky and viscous mud that created an effective seal. Also, the liner failure may have been initiated by drilling vent holes in the liner to vent gas pressure, a practice that will need to be reviewed.

H_2S precautions were taken throughout the leg. Several shows were detected with H_2S levels at >100 ppm (measured in the liner). These cores were processed according to the H_2S guidelines, without incident.

Special Projects

The cc:Mail postoffice was installed for testing purposes. A full, ship-wide implementation of cc:Mail was delayed until additional testing could be completed. A considerable amount of work was completed on the new LabVIEW version of the MST software. A full test was scheduled for the Napoli port call. In the physical properties lab a new pycnometer was installed. Also, the VSR system was upgraded with new instrument stands, transducers for all three DSV stations, and a digital scale for DSV no. 3.

LEG 160 SAMPLING AND ANALYSIS TOTALS (estimates only)

SAMPLES	
Total number:	17,000
PHYSICAL PROPERTIES LAB	
MST(includes Susceptibility, GRAPE, P-wave, and Nat. Gamma):	3000 m scanned
Index Properties:	753
Velocity:	1131
Strength:	650
Thermal Conductivity:	278
DOWNHOLE TOOLS LAB	
In situ temperature:	24
THIN SECTION LAB	
Thin sections:	206
CHEMISTRY	
Carbon-Carbonate:	1042
Rock-Eval:	286
CNS:	850
Interstitial water analysis:	187
Headspace (GC):	229
X-RAY LAB	
XRD:	265
PALEOMAGNETICS LAB	
discrete:	100
cryomagnetometer:	3000 m scanned
UNDERWAY GEOPHYSICS	
Magnetics and Bathymetrics:	4047 nmi
Seismic:	230 nmi