OCEAN DRILLING PROGRAM

LEG 160 SCIENTIFIC PROSPECTUS

MEDITERRANEAN I

Dr. Kay-Christian Emeis
Co-Chief Scientist, Leg 160
Institut für Ostseeforschung Warnemüende
Seestrasse 15
18119 Warnemüende
Federal Republic of Germany

Dr. Alastair Robertson
Co-Chief Scientist, Leg 160
Grant Institute of Geology
University of Edinburgh
West Mains Road
Edinburgh EH9 3JW
United Kingdom

Dr. Carl Richter
Staff Scientist, Leg 160
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.

Philip D. Rabinowitz
Director
ODP/TAMU

Jack Baldauf
Manager
Science Operations
ODP/TAMU

Timothy J.G. Francis
Deputy Director
ODP/TAMU

November 1994

Scientific Prospectus No. 60
First Printing 1994

Distribution

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77845-9547, U.S.A. Orders for copies may require payment for postage and handling.

D I S C L A I M E R

This publication was prepared by the Ocean Drilling Program, Texas A&M University, as an account of work performed under the international Ocean Drilling Program, which is managed by Joint Oceanographic Institutions, Inc., under contract with the National Science Foundation. Funding for the program is provided by the following agencies:

Canada/Australia Consortium for the Ocean Drilling Program
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
Institut Français de Recherche pour l'Exploitation de la Mer (France)
Ocean Research Institute of the University of Tokyo (Japan)
National Science Foundation (United States)
Natural Environment Research Council (United Kingdom)
European Science Foundation Consortium for the Ocean Drilling Program (Belgium, Denmark, Finland, Iceland, Italy, Greece, The Netherlands, Norway, Spain, Sweden, Switzerland, and Turkey)

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, the participating agencies, Joint Oceanographic Institutions, Inc., Texas A&M University, or Texas A&M Research Foundation.

This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

ABSTRACT

Leg 160 represents the first in a two-leg program to investigate the tectonic and paleoceanographic history of the Mediterranean Sea. Its first focus is upon accretionary and collisional processes associated with the convergent boundary between the African and Eurasian plates. Its second focus is upon the origin and paleoceanographic significance of sapropels, organic-rich layers intercalated in the Plio-Quaternary sediments of the Mediterranean Basin.

The African/Eurasia plate boundary in the Eastern Mediterranean region 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 to investigate the transition from subduction to collision, processes that may be recorded on land in orogenic belts, but which are presently poorly understood. Tectonic-oriented drilling on Leg 160 will focus on relatively shallow objectives (mainly <500 m). The first objective is 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 is to study the origin of mud volcanism, now recognized as creating the widespread "cobblestone topography" over large areas of the Mediterranean Ridge, by drilling at both crestal and flank locations. The third objective is to study subduction and accretion in an area where subduction is still taking place, by drilling sites both on the abyssal plain and 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-Recent subduction/accretion history of the Eastern Mediterranean.

Sapropels are sedimentary expressions of rhythmic changes in the physical circulation system and in biogeochemical cycling of the Mediterranean Sea during the Neogene. They are thin (<0.5 m) organic-rich (up to 15% organic carbon [OC]) layers intercalated in hemipelagic, organic-lean muds and oozes. The timing of sapropel deposition appears to be unrelated to glacial-interglacial cycles, but instead is closely linked to precession-induced fluctuations of monsoonal circulation. One hypothesis for the origin of sapropels postulates that the deeper water column was anoxic during their formation, enhancing preservation of organic carbon at the seafloor. A second hypothesis favors increased primary productivity at the sea surface and increased rates of carbon flux to the seafloor as the reason for sapropel formation. Both hypotheses require a set of testable boundary conditions in the physical, chemical, and biological environment. Drilling a transect of sites across the entire Mediterranean Sea, Legs 160 and 161 will establish both the nature of the environmental change, and the temporal and spatial patterns of environmental conditions leading to sapropel deposition during the Plio-Quaternary.

INTRODUCTION

Leg 160 includes sites from the Mediterranean Ridges proposal from three areas (Fig. 1): (1) the Eratosthenes Seamount (ESM) area, in a zone of incipient continental collision; (2) the Mud Volcano (MV) site on the Mediterranean Ridge, an accretionary wedge in a collisional setting; (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 will be drilled at additional sites during Leg 161 in the Western Mediterranean. The Mediterranean Ridge objectives are largely concerned with tectonic processes, while the Sapropels objectives are largely paleoceanographic. However, strong overlaps in the science between the two sets of objectives exist, and a fully integrated program of drilling is planned.

REGIONAL FRAMEWORK AND TECTONIC OBJECTIVES

The Mediterranean Ridge is a 1300-km-long, 300- to 150-km-wide arcuate feature of submerged relief (Fig. 2). To the southeast and southwest of the ridge, narrow abyssal plains (Ionian, Sirte, and Herodotus) separate the deformation front from the African continental slope. South of the central section of the ridge, folded sediments of the deformation front abut directly against the African continental slope of the Cyrenaica Peninsula. North of the ridge is a complex system of deep trenches, on average deeper than the southern abyssal plains, called the Hellenic Trench System. The minimum water depth on the ridge crest is about 1200 m. The maximum water depth in the Hellenic Trench is 5100 m, and the water depths of the outer abyssal plains are between 4150 and 3200 m, shallowing toward the Nile deep-sea fan. The topography of the ridge is characterized by the alternation of small rimmed basins and ridges oriented roughly parallel to the deformation front, which produces a hummocky acoustic reflection (cobblestone topography of Emery; in Hersey, 1965).

Convergence in the Eastern Mediterranean is produced by relative plate motion between the Africa and Eurasia plates. According to kinematic analysis (Le Pichon and Angelier, 1979; Jongsma et al., 1987), subduction is near orthogonal in a northeast direction in the Ionian Basin, at low angle in the western Levantine Basin (prevailing left-lateral strike slip), and again near orthogonal in the easternmost Levantine Basin (Cyprus Arc).

Crustal thickness of the incoming plate indicates that southwest and southeast of the Mediterranean Ridge, oceanic or thinned continental crust exists, while crustal thickening occurs under the Mediterranean Ridge and the Hellenic Trench System (Rabinowitz and Ryan, 1970; Woodside and Bowin, 1970; Finetti, 1976; Makris, 1977; Giese et al., 1982; Makris et al., 1983; Makris and

Stobbe, 1984; Underhill, 1989; deVoogd et al., 1992). The crust is thicker between the Cyrenaica Promontory and Crete Island (the narrower segment of the eastern Mediterranean with no abyssal plain seaward of the deformation front) where continental collision occurs. North of the Hellenic Trench System, are the nonvolcanic arc of Crete (continental crust) and the Aegean backarc basin (Horvath and Berckhemer, 1982) in which andesitic volcanism has developed (Fytikas et al., 1984). The horizontal component of the gravity vector (Brennecke and Lelgemann, 1986) clearly demonstrates the horizontal heterogeneities in the mass distribution of depth related to the continental convergence. The seismological evidence of the African/Eurasian plate boundary in the Eastern Mediterranean is located along the Hellenic Trench System, where a broad zone of intermediate-depth earthquakes (not exceeding a depth of 200 km) roughly delineates a generally northward-dipping subducting lithospheric slab (Wortel et al., 1990). One uncertainty in the Hellenic subduction zone concerns the age of the onset of subduction, which has been estimated to occur between 5 Ma (McKenzie, 1978; Kissel and Laj, 1988) and about 100 Ma (Wortel et al., 1990), although an age of 17 Ma (early Miocene) is currently favored.

The accretionary nature of the Mediterranean Ridge has been defined through gradual recognition of the compressional tectonics that moved the ridge from the role of outer swell to that of accretionary complex. Offscraping of sediments from the African plate must be older than 33 Ma (Kastens, 1991) and has led to development of two deformation fronts with opposite vergence (Fig. 2). The Outer Deformation Front is located along the abrupt morphologic change between the flat abyssal plains and the rough topography of the ridge, and exhibits generally southward vergence of tectonic structures. The Inner Deformation Front is located along the escarpment that delimits to the north the ridge crestal plateau, and shows generally northward vergence and widespread evidence of mud diapirism. Diapirism associated with the Inner Deformation Front causes the deformed sediments of the Mediterranean Ridge to be thrust over a rather flat and undeformed continental plateau (Inner Plateau), where a Messinian sedimentary depocenter provides the evidence of an ancient forearc basin (Camerlenghi, 1991; Camerlenghi et al., 1994).

Reliable and accurate temperature measurements were taken at DSDP Sites 374 (Ionian Abyssal Plain, seaward of the Western Deformation Front of the Mediterranean Ridge), 376 (Florence Rise, Cyprus Arc), and 378 (Southern Aegean Sea) (Erickson and Von Herzen, 1978). The low heat flow obtained from Sites 374 and 376 (33.5 mWm^{-2} and 39.4 mWm^{-2}, respectively) provides a valuable constraint to the regional thermal regime of the Eastern Mediterranean. The few heat-flow measurements located on the Mediterranean Ridge show, on average, values lower that 30 mWm^{-2}, which could be caused by widespread downward flux of seawater in the sediments overlying the evaporites. Local positive anomalies, however, can be expected where fluid expulsion or mud diapirism occurs (e.g., Barbados Ridge). Heat-flow measurements in the drill holes across the Eastern Mediterranean area may thus provide valuable in reconstructing fluid paths within the accretionary complex.

DEFORMATION SETTINGS

The style and nature of deformational processes differ along different parts of the Africa/Eurasia plate boundary. Three aspects will be studied on Leg 160, as follows:

Incipient continental collision: Eratosthenes-Cyprus margin transect

The substantial Eratosthenes Seamount in the Eastern Mediterranean Sea (Figs. 2, 3) is believed to be a fragment of continental crust that was rifted from the northern margin of Gondwana to form a continental sliver "floating" within Tethys during Mesozoic to Holocene time (e.g., Kempler and Ben-Avraham, 1987). With the subsequent northward subduction of Tethys, the Eratosthenes Seamount remained near the North African continental margin until relatively recent times, when it began to be consumed northward along an active plate boundary located to the south of Cyprus ("Cyprus trench") (Figs 2, 3). Indeed, the interpretation of available seismic, gravity, and magnetic data, combined with evidence from coring and limited dredging, leads to the hypothesis that the Eratosthenes Seamount is currently in the process of subsidence, breakup, and thrusting beneath Cyprus. The East-West-trending plate boundary accommodates most of the present-day convergence between Africa and Eurasia in the Eastern Mediterranean region (Fig. 2). Recent work on the sedimentary and structural geology of southern Cyprus indicates that strong uplift took place in the late Pliocene to early-middle Quaternary, and this probably relates to underthrusting of the Eratosthenes Seamount (Robertson et al., 1991; Poole and Robertson, 1992).

The Eratosthenes Seamount is the most prominent bathymetric feature between the Nile Cone and Cyprus, rising from a surrounding moat at a depth of ca. 2000 m to shallowest depths of <800 m (Fig. 4). Seismic refraction data and gravity modeling (Woodside and Bowin, 1970) suggest that the crust thins by about 2-3 km along a North Northeast-South Southwest line through Eratosthenes, from a depth of about 24-26 km in the Levantine Basin in the east (Woodside, 1977; Makris and Stobbe, 1984). The sedimentary succession is perhaps as much as 15 km thick. The seismic velocity of the underlying crust is about 6.7 km/s which is high for continental crust and would be reasonable for oceanic crust (layer 3) if it were not so thick (10 km compared to a more typical value of 5 km). A large magnetic anomaly is associated with the Eratosthenes structure, suggesting a broad, deep-seated source (Ben-Avraham et al., 1976). It ranges in amplitude from -150 nT to the northwest to 450 nT to the southeast and is elongated in the same direction as the seamount. The length of the anomaly in the North Northeast-South Southwest direction is almost 300 km between enclosing nT contour lines and over 1000 km in the Northwest-Southeast direction between the maximum and minimum values. Several small local anomalies superimposed on the main anomaly distort the overall anomaly in the northwest. Ben-Avraham et al. (1976) interpret the source as basic and ultrabasic (possibly ophiolitic) material. Woodside (1977) suggested that the source might be volcanic intrusions.

In strong contrast to the magnetic anomaly pattern, the gravity anomaly is almost entirely topographic (Woodside, 1977). There is a free air anomaly of about 75 mGal that diminishes to a Bouguer anomaly of less than 20 mGal after correction for a topographic mass with an assumed mass of 2.67 g/cm^3. This suggests that the seamount is supported by the crust alone or by forces within the upper lithosphere, because there appears to be no lower crustal root or flexural response to the topographic load. A regional westward increase in gravity by about 20 mGal just to the west of the seamount corresponds to the westward thinning of the crust by about 2-3 km as noted above; and to the west of this line there is a North Northeast-South Southwest-oriented long-wavelength linear positive residual gravity anomaly of 30-50 mGal, which indicates the presence of a major crustal discontinuity there (Woodside, 1992).

Bathymetric charts and the results of a swath bathymetric survey, carried out over the southern part of the Seamount during a cruise of the *Academician Nikolai Strakhov* indicate that the Eratosthenes Seamount is approximately rectangular (Fig. 4). The South and East margins are steep to locally very steep. The North and Northwest flanks are markedly terraced. The summit area is broadly undulating along an East Northeast-West Southwest trend. Early seismic data revealed that the northern and southern margins of the seamount are bordered by thick sedimentary basins, here termed the Northern and Southern troughs. These seismic data were interpreted as evidence of northward underthrusting of the Eratosthenes Seamount beneath the Cyprus margin. Available seismic evidence suggested that Messinian evaporites were probably not deposited on the seamount. Successions of nannofossil muds with sapropels and tephra were cored from near the crest of the Eratosthenes Seamount at station KC20. In addition, Cretaceous/Mesozoic limestones were dredged from the southern lip of the Seamount.

Additional site-survey data acquired during the 1993 TREDMAR-3 cruise (Woodside, Ivanove, et al., in press) comprised 12 channel air-gun seismics, OKEAN long-range sidescan sonar, and MAK deep-towed short-range sidescan sonar, combined with a deep-towed 5.5-kHz high-resolution profile; gravity and box coring was also carried out. The various lines run using these techniques are shown in Fig. 4).

Seismic imaging of Eratosthenes Seamount reveal the following main features (Robertson et al., 1994; Robertson et al., in press):

i) The base of the Plio-Quaternary succession on the Seamount is clearly imaged and is estimated as being at a depth of <200 m throughout the crestal area;
ii) the inferred Messinian reflectors can be seen to pinch out against the margins of the seamount, confirming that evaporites are unlikely to be present on the seamount;
iii) the sediments beneath the Northern Trough, as indicated on previously collected seismic data, are seen to dip beneath the Cyprus margin, suggesting that active underthrusting is taking place;
iv) there is an approximately East-West-trending narrow ridge near the base of the slope of the northern margin of the seamount. This ridge is separated from the lower slope of the seamount by a small basin in which sediments appear to be being actively underthrust northward. Also the North and East margins of the seamount are strongly faulted (normal faults). Bedrock is exposed along scarps, e.g., at the southern lip of the seamount;
v) the crestal areas of the seamount are cut by numerous high-angle faults that appear to cut and offset both basement and cover;
vi) sediments within the southern trough appear to dip southward under the slope of the Levantine Basin, suggesting that active underthrusting of the Eratosthenes Seamount is taking place, both northward and southward.

Deep-tow high-resolution profiles reveal numerous additional smaller scale features, notably trains of meter-scale upright folds within the small basin near the foot of the northern slope. These can be interpreted as the result of compression of the sedimentary fill, related to active underthrusting.

Mud Diapirism on the Mediterranean Ridge

Mud diapirism on the Mediterranean Ridge has been identified through high resolution seismic reflection profiles and gravity coring (Cita et al., 1989; Camerlenghi et al., 1992) in a narrow area of the northern edge of the "upper plateau", the flat crestal area of the ridge. Extensive Mark 2 Gloria surveys of the Mediterranean Ridge (Kenyon et al., 1982) outlined the presence on the central crestal area of the Mediterranean Ridge of numerous tectonic trends with relief up to 130 m, but these were interpreted as outcrops of thrusts. Presumably the features are evidence for mud diapirism.

The sediment section entering the Mediterranean Ridge deformation front is characterized by a thick layer of upper Miocene evaporitic deposits (ranging in thickness from 1.3 to 2.8 km), overlain by Plio-Quaternary hemipelagic and turbiditic sediments and underlain by Tertiary fine-grained siliciclastics. The age of the sediments recovered in the mud diapirs of the Mediterranean Ridge indicates a mainly upper Oligocene to lower Miocene sediment source.

Mud volcanoes, mud cones, and mud ridges have been identified on the inner portion of the crestal area, and possibly on the inner escarpment, of the Mediterranean Ridge accretionary complex. Unlike in other accretionary prisms as Barbados, Makran, Sumba, and Costa Rica, there is neither evidence of mud diapirism on the frontal slope nor on the abyssal plain seaward of the deformation front. The distribution of the diapirs is related to the combination of tectonic structures and the areal distribution of upper Miocene evaporites (Fig. 5).

The presence of evaporites is documented on the entire Mediterranean Ridge by the occurrence of the M horizon, a strong seismic reflector (or multiple reflection) that on high-resolution, single-channel seismic reflection profiles often constitutes the acoustic basement. However, the thickness and the composition of the evaporites are variable, and in some cases are poorly known.

Below the frontal abyssal plain, the seismic record indicates a thickness of evaporites exceeding 1000 m, in which a high-velocity layer identifies a salt body. Overpressured mud present at depth below the evaporites in this region cannot break through the plastic and impermeable salt layer to produce mud diapirism and volcanism. Below the outer slope of the ridge the seismo-stratigraphic sequence is less known, because the seismic record becomes less coherent due to the tectonic deformation and to the roughness of the seafloor topography. However, at least 60 km of sedimentary section formerly lying below the Sirte Abyssal Plain is now tectonically uplifted on the outer slope of the Mediterranean Ridge so that the evaporites prevent the extrusion of deeper overpressured sediments to the surface. On the crestal plateau of the ridge (where Site MV-1 is proposed), the seismic record does not indicate the thickness of the evaporites. Geological evidence from DSDP Sites 126 and 377 (Ryan, Hsü, et al., 1973; Hsü, Montadert, et al., 1978) has shown that pre-evaporitic sediments exist about 100 m below the M horizon; thus the thickness of the sequence is noticeably reduced. The inner escarpment is a continuous morphologic break along the western and central Mediterranean Ridge, which offsets the seafloor up to 1000 m. Single-channel seismic lines suggest the presence of mud diapirs also along the inner escarpment. There is evidence that the inner escarpment is produced by a seaward-dipping reverse fault, or thrust, originated by the northward force of the deformed sediments against the seaward-dipping continental backstop of the Mediterranean Ridge.

The distribution of mud diapirism on the Mediterranean Ridge is thus probably controlled by the presence of a landward-vergent front of sediment deformation (inner deformation front) emplaced on a zone of thin (100 m or less) evaporitic thickness, which elsewhere acts as a seal to deep mud expulsion to the surface.

Lithostratigraphy

The reference hemipelagic section recovered from the mud diapirs is composed of Holocene and Pleistocene calcareous nannofossil ooze with foraminifers and minor terrigenous fraction, and is comparable to that recorded in non-diapiric areas of the ridge. The carbonate content ranges from 60% to 100%. The terrigenous components of the sediments (clays, quartz, plagioclase, K-feldspar) are from river discharge and eolian input, mainly from the Nile river and the Saharan region respectively (Camerlenghi et al., 1992; Camerlenghi et al., 1994).

In cores from mud diapir slopes the thickness of the hemipelagic sediments generally increases downslope, where sediments are highly disturbed by local hiatuses, graded beds, microfaulting, and gas-escape structures. Carbonate crusts are found mostly in slope sections within hemipelagic sediments. Typical core logs found on a transect from the top to the flank of a dome are shown in figure 6.

The term *mud breccia* was used by Cita et al., 1981 to describe a gray clay and silt-sized matrix supporting centimetric subrounded clasts of semi-indurated sediment. In the Olimpi mud diapir field (Camerlenghi et al., 1992), the typical color of the matrix is gray and dark gray to olive, but a yellowish oxidation layer commonly marks the uppermost decimeters just below the contact with the hemipelagic host sediments. The mud breccia recovered from the top of Napoli mud volcano contains several centimeteric layers of dark gray sapropelic material. Clasts may vary in color from gray for the matrix to brown for the hemipelagic sediments. The smallest clasts (millimetric) are rounded and indurated. The largest clasts (centimetric) are less indurated and commonly subangular. The clasts vary in lithology from soft marls (most recurrent) to scaly siltstones, quartzites, and biocalcarenites. The occurrence of large pieces of indurated sandstone often limited the penetration of the corer. The carbonate fraction of the breccia from the Olimpi field ranges from 12% to 34%, with lower concentrations typically found in the fine-grained sections. The clay mineral assemblage in the fraction finer than 2 μm shows a trend with decreasing smectite and increasing kaolinite from east to west in the four diapiric areas. The natural water content of the mud breccia varies from 33% to 51%, against about 50% in the upper hemipelagic sediments, and is slightly higher than the saturation water content. The bulk density of the mud breccia ranges between 1.779 and 1.900 g/cm^3.

Rounded holes of no more than 5 mm in diameter, linked to gas vesicles trapped in the mud, are visible in the split core sections, and a "mousse" -like texture due to pervasive gas microvesicles has been repeatedly observed. The extrusion from the core liner of a whole-round sample of the mud breccia produced instantaneous expansion of the sediment with destruction of the sediment fabric. Sedimentary structures suggesting gas-escape structures in the host sediments also have been found.

Nannofossil and foraminifer content indicates that a mixed fauna of predominantly Oligocene-Neogene species is typical of the mud breccia of the Olimpi mud diapir field. Clasts are commonly barren of foraminifers; nannofossils indicated mostly a Miocene and Pliocene age.

Depth of origin of the mud

The origin of the mud diapirs is deep within the Mediterranean Ridge (Camerlenghi et al., 1992). The hydrocarbon gas present in small percentages (1%-3%) in the diapiric mud breccia is composed of methane with rather light carbon isotopic composition and relevant quantities of C^{2+} hydrocarbon gases, which suggest a partly thermogenic origin.

Furthermore, it has been shown that if fluid mud originated at the depth indicated by thermogenic gas and reached the base of the impermeable evaporitic section, the simple lithostatic load of the overlying sedimentary rocks could create mud extrusion to the surface and produce the vertical relief observed in the Olimpi diapiric field. However, if the mud is not completely liquefied and a certain amount of effective stress exists during extrusion (as suggested by the internal friction angle measured on core samples), then an internal driving force is needed to produce such a vertical relief. This was probably produced by gas expansion within diapiric masses, driven by overpressured pore fluids.

The sedimentary sources of the mud diapirs of the central Mediterranean Ridge are upper Oligocene-middle Miocene shales. In the incoming sediment section of the Sirte Abyssal Plain, these sediments should be located between 1.5 and 3.2 km below the seafloor if a rather constant rate of sediment accumulation is assumed in the Tertiary sequence. If these sediments are diapirically extruded at the seafloor, it means that they may come from any depth within the accreted units shallower than, or as deep as, the décollement fault. Taking into account the angle of taper of the Mediterranean Ridge of 2.2°, and assuming that the dip of the subducting plate is constant between the 100 km separating the outer deformation front and the ridge crest, the depth of a likely upper Oligocene-middle Miocene décollement fault below the area of occurrence of mud diapirism would range from 5.3 to 7.0 km (Fig. 7). This is the only possible constraint for the maximum depth of origin of the diapiric sediments of the Mediterranean Ridge.

Source formations for mud mobilization

At present we are not able to explain what triggered the mud diapirism in the Eastern Mediterranean, because the pre-evaporite stratigraphic succession of the Eastern Mediterranean is mostly unknown. We know that the source formations must be pre-Messinian, lying beneath the evaporites. The source material may be as old as Oligocene in the Olimpi mud diapir field. As mud diapirism has been related to the subduction of clay-rich high-porosity/low-permeability deep-sea-fan deposits, it is likely that the high sedimentation rate (55 cm/10^{-3} years) and the smectite-rich and low-carbonate (<10%) Nile-derived sediments are responsible for sediment mobilization on the Mediterranean Ridge. A comparison of the clay mineral composition in mud breccia samples, in the Plio-Quaternary hemipelagic sediments, and in the Messinian and pre-Messinian sediments, on the basis of available data from the Eastern Mediterranean, shows that the diapiric material appears as a mixture of present-day clay mineral sources. The increasing kaolinite/smectite ratio from the eastern to the western diapiric fields, in conjunction the with pre-Messinian sediments and with a Nile source, indicates that the Oligocene-Miocene formations were influenced by Nile-derived sedimentation.

Inferred mechanisms of emplacement

A sequence of events has been identified during the emplacement of the mud diapirs of the Mediterranean Ridge. A common feature in high-resolution single-channel seismic records is the downward deflection of the host sediment reflectors around the diapirs dipping toward the conduit. This is reflected in the ring-shaped seafloor depression and suggests concentric seafloor collapse around each diapiric structure. Seafloor depressions with downward deflection of the surrounding sediments also characterize the mud volcanoes of the Barbados Ridge (Brown and Westbrook, 1988). Because the size of the depression can be larger than the size of the extruded muddy edifice, the collapse is likely due to degassing during the initial stage of mud extrusion. Larger depressions are in fact commonly found around flat-topped mud volcanoes, produced by low-viscosity muds of higher fluid content. Laboratory measurements on cores of the Mediterranean Ridge mud diapirs show that the bulk density of the diapiric mud breccia is comparable to that of the host hemipelagic sediments; thus the formation of the seafloor depression cannot be attributed to isostatic adjustment of the seafloor to the load of the diapir.

Seismic lines from the Mediterranean and Barbados diapirs also suggest that the seafloor depression becomes gradually filled by mud extrusions and local sediment redeposition that cause lateral transition through interfingering between mud and host sediments. These stages of the mud volcano evolution are thus not characterized by high-pressure gas expulsion, but rather by liquid mud extrusions at the surface, which radially expand into the seafloor depression. In the case of the mud volcano of the Olimpi mud diapir field, three main phases of eruption are suggested by the three-step profile. The slope angle measured on this mud volcano ranges between 10° and 15 °, and is lower than the 26° internal friction angle measured with direct shear test on undisturbed specimens of the diapiric material. This means that the equilibrium of the mud volcano is reached under undrained conditions and is due to the cohesion strength of the material that has been measured as 180 kN/m^2. Thus the mud experienced an excess pore pressure at the time of extrusion.

"Age" of mud intrusions and extrusions

The "age" discussed here refers to the youngest diapiric events that caused contacts between mud breccia and host sediments. "Age" determination does not exclude older events. Establishing the age of the intrusive events is not straightforward. The stratigraphic position of the contact between primitive mud breccia and the host sediment is well known, but the intrusive event does not necessarily coincide with the age of that stratigraphic position. Slope cores from Napoli Dome indicate that normal pelagic sedimentation was reestablished just prior to sapropel S-1 deposition (approximately 10,000 years before present). Napoli Dome's top cores do not show S-1, so that the mud ponds persisted until post S-1 time but ceased to exist between S-1 and today, as indicated by the thin hemipelagic drape.

Another tool for dating extrusive activity is the presence of reworked microfossils in the host sediments. Reworked microfossils extruded by vents or mud eruptions may in fact travel from the dome downslope and spread on the surrounding sediments through the nepheloid layer or as very thin local turbid flows. The oldest traces of reworked microfossils were in Napoli Dome, approximately 300,000 years before present. From this age through sapropel S-6 deposition (180,000 years before present), eruptive activity is continuously documented. Evidence of eruptions also comes from the pre-tephra Y-5 sediments (30,000-40,000 years before present), and from sediments between sapropels S-5 and S-4 (125,000/~100,000 years before present) (Camerlenghi et al., 1994).

Additional information from the TREDMAR 3 cruise

Extensive mud diapirism on the Mediterranean Ridge was confirmed by a combination of high-resolution seismic reflection profiles, gravity coring, and both wide-beam (OKEAN) and narrow-beam (MAK-1) side-scan sonar (with high-resolution profile) during the recent TREDMAR-3 cruise. The data also include a deep-towed video over the Napoli Dome.

A 12-air-gun seismic survey picked out the well-known cobblestone topography. A number of dome-like structures were imaged. The largest were selected for more detailed study. The OKEAN wide-beam side-scan data allowed the mud volcanoes to be picked out by relatively high reflectivity.

On this basis, it is clear that the density of mud volcanoes is greater in the Olimpi field than anywhere else in the surveyed mud volcano region.

On the narrow-beam side-scan sonar (MAK-1) there is again a sharp reflectivity contrast between the pelagic sediment and the adjacent mud volcano material. The shape of the mud volcanoes is generally circular with a maximum radius of 750 m. The mud volcanoes typically exhibit a synclinal rim developed around the center. Semicircular patterns of lineations are inferred to represent debris flows composed of "mud breccias" that were erupted from the tops of the mud volcanoes. Circular rims are identified around and inside the mud volcano complex that may represent local "cones. "

Three cores were taken from the Napoli mud volcano area. They all comprise "mud breccia" overlain by a veneer of pelagic sediments (Holocene oozes). The mud breccia has a mousse-like texture and contains abundant millimeter-sized voids; these are inferred to result from gas expansion. The cores smell of hydrogen sulfide. The mud mousse becomes finer grained upward and passes transitionally upward into pelagic marls. The boundary between the "mud breccia" and the overlying Holocene ooze is marked by an oxidized interval up to 10 cm thick. A number of different types of "mud breccias" have been recorded. Smear slides from the mud matrix reveal high contents of clay, dolomite, nannofossils, quartz, and sporadic abundant pyrite. The calcareous nannofossils from the Olimpi mud volcano matrix are of Pleistocene, Pliocene, Miocene, and late Oligocene age. This suggests that deep-sea muddy sediments within the Mediterranean Ridge accretionary wedge of different ages were mobilized and expelled upward onto the seafloor at the site of the mud volcanoes, as discussed above.

Transect of the Ionian Deformation Front

The deformation front (Figs. 2, 8) is defined by the sudden change from the flat and layered reflections of the Ionian Abyssal Plain to the hyperbolic patterns produced by the "cobblestone topography" of the Mediterranean Ridge. A 10.5-km-long, 310-m-high "seahill" strongly oriented in a southwest-northeast direction (about 45° with respect to the regional trend of the Mediterranean Ridge) is located a few kilometers seaward of the deformation front (Hieke, 1978). The highest part of the Victor Hensen Structure, can be traced in the sub-bottom for more than 60 km in a southwest-northeast direction.

Recently acquired MCS lines (Cruise *Valdivia* 120 MEDRAC, 1992) provide evidence of several elongate structures indicating intense pre-Messinian tectonic activity under the Ionian Abyssal Plain, seaward of the Ionian Deformation Front (Hirschleber et al., 1994). The structures are elevated from a sequence of partly tilted pre-Messinian sediments. However, some tops of elongate structures are free of evaporites. The style of deformation is considered to be indicative of extensional block faulting.

Since Messinian evaporites and overlying P-Q turbidites show less evidence of deformation, the main part of the tectonic phase that produced these structures must be, at the latest, of Messinian age (about 5 Ma). However, the deformation continued during the Pliocene-Quaternary with synsedimentary extensional faulting (Avedik and Hieke, 1981; Hieke and Wanninger, 1985; Hirschleber et al., 1994).

The Victor Hensen Structure interacts with the present-day deformation front, indicating that a complicated pattern of varying lithologies and thicknesses of sediments has become incorporated in the Mediterranean Ridge accretionary complex. The styles of initial deformation are thus expected to be correspondingly different.

The proposed transect of shallow holes (Fig. 8) is intended to sample the incoming sediment section overlying the buried Victor Hensen structure in the abyssal plain and the post-Messinian deformed sediment of the ridge. If time permits, we also hope to sample part of the upper flanks of the Victor Hensen Structure and thus determine its lithology and origin insofar as possible.

THE ORIGIN OF SAPROPELS

Depositional sequences retrieved in sediment cores from the Eastern Mediterranean, the Tyrrhenian Sea, and land sections of Neogene age in southern Italy, Sicily, and Crete, have revealed the existence of numerous dark to black layers that are intercalated in "normal" hemipelagic sediments. These layers are enriched in organic carbon and often laminated, and are referred to as sapropels. Sapropels are believed to be deposits characteristic of restricted basins of marginal seas (e.g., Japan Sea, Red Sea). In all cases it seems that the deposition of organic-rich sediments occurred in response to unusual, very distinctive changes in the depositional environment. The Mediterranean sapropels represent paleoceanographic windows through which we may study, in great detail, key processes that determine the burial and preservation of carbon at the seafloor. Among the candidates for key processes are marine chemical cycling, physical water-mass circulation, and biological response to environmental change.

According to one model (the preservation model), sapropels originate when a change in the physical circulation system create anoxic conditions in the bottom water of the Mediterranean Sea. This model, introduced by Kullenberg (1952) and adopted by Olausson (1961), is based on the assumption that organic matter is more amenable to oxic as compared to anoxic degradation. Under anoxic conditions, organic carbon preservation is thought to be greatly enhanced. The rival model (the production model) proposes that organic carbon levels in marine sediments are primarily a function of sediment texture, dilution, and carbon flux, rather than of water-column oxygen levels (Pedersen and Calvert, 1990). Thus, these studies are now calling attention to biological productivity combined with distinctive changes in physical water-mass circulation as important controls on the formation of organic-rich, sapropelic deposits.

Both models require that the physical circulation system of the Mediterranean Sea operated differently from the modern situation during periods of sapropel deposition.

The Deep-Water Stagnation Hypothesis

The most viable means to deplete oxygen in deep waters is by way of extremely strong gravitational stability of the water column; this would shut off thermohaline overturn and thus terminate deep-water ventilation. The strongest support for this model comes from negative oxygen isotope anomalies recorded in planktonic foraminifers that are associated with the sapropels (e.g., Williams et al., 1978; Vergnaud-Grazzini et al., 1986). These anomalies imply the existence of a low-salinity and, thus, low-density surface layer in the Eastern Mediterranean at times of sapropel deposition.

High abundances of planktonic foraminiferal species in most of the upper Pleistocene sapropels, which calcify preferentially under low-salinity conditions, provided additional evidence for marine-brackish surface waters during these times (Thunell et al., 1984) (although an association of these planktonic assemblages with increased nutrient scenarios can to date not be excluded; see Rohling and Gieskes, 1989). Presumed sources for the freshwater diluent are the Black Sea, which conceivably exported large volumes of glacial meltwaters to the Eastern Mediterranean as the sea level rose above the depth of the Bosporus sill; the Nile (Rossignol-Strick, 1983); and the inflowing Atlantic waters (Müller, 1990). Rossignol-Strick (1983) demonstrated that the temporal distribution of the Eastern Mediterranean sapropels correlates with maximum potential strength of the African monsoons, which would have resulted in maximum discharge from the Nile. This could have finally resulted in a periodic reversal of flow patterns between the Eastern and Western Mediterranean, which would have caused the Eastern Mediterranean to become a nutrient trap, thereby increasing the oxygen demand and resulting in episodic anoxia (Sarmiento et al, 1988).

This stagnation hypothesis has been recently questioned for several reasons. First, the modern Mediterranean receives largely all of its waters from inflowing Atlantic surface-subsurface waters, which are intrinsically nutrient-depleted. Thus, overall nutrient concentrations are low, and the

Mediterranean is an oligotrophic system in which no major productive areas exist (e.g., Murdoch and Onuf, 1974). Estimates of the annual primary production range from 25-50 g/m^2 Carbon for the open Mediterranean to 60-75 g/m^2 Carbon in some coastal zones. At this low rate of biosynthetic marine organic carbon input, sedimentary organic carbon concentrations would barely reach the elevated levels observed in the sapropels (Calvert, 1983). Only in localities such as the Bannock and Tyro basins, in which anoxic and hypersaline bottom waters prevail (Jongsma et al., 1983; de Lange and ten Haven, 1983; Cita et al., 1985; Parisi et al., 1987), is the preservation of organic carbon in the sediments distinctly enhanced. Organic carbon contents there are higher (up to 1.3% C_{org}) than in normal Mediterranean sediments (0.3% C_{org}) probably due to the "red herring/ pickling effect" of the deep-seated brines, which suppress bacterial activity and decomposition of the organic sediment fraction (Klinkhammer and Lambert, 1989); but they are still much lower than the values often encountered in sapropels (3%-17% C_{org}).

Second, areal mapping of the negative oxygen isotope anomalies observed in sediment cores from around the Nile Cone suggests that the low-salinity surface layer extant during the formation of sapropel S1 was strongest in the immediate vicinity of the river mouth, presumably because the fresh waters mixed rapidly with the highly saline waters of the easternmost Mediterranean (Jenkins and Williams, 1984). Thus, the potential stabilizing effect of the low-salinity surface layer could have been restricted to the area closest to the Nile Cone, whereas thermohaline overturn could have still prevailed in the easternmost Mediterranean.

The Productivity Hypothesis

Enhanced rates of biosynthetic carbon fixation are well recognized to be the primary factor controlling elevated levels of carbon in seafloor sediments. Organic carbon variations in sediment cores from high-productivity areas of equatorial divergence and coastal upwelling systems have been attributed to climate-controlled variations of primary productivity (Arrhenius, 1952; Pedersen, 1983; Müller et al., 1983; Morris et al., 1984; Zahn et al., 1986; Lyle et al., 1988; Prahl et al., 1989a, 1989b; Sancetta et al., 1992). Using empirically derived relationships between carbon production in the surface waters and carbon burial rates at the seafloor (Müller and Suess, 1979), and assuming average physical properties of the sapropels, imply that productivity rates of 100-200 g/m^{2}yr Carbon are required for the Mediterranean to produce carbon concentrations of 5%-15% at depth, which are typically found in the Eastern Mediterranean sapropels. These estimated production rates are similar to low to moderate primary production rates observed, for example, in the upwelling system off Northwest Africa. Although new cadmium and barium data (Boyle and Lea, 1989) suggest a possible contribution of riverine carbon input to early Holocene sapropel S1, other isotopic and geochemical tracers point to a predominantly marine origin of the sapropel organic carbon (Sutherland et al., 1984; Smith et al., 1986; ten Haven et al., 1987). Therefore, formation of the Mediterranean sapropels was probably promoted by enhanced rates of marine productivity rather than by increased supplies of terrestrial carbon.

Several models have been put forward to explain how higher productivity levels in the otherwise oligotrophic Mediterranean could have been brought about. It has been postulated, for instance, that enhanced volumes of freshwater input during deglacial meltwater surges and/or monsoon-controlled river floodings would have reversed the Mediterranean circulation toward an anti-estuarine system (Sarmiento et al., 1988; Lohmann and Pride, 1989; Thunell and Williams, 1989). In this case, the Mediterranean would have imported nutrients via an inflow of nutrient-enriched subthermocline waters from the Atlantic, which would have upwelled in the Eastern Mediterranean. This is likely to have increased primary productivity. However, the circulation reversal postulated by this model would be in apparent contradiction with benthic foraminiferal $\delta^{13}C$ signatures obtained from sediment cores to the west of the Strait of Gibraltar, which imply that the outflow of deeper waters from the Mediterranean to the North Atlantic, though at reduced rates, continued also during the formation of sapropel S1 (Zahn et al., 1987).

Rohling and Gieskes (1989) recently postulated a causal link between the development of deep chlorophyll maxima at the base of the euphotic zone and the formation of sapropels. Accordingly, the development of a marine-brackish, low-density surface layer in the Mediterranean would have resulted in a shoaling of the pycnocline and its associated nutrient maxima into the euphotic zone, thereby promoting enhanced primary production of deep phytoplankton and stimulating the development of a deep chlorophyll maximum.

The deep-chlorophyll-maximum model appears to be constrained by unusually high abundances of neogloboquadrinids (*N. dutertrei* and *N. pachyderma*) in the sapropels, deep-dwelling planktonic foraminiferal species that are typically associated with deep chlorophyll maxima extant in the modern open ocean (Rohling and Gieskes, 1989). However, this species appears to be absent from the Holocene sapropel S1, and, thus, the model does not provide a unique solution to the problem of sapropel formation. Nevertheless, the model has recently been supported by quantitative analyses of calcareous nannofossil assemblages in Eastern Mediterranean sediment cores. The core profiles show salient maxima of deep-dwelling floral species during sapropel events S4, S5, and S7, thus also pointing to the existence of deep chlorophyll maxima (Castradori, 1993). Sapropel events S1 and S6 do not show as distinctive a nannofloral distribution as the other events, again hinting at different origins for the different sapropels.

Salient maxima of dinosterols and long-chain alkenones, which are associated with sapropels S1 and S7 (Smith et al., 1986; ten Haven et al., 1987), were used to infer that coccolithophorid and dinoflagellate productivity was high during sapropel formation, thus pointing to the potential importance of primary productivity for the formation of the Mediterranean sapropels.

A Review of Physical Circulation and Water-Mass Distribution in the Modern Mediterranean Sea

The Mediterranean's physical circulation is mainly driven by the surface-wind field and modulated by its complex bottom topography. Its principal features resemble those of an open-ocean sub-basin (100-km-scale) and mesoscale (10-km-scale) eddy circulation, which is driven by seasonal winds and thermohaline gradients. This circulation pattern defines the distribution of nutrients in the Mediterranean, which tend to be highest in the western basin and lowest in the eastern basin, thus leading to inter-basin differences in primary production.

In the present situation, evaporation exceeds precipitation and river runoff, the negative water balance being compensated by the inflow of Atlantic waters through the Strait of Gibraltar. Inflowing Atlantic waters are nutrient-enriched, warmer (15°C), and less saline (36.3‰) compared to the outflowing deeper water masses (13°C, 38.2‰). Inflowing Atlantic waters affect the circulation of the entire Mediterranean Basin in that they generate cyclonic gyres in the Balearic and Tyrrhenian seas. Atlantic water is transported into the eastern Mediterranean Basin by way of the North African Current, which flows along the African coast and passes through the Sicily Channel. Once the water has reached the far eastern parts of the eastern basin, evaporation is high enough to increase surface salinities to an extent that convection of the surface water to greater depth occurs. This way, Levantine Intermediate Water is formed, which flows westward into the Western Mediterranean and further through the Strait of Gibraltar into the Gulf of Cadiz and the North Atlantic. Bottom waters are also generated in the eastern basin; they are restricted in areal extent to the eastern basin, since the shallow topography of the Sicily Channel prevents any exchange of abyssal water masses between the eastern and western basins.

Besides their influence on the Mediterranean's physical circulation, inflowing Atlantic waters also define the biogeochemical and physical inventory of the upper layer (50 m) that drives the primary production in the Mediterranean and controls the flux of biologically cycled constituents to the seafloor and into the sediments. The close connection between the Mediterranean's general circulation and the asymmetric distribution of trophic levels between its western and eastern basins points to the importance of understanding the past variability of the Mediterranean's physical oceanography as a whole so as to unravel the origin of sapropel formation in the east. In particular, inversions of the evaporation-precipitation balance could have resulted in the development of a much stronger pycnocline and altered the physical circulation throughout the Mediterranean. This could ultimately have increased the rates of primary production in some areas, thus altering the Mediterranean's gross nutrient budget. Understanding the Mediterranean's past circulation, therefore, plays a fundamental role in determining the origin of sapropels.

Timing of Sapropel Deposition

Sapropel formation occurred basinwide within the Eastern Mediterranean throughout Miocene-Pliocene-Pleistocene times. Correlation with standard oxygen isotope stratigraphy provides an excellent framework to evaluate the occurrence of the late Pleistocene sapropels with respect to the state of global climate (Fig. 6). Apparently, sapropels formed rather unsystematically during full glacial stages (sapropels S6, S12), full-interglacial stages (sapropels S8, S10, S11), and during interstadial stages (e.g., Vergnaud-Grazzini et al., 1977; Cita et al., 1977).

A more systematic correlation has been obtained between the distribution of sapropels and maxima of the so-called orbital insolation monsoon index, which is a function of precessional insolation anomalies (Rossignol-Strick, 1983). Maxima in the monsoon index point to an intensified Indian Ocean summer monsoon leading to enhanced continental humidity in tropical Africa and ultimately enhanced discharge rates of the Nile. Increased rates of continental runoff would possibly have changed the circulation of the Mediterranean from today's anti-estuarine system toward an estuarine pattern, thereby preconditioning the Eastern Mediterranean toward sapropel formation. New compilations of paleoclimatologic data also point to the importance of humid phases in the northern borderlands of the Eastern Mediterranean for stimulating the formation of sapropels (Rohling and Hilgen, 1991). Apparently, increased summer precipitation along the borderlands was due to increased activity of Mediterranean depressions which tend to lower evaporation rates over the eastern Mediterranean thus redistributing freshwater between the eastern and western Mediterranean basins.

The existence of early Pleistocene, Pliocene, and Miocene sapropels is known from eastern Mediterranean DSDP sites which were drilled during *Glomar Challenger* Legs 13 and 42A (Ryan, Hsü, et al., 1973; Hsü, Montadert, et al., 1978; Kidd et al., 1978) and from exposed sections in southern Italy, Sicily, and Crete (for a recent review, see Hilgen, 1991). The westernmost occurrence of sapropels was documented at Leg 107 drilling sites in the Tyrrhenian Sea (Emeis et al., 1991). However, a detailed evaluation of these old sapropels with respect to the state of Mediterranean climate, water mass, and atmospheric circulation has not been possible because the required continuous, multi-proxy records are not at hand. Sampling of sapropel deposits at on-land sites is not adequate, since many geochemical tracers are labile, and their alteration due to exposure to the atmosphere and ground waters makes the interpretation of the data very difficult if not impossible.

SCIENTIFIC OBJECTIVES AND METHODOLOGY

The objectives and methology may be summarized as follows:

1) To estimate deformation processes in relation to incipient continental collision (Eratosthenes transect).
2) To investigate mud diapirism at the Mediterranean accretionary complex, including the influence of salt in sediment deformation and interstitial fluids (Napoli mud diapir).
3) To study accretionary processes at the Mediterranean Ridge related to the incorporation of sediment from an incoming abyssal plain in an area of nearly orthogonal plate convergence (Ionian transect) .
4) To investigate the history of sapropel formation in relation to global and regional variations in atmospheric circulation and water-mass variability in the Mediterranean since the Pliocene.
5) To establish variations in environmental conditions at each site as recorded in geochemical, paleontological, and isotopic proxy indicators for water-column stratification, paleo-redox conditions and paleo-productivity levels.
6) To examine the spatial gradients in environmental conditions for coeval sapropels along an East-West transect of drill sites.

DRILLING PLAN/SCIENCE STRATEGY

Drilling in the Napoli mud volcano area is designed to allow sampling of fluids from the crestal area of the Napoli Dome and to investigate its anatomy and construction history by drilling on the flanks.

To determine the influence of the various factors on sapropel formation, we must obtain multi-proxy records along an east-west transect across the entire Mediterranean. The transect permits synoptic mapping of hydrographic and climatic conditions throughout the Mediterranean. It is important not only to investigate the sites of sapropel formation in the eastern basin but also sedimentary records from sites in the western basin where no sapropels formed. Only basinwide analysis of paleoenvironmental conditions will distinguish the driving force behind sapropel formation at different times, and how the Mediterranean's physical circulation and chemical cycling preconditioned the eastern basin toward sapropel formation: The paleoceanography of the entire Mediterranean must be understood if we are to unravel the origin of sapropel formation in its eastern basin.

To achieve these scientific goals, the drill sites for paleoenvironmental reconstructions of Neogene sedimentation have been selected to fulfill three essential requirements:

1) Stratigraphic continuity.
   Sedimentary sections at targeted sites have to be complete, undisturbed, hemipelagic and pelagic, and shielded from the occasionally drastic effects of submarine karstification, mud volcanism and tectonics of the Mediterranean.

2) High stratigraphic resolution.
   Sedimentation rates must be high enough to allow for a detailed documentation of the transition into and out of the various sapropels as well as possible internal variability within individual sapropels. High-resolution records are also important for accurate cross-correlation of the multi-proxy records along the drilling transect.

3) Optimum areal coverage.
   The drill sites must cover the entire Mediterranean Basin to permit evaluation of paleoceanographic, paleochemical, and paleontological zonality and teleconnections throughout the basin. Key locations are close to the Nile Cone (but far enough away from it to avoid its turbidites) as a freshwater source, the Strait of Sicily as the seaway determining water-mass exchange between the eastern and western basins, an Alboran Sea site as the watchdog for Atlantic-Mediterranean water exchange, and central western and eastern basin sites to document pelagic environments between these hydrographic end members.

In order to ensure highest quality information on the depositional environment during sapropel formation, sampling density in the sapropel layers, as well as in the "normal" sediments immediately below and above the sapropels, must be on scales of centimeters to millimeters. Such high sampling resolution is essential for determining the factors that have led to the formation of the sapropels and that have helped in maintaining an environment favorable for the formation of sapropels. At typical rates of sedimentation around 2 cm/k.y., our goal is to distinguish processes operating on time scales of <1000 to 10,000 years. Multiple APC coring (at least quadruple) will provide sufficient material to allow detailed sampling at the sites specifically designed for the study of sapropels (Medsap 1, 2, 3, and 4). To ensure meeting scientific objectives sampling strategy at these sites may require modification of routine sampling constraints based on the limitations in sediment, but will ensure that crucial parameters can be successfully measured. Economic usage of the limited sediment in sapropel intervals will be possible through on-board construction of composite depth sections from multiple penetration of each sedimentary section.

At sites not specifically designated as sapropel targets, we expect to recover sapropels as well. Here, normal sampling constraints as to the extent and density of shipboard sampling will apply.

A site survey is necessary for all sites in the program, because many of the targets are situated in areas of diverse seafloor morphology and highly variable sub-bottom structures. For sites with express sapropel-related objectives, we aim to drill four APC/XCB holes to recover complete sections (a composite section will be constructed while drilling proceeds) and to recover enough material for high-resolution sampling. Should time permit, we will attempt to drill additional APC holes at these sites. On a similar note, we decided that logging shallow holes at dedicated sapropel sites is likely to be impossible because of time constraints. Should our schedule permit, we hope to log some of the sites (priorities: Medsap 2B, MR-1, MR-2, MR-3) with standard tool combinations and the formation microscanner tool.

REFERENCES

Arrhenius, G.O., 1952. Sediment cores from the East Pacific. *In* Petterson, H. (Ed.), *Reports of the Swedish Deep-Sea Expedition*, 5(1): Goteborg (Elanders Boktryckeri).

Avedik, F., and Hieke, W., 1981. Reflection seismic profiles from the Central Ionian Sea (Mediterranean) and their geodynamic interpretation. *Meteor Forsch. Ergebnisse*, 34:49-64.

Ben-Avraham, Z., Shoham, Y., and Ginzburg, A., 1976. Magnetic anomalies in the eastern Mediterranean and the tectonic setting of the Eratosthenes Seamount. *Geophys. J. R. Astron. Soc.,* 45:105-123.

Boyle, E.A., and Lea, D.W., 1989. Cd and Ba in planktonic foraminifera from the eastern Mediterranean: evidence for river outflow and enriched nutrients during sapropel formation. *Eos*, 43:1134.

Brennecke, J., and Lelgemann, D., 1986. The shape of the European Geoid and the geotectonic structures. *In* Freeman, R., Mueller, St., and Giese, P. (Eds.), *Proc. Third Workshop on the European Geotraverse (EGT) Project,* The Central Segment, ESF, 241-248.

Brown, K., and Westbrook, G.K., 1988. Mud diapirism and subcretion in the Barbados Ridge accretionary complex: the role of fluids in accretionary processes. *Tectonics*, 7:613-640.

Calvert, S.E., 1983. Geochemistry of Pleistocene sapropels and associated sediments from the eastern Mediterranean. *Oceanol. Acta,* 6:255-267.

Camerlenghi, A., 1991. Il diapirismo d'Argilla Sulla Dorsale Mediterranea. Doctoral thesis, Universita degli Studi di Milano, 193 p.

Camerlenghi, A., Cita, M.B., Hieke, W., and Ricchiuto, T.S., 1992. Geological evidence of mud diapirism on the Mediterranean Ridge accretionary complex. *Earth Planet. Sci. Lett.*, 109:493-504.

Camerlenghi, A., Cita, M.B., Della Vedova, B., Fusi, N., Mirabile, L., and Pellis, G., 1994. Geophysical evidence of mud diapirism on the Mediterreanean Ridge accretionary complex. *Marine Geophys. Res*., v. 16 (in press).

Castradori, D., 1993. Calcareous nannofossils and the origin of eastern Mediterranean sapropels. Submitted to *Paleoceanography*.

Cita, M.B., Camerlenghi, A., Erba, E., McCoy, F.W., Castradori, D., Cazzani, A., Guasti, G., Giambastiani, M., Lucchi, R., Nolli, V., Pezzi, G., Redaelli, M., Rizzi, E., Torricelli, S., and Violanti, D., 1989. Discovery of mud diapirism in the Mediterranean Ridge - A preliminary report. *Boll. Soc. Geol. It.*, 108:537-543.

Cita, M.B., et al., 1985. Gypsum precipitation from cold brines in an anoxic basin in the eastern Mediterranean. *Nature*, 314:152-154.

Cita, M.B., Ryan, W.F.B., and Paggi, L.,1981. Prometheus mud-breccia: An example of shale diapirism in the Western Mediterranean Ridge. *Ann. Geol. Pays Hellen.*, 30:543-570.

Cita, M.B., Vergnaud-Grazzini, C., Robert, C., Chamley, H., Ciaranfi, N., and D'Onofrio, S., 1977. Paleoclimatic record of a long deep sea core from the eastern Mediterranean. *Quat. Res.*, 8: 205-235.

de Lange, G.J., and ten Haven, H.L., 1983. Recent sapropel formation in the eastern Mediterranean. *Nature*, 305:797-798.

de Voogd, B., Truffert, C., Chamot-Rooke, N., Huchon, P., Lallemant, S., and Le Pichon, X., 1992. Two-ship deep seismic soundings in the Basins of the eastern Mediterranean Sea (*Pasiphae* cruise). *Geophys. J. Int*, 109:536-552.

Emeis, K.-C., Camerlenghi, A., McKenzie, J.A., Rio, D., and Sprovieri, R., 1991. The occurrence and significance of Pleistocene and Upper Pliocene sapropels in the Tyrrhenian Sea. *Mar. Geol.*, 100:155-182.

Erickson, A.J., and Von Herzen, R.P., 1978. Down-hole temperature measurements, Deep Sea Drilling Project, Leg 42A. *In* Hsü, K.J., Montadert, L., et al., *Init. Repts. DSDP*, 42: Washington (U.S. Govt. Printing Office), 1114-1118.

Finetti, I., 1976. Mediterranean Ridge. A young submerged chain associated with the Hellenic arc. *Boll. Geol. Teor. Appl.,* 28(69):31-62.

Fytikas, M., Innocenti, P., Manetti, P., Mazzuoli, R., Peccerillo, A., and Villari, L., 1984. Tertiary to Quaternary evolution of volcanism in the Aegean region. *In* Dixon, J.E., and Robertson, A.H.F. (Eds.), *The Geological Evolution of the Eastern Mediterranean.* Spec. Publ. - Geol. Soc. London, 17:687-700.

Giese, P., Nicolich, R., and Reutter, K.J., 1982. Explosion seismic crustal studies in the Alpine-Mediterranean region and their implication to tectonic processes. *In* Berckhemer, H., and Hsü, K. (Eds.), *Alpine-Mediterranean Geodynamics.* AGU-GSA Geodynamic Series, 6:39-74.

Hersey, J.B., 1965. Sedimentary basins of the Mediterranean Sea. *In* Whitard, W.F., and Bradshaw, W. (Eds.), *Submarine Geology and Geophysics. Proc.* 17th Symp. of the Colston Research Society, London, 75-91.

Hieke, W., 1978. The "Victor Hensen Seahill"; part of a tectonic structure in the Central Ionian Sea. *Mar. Geol.,* 26:M1-M5.

Hieke, W., and Wanninger, A., 1985. The Victor Hensen Seahill (Central Ionian Sea)- Morphology and structural aspects. *Mar. Geol.*, 64:343-350.

Hilgen, F.J., 1991. Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implication for the geomagnetic polarity time scale. *Earth Planet. Sci. Lett.*, 104:226-244.

Hirschleber, H.B., Hartmann, J.M., and Hieke, W., 1994. The Mediterranean Ridge accretionary complex and its forelands - seismic reflection studies in the Ionian Sea. Cruise Report of the Meteor, 491-509.

Horvath, F., and Berckhemer, H., 1982. Mediterranean back arc basins. *In* Berckhemer, H., and Hsü, K. (Eds.), *Alpine-Mediterranean Geodynamics*. AGU-GSA Geodynamic Series, 6:141-174.

Hsü, K.J., Montadert, L., et al., 1978. *Init. Repts. DSDP*, 42: Washington (U.S. Govt. Printing Office).

Jenkins, P., and Williams, D.F., 1984. Nile water as a cause of eastern Mediterranean sapropel formation: Evidence for and against. *Mar. Micropaleontol.*, 8:521-534.

Jongsma, D., Fortuin, A.R., Huson, W., Troelstra, S.R., Klaver, G.T., Peters, J.M., van Harten, D., de Lange, G.J., and ten Haven, L., 1983. Discovery of an anoxic basin within the Strabo Trench, eastern Mediterranean. *Nature,* 305:795-797.

Jongsma, D., Woodside, J.M., King, G.C.P., and van Hinte, J.E., 1987. The Medina Wrench: a key to the kinematics of the central and eastern Mediterranean over the past 5 Ma. *Earth Planet. Sci. Lett.*, 82:87-106.

Kastens, K.A., 1991. Rate of outward growth of the Mediterranean Ridge accretionary complex. *Tectonophysics*, 199:25-50.

Kempler, D., and Ben-Avraham, Z., 1987. The tectonic evolution of the Cyprean Arc. *Annales Tectonicae,* 1(1):58-71.

Kenyon, N.H., Belderson, R.H., and Stride, A.H., 1982. Detailed tectonic trends on the central part of the Hellenic Outer Ridge in the Hellenic Trench System. *In* Leggett, J.K. (Ed.), *Trench-Forearc Geology*. Spec. Publ. - Geol. Soc., 10:335-343.

Kidd, R.B., Cita, M.B., and Ryan, W.B.F., 1978. Stratigraphy of eastern Mediterranean sapropel sequences recovered during DSDP Leg 42 and their paleoenvironmental significance. *In* Hsü, K.J., Montadert, L., et al., *Init. Repts. DSDP*, 42, Part 1: Washington (U.S. Govt. Printing Office), 421-443.

Kissel, C., and Laj, C., 1988. The Tertiary geodynamical evolution of the Aegean Arc: a paleomagnetic reconstruction. *Tectonophysics*, 146:183-201.

Klinkhammer, G.P., and Lambert, C.E., 1989. Preservation of organic matter during salinity excursions. *Nature*, 339:271-274.

Kullenberg, B., 1952. On the salinity of the water contained in marine sediments. *Göteborgs Kungl. Vetens. Vitter. Handl.*, Ser. B., 6:3-37.

Le Pichon, X., and Angelier, J., 1979. The Hellenic Arc and Trench system: A key to the neotectonic evolution of the eastern Mediterranean area. *Tectonophysics,* 60:1-42.

Lohmann, G.P., and Pride, C.J., 1989. The eastern Mediterranean estuary: observational evidence favoring estuarine circulation during sapropel formation. *Eos*, 43:1134.

Lyle, M., Murray, D.M., Finney, B.P., Dymond, J., Robbins, J.M., and Brooksforce, K., 1988. The record of Late Pleistocene biogenic sedimentation in the eastern tropical Pacific Ocean. *Paleoceanography*, 3:39-59.

Makris, J., 1977. Geophysical investigations of the Hellenides. *Hamburger Geophys. Einzelschriften, H.*, 27.

Makris, J., Ben-Avraham, Z., Behle, A., Ginzburg, A., Gieze, P., Steinmetz, L., Whitmarsh, R.B., and Eleftheriou, S., 1983. Seismic refraction profiles between Cyprus and Israel and their interpretation. *Geophys. J. R. Astron. Soc.*,75:575-591.

Makris, J., and Stobbe, C., 1984. Physical properties and state of the crust and upper mantle of the eastern Mediterranean Sea as deduced from geophysical data. *Mar. Geol.,* 55:347-363.

McKenzie, D.P., 1978. Active tectonism in the Alpine-Himalayan belt: the Aegean Sea and the surrounding regions (tectonics of the Aegean region). *Geophys. J. R. Astron. Soc.,* 55:217-254.

Morris, R.J., McCartney, M.J., and Weaver, P.P.E., 1984. Sapropelic deposits in a sediment from the Guinea Basin, South Atlantic. *Nature*, 309:611-614.

Müller, C., 1990. Nannoplankton biostratigraphy and paleoenvironmental results from the Tyrrhenian Sea, ODP Leg 107. *In* Kastens, K.A., Mascle, J., et al., *Proc. ODP, Sci. Results,* 107: College Station, TX (Ocean Drilling Program), 495-512.

Müller, P.J., and Suess, E., 1979. Productivity, sedimentation rate and sedimentary organic matter in the oceans - organic carbon preservation. *Deep-Sea Res.*, 27A:1347-1362.

Müller, P.J., Erlenkeuser, H., and von Grafenstein, R., 1983. Glacial-interglacial cycles in ocean productivity inferred from organic carbon contents in eastern North Atlantic sediment cores. *In* Thiede, J., and Suess, E. (Eds.), *Coastal Upwelling*, Part B:New York (Plenum), 365-398.

Murdoch, W.W., and Onuf, C.P., 1974. The Mediterranean as a system, part I - large ecosystems. *Intern. J. Environmental Stud.*, 5:275-284.

Olausson, E., 1961. Studies of deep-sea cores. *Rep. Swedish Deep-Sea Expedition*, 8 (6):337-391: Goteborg (Elanders Boktryckeri).

Parisi, E., Erba, E., and Cita, M.B., 1987. Stratigraphy and sedimentation in the anoxic Bannock Basin (eastern Mediterranean). *Mar. Geol.,* 75:93-117.

Pedersen, T.F., 1983. Increased productivity in the eastern equatorial Pacific during the last glacial maximum (19000 to 14000 yr B.P.). *Geology,* 11:16-19.

Pedersen, T.F., and Calvert, S.E., 1990. Anoxia vs. productivity: what controls the formation of organic-carbon-rich sediments and sedimentary rocks? *Am. Ass. Petr. Geol. Bull.*, 74:454-466.

Poole, A.J., and Robertson, A.H.F., 1992. Quaternary uplift and sea-level change at an active plate boundary, Cyprus. *J. Geol. Soc.* Lond., 148:909-921.

Prahl, F.G., Muehlhausen, L.A., and Lyle, M., 1989a. An organic geochemical assessment of oceanographic conditions at MANOP Site C over the past 26,000 years. *Paleoceanography,* 5:495-510.

Prahl, F.G., de Lange, G.J., Lyle, M., and Sarrow, M.A., 1989b. Post-depositional stability of long-chain alkenones under contrasting redox conditions. *Nature*, 341:434-437.

Rabinowitz, P.D., and Ryan, W.B.F., 1970. Gravity anomalies and crustal shortening in the eastern Mediterranean. *Tectonophysics*, 10:585-608.

Robertson, A.H.F., Eaton, S., Follows, E.J., and McCallum, J.E., 1991. The role of local tectonics versus global sea-level change in the Neogene evolution of the Cyprus active margin. *Spec. Pub. Int. Ass. Sediment.*, 12:331-369.

Robertson, A.H.F., Kidd, R.B., Ivanov, M.K., Limaonov, A.F., Woodside, J.M., Galindo-Zaldivar, J., and Nieto, L., l994. Probing continental collision in the Mediterranean Sea. *Eos*, v. 75, no. 21.

Robertson, A.H.F., Kidd, R.B., Ivanov, M.K., Limaonov, A.F., Woodside, J.M., Galindo-Zaldivar, J., and Nieto, L., in press, Erastosthenes Seamount, easternmost Mediterranean: evidence of active collapse and thrusting beneth Cyprus. *Terra Nova.*

Rohling E.J., and Gieskes, W.W.C., 1989. Late Quaternary changes in Mediterranean intermediate water density and formation rate. *Paleoceanography*, 4:531-545.

Rohling, E.J., and Hilgen, F.J., 1991. The eastern Mediterranean climate at times of sapropel formation: a review. *Geol. Mijnbouw*, 70:253-264.

Rossignol-Strick, M., 1983. African monsoons, an immediate climate response to orbital insolation. *Nature*, 304:46-49.

Ryan, W.B.F., Hsü, K.J., et al., 1973. *Init. Repts. DSDP*, 13: Washington (U.S. Govt. Printing Office).

Sancetta, C., Lyle, M., Heuser, L., Zahn, R., and Bradbury, J.P., 1992. Late-glacial to Holocene changes in winds, upwelling, and seasonal production of the northern California Current system. *Quat. Res.*, 38:359-370.

Sarmiento, J., Herbert, T., and Toggweiler, J., 1988. Mediterranean nutrient balance and episodes of anoxia. *Global Biogeochem. Cycles*, 2:427-444.

Smith, D.J., Eglinton, G., and Morris, R.J., 1986. The lipid geochemistry of a recent sapropel and associated sediments from the Hellenic Outer Ridge, eastern Mediterranean Sea. *Philos. Trans. R. Soc. London*, A319:375-419.

Sutherland, H.E., Calvert, S.E., and Morris, J.R., 1984. Geochemical studies of the recent sapropel and associated sediment from the Hellenic Outer Ridge, eastern Mediterranean Sea I. Mineralogy and chemical composition. *Mar. Geol.*, 56:79-92.

ten Haven, H.I., Baas, M., Kroot, M., de Leeuw, J.W., Schenck, P.A., and Ebbing, J., 1987. Late Quaternary Mediterranean sapropels. III: assessment of source of input and palaeotemperature as derived from biological markers. *Geochim. Cosmochim. Acta*, 51:803-810.

Thunell, R.C., and Williams, D.F., 1989. Glacial-Holocene salinity changes in the Mediterranean Sea: hydrographic and depositional effects. *Nature*, 338:493-496.

Thunell, R.C., Williams, D.F., and Belyea, P.R., 1984. Anoxic events in the Mediterranean Sea in relation to the evolution of late Neogene climates. *Mar. Geol.*, 59:105-134.

Underhill, J.R., 1989. Late Cenozoic deformation of the Hellenide foreland, western Greece. *Geol. Soc. Am. Bull.*, 101(5):613-634.

Vergnaud-Grazzini, C., Ryan, B.F.W., and Cita, M.B., 1977. Stable isotopic fractionation, climate change and episodic stagnation in the eastern Mediterranean during the late Quaternary. *Mar. Micropaleontol.*, 2:353-370.

Vergnaud-Grazzini, C., Devaux, M., and Znaidi, J., 1986. Stable isotope"anomalies" in Mediterranean Pleistocene records. *Mar. Micropaleontol.*, 10:35-69.

Williams, D.F., Thunell, R.C., and Kennett, J.P., 1978. Periodic freshwater flooding and stagnation of the eastern Mediterranean Sea during the late Quaternary. *Science*, 201:252-254.

Woodside, J., and Bowin, C., 1970. Gravity anomalies and inferred crustal structure in the eastern Mediterranean Sea. *Geol. Soc. Am. Bull.,* 81:1107-1122.

Woodside, J.M., 1977. Tectonic elements and crust of the eastern Mediterranean Sea. *Marine Geophys. Res.*, 317-354.

Woodside, J.M., 1992 Disruption of the African plate margin in the Eastern Mediterranean. *In*: M.J Salem (Ed.) *The Geology of Libya*: Elsevier, 6:2319-2329.

Woodside, J.M., Ivanov, M., et al. Report of the 1993 TREMAR 3 Cruise in the Eastern Mediterranean, UNESCO Report, in press.

Wortel, M.J.R., Goes, S.D.B., and Spakman, W., 1990. Structure and seismicity of the Aegean subduction zone. *Terra Nova*, 2(6):462-554.

Zahn, R., Winn, K., and Sarnthein, M., 1986. Benthic foraminiferal dδ^{13}C and accumulation rates of organic carbon (*Uvigerina peregrina* group and *Cibicidoides wuellerstorfi*). *Paleoceanography*, 1:27-42.

Zahn, R., Sarnthein, M., and Erlenkeuser, H., 1987. Benthic isotope evidence for changes of the Mediterranean outflow during the late Quaternary. *Paleoceanography*, 2:543-559.

Table 1. Summary Site Information, Leg 160

Site	Lat./Long.	Water Depth(m)	Sediment Thickness(m)
Priority Sites			
ESM-1A/ MEDSAP-1D	33°47.8'N, 32°42.1'E	750	1000+
ESM-2A	33°55.1'N, 32°42.8'E	1500	50
ESM-3A	34°04.01'N, 32°43.52'E	2750	135
ESM-4A	34°19.9'N, 32°45.3'E	2000	5000+
MR-1	35°42.1'N, 018°21.2'E	4100	5000+
MR-2	35°46.8'N, 018°42.8'E	3590	5000+
MR-3	35°46.8'N, 018°56.8'E	3700	5000+
MEDSAP-2B	33°51'N, 24°53.9'E	2200	1000+
MEDSAP-3	36°15.3'N, 17°44.3'E	3640	5000+
MEDSAP-4A	37°1.9'N, 13°10.9'E	470	300
MV-1/1, MV-1/2	33°43.7'N, 24°41.8'E	1980	10,000+
Alternate Sites			
ESM-1/ MEDSAP-1D	33°38'N, 32°40'E	750	?
MR-1B	35°41.99'N, 018°25.76'E	4100	5000+
MEDSAP-4C	37°3.9'N, 13°15.3'E	502	450
MV-2	33°44.2'N, 24°47.1'E	1990	10,000

Table 2. Drilling and Transit Time Estimates, Leg 160

Site	Priority	Drilling Option	Transit Time To Next Site (hrs)	Time on Site (days)	Logging (hrs)
Transit - Marseille to MEDSAP-4A; 50 hr					
MEDSAP-4A	1	APC	21	2.4	
MEDSAP-3	1	APC	72	3.2	
ESM-2A	1	APC/XCB/RCB	01	4.2	26
ESM-1A/MEDSAP-1D	1	APC/XCB/RCB	02	5.2	26
ESM-3A	1	APC/XCB/RCB	02	7.8	29
ESM-4A	1	APC/XCB	37	3.7	28
MEDSAP-2B	1	APC	01	2.6	
MV-1/1,1/2	1	APC	01	4.3	
MR-1	1	APC/XCB	02	2.8	
MR-2	1	APC	01	2.0	
MR-3	1	APC		2.0	
Transit - MR-3 to Naples; 40 hr					

FIGURE CAPTIONS

Figure 1. Locations of the proposed drill sites in the Eastern Mediterranean.

Figure 2. Tectonic scheme of the eastern Mediterranean collisional margin.

Figure 3. Tectonic setting of the Eratosthenes Seamount as based on the TREDMAR 1993 cruise. The approximate locations of the proposed drill sites are added.

Figure 4. Proposed drill sites and simplified bathymetry of the Eratosthenes Seamount in relation to the geology of south Cyprus. Bathymetry in meters. North-South line is at the approximate location of section in Figure 3.

Figure 5. Generalized cross section of the Mediterranean ridge in an approximately Southwest-Northeast direction, indicating the relationship between evaporite distribution, main tectonic structures, and mud diapirism. It is proposed that mud diapirism occurs where the thickness of evaporites is reduced and faults allow overpressured mud to be extruded to the surface. This occurs at the northeastern edge of the crestal plateau and on the inner escarpment.

Figure 6. Composite sections of typical cores obtained on a transect from top to bottom of a mud diapir. This figure shows the identification of lithostratigraphic markers (sapropels and tephras) that allow dating and correlation of phases of mud emplacement.

Figure 7. Simplified cross section of the external part of the Mediterranean Ridge. The Oligocene sediments are found diapirically extruded at the seafloor on the crest of the ridge. With a taper angle of 2.2°, and assuming a constant dip of the subducting plate between the 100 km separating the outer deformation front and the ridge crest, the depth of a likely upper Oligocene-middle Miocene décollement fault below the area of occurence of mud diapirism ranges between 5.3 and 7.0 km.

Figure 8. Available site-survey data and proposed drill sites (solid circles) at the Ionian Deformation Front. Triangles = heat flow stations; diamonds = cores; open circles = DSDP Sites.

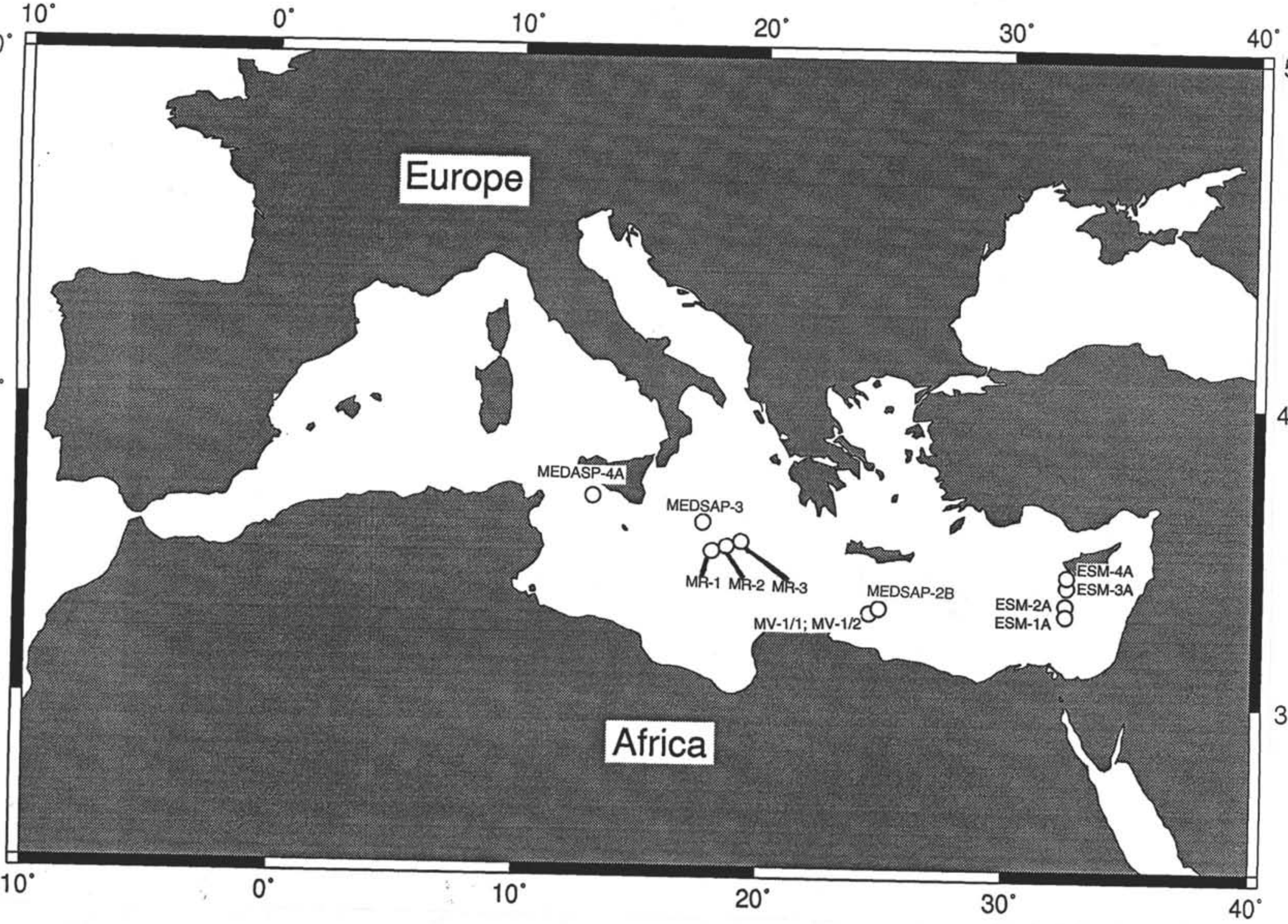

Europe
Africa
MEDASP-4A
MEDSAP-3
MR-1
MR-2
MR-3
MEDSAP-2B
MV-1/1; MV-1/2
ESM-4A
ESM-3A
ESM-2A
ESM-1A
10°
0°
10°
20°
30°
40°
50°
40°
30°

Figure 1

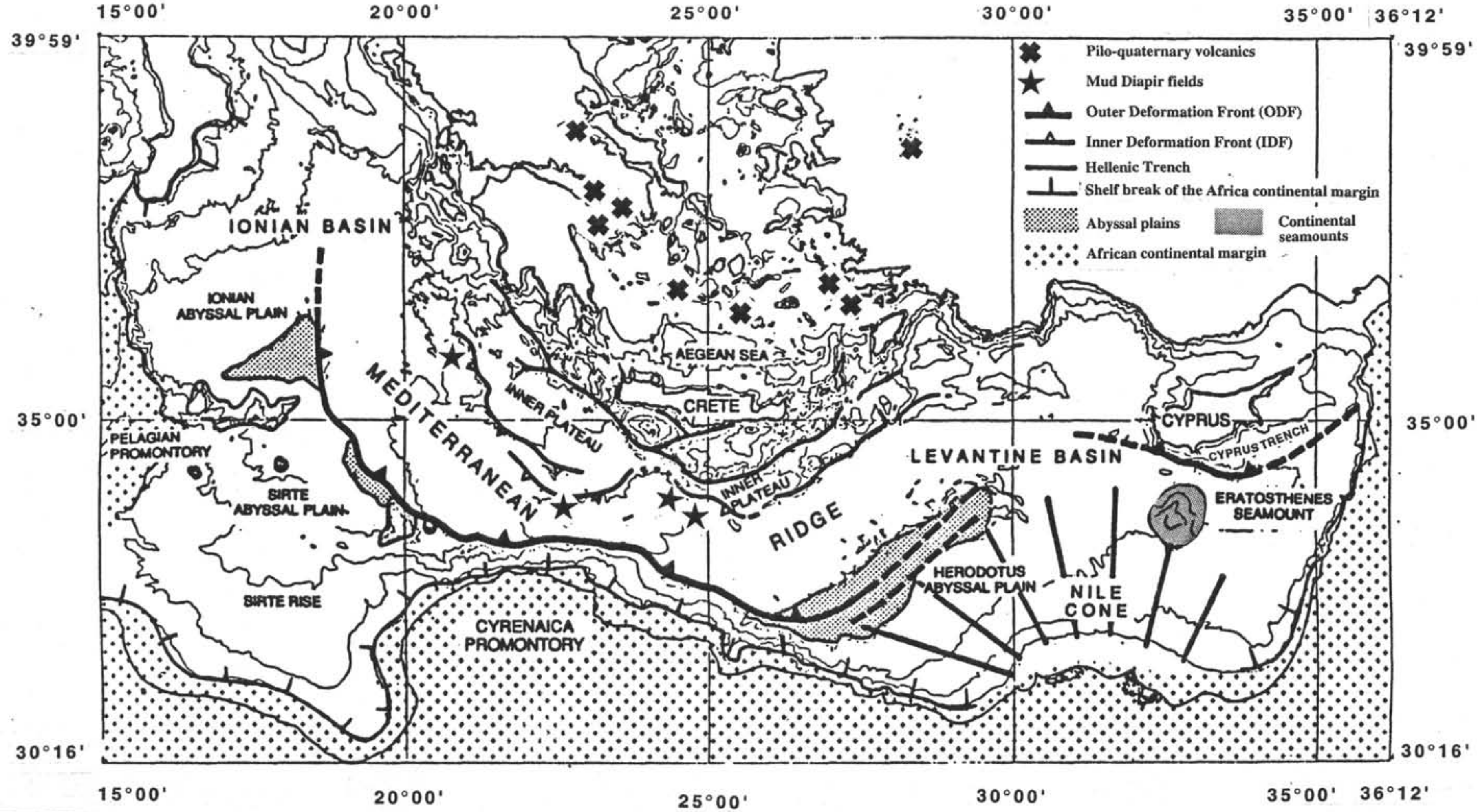

15°00'
20°00'
25°00'
30°00'
35°00'
36°12'
39°59'
35°00'
30°16'
Pilo-quaternary volcanics
Mud Diapir fields
Outer Deformation Front (ODF)
Inner Deformation Front (IDF)
Hellenic Trench
Shelf break of the Africa continental margin
Abyssal plains
Continental seamounts
African continental margin
IONIAN BASIN
IONIAN ABYSSAL PLAIN
MEDITERRANEAN RIDGE
INNER PLATEAU
AEGEAN SEA
CRETE
CYPRUS
CYPRUS TRENCH
LEVANTINE BASIN
ERATOSTHENES SEAMOUNT
PELAGIAN PROMONTORY
SIRTE ABYSSAL PLAIN
SIRTE RISE
CYRENAICA PROMONTORY
HERODOTUS ABYSSAL PLAIN
NILE CONE

Figure 2

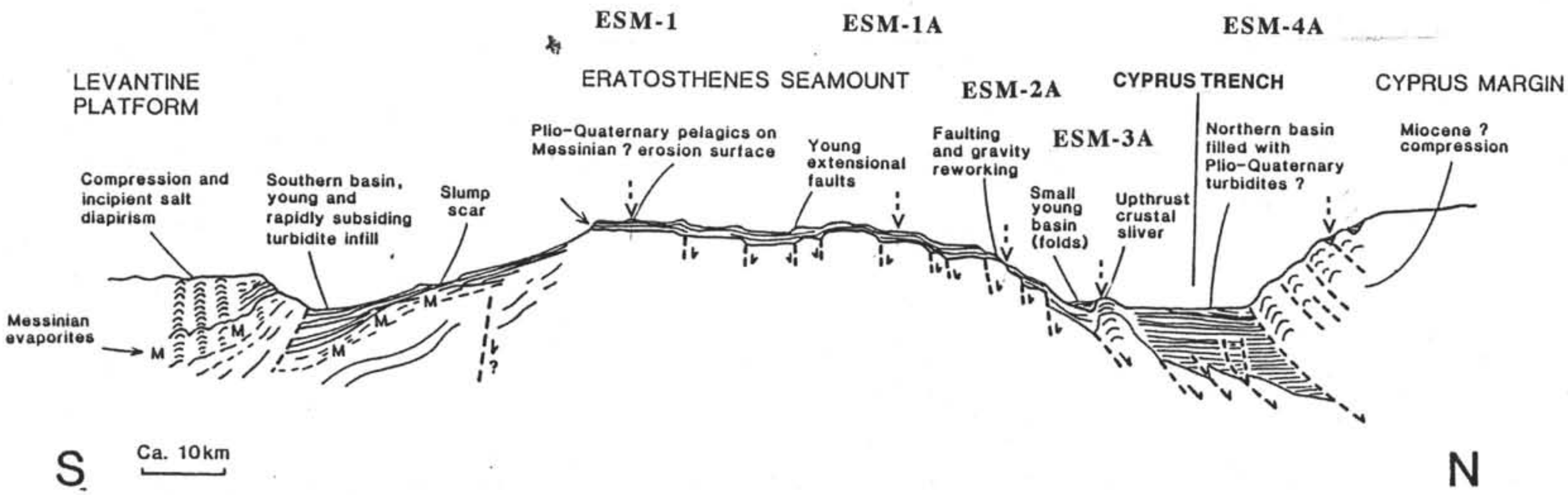
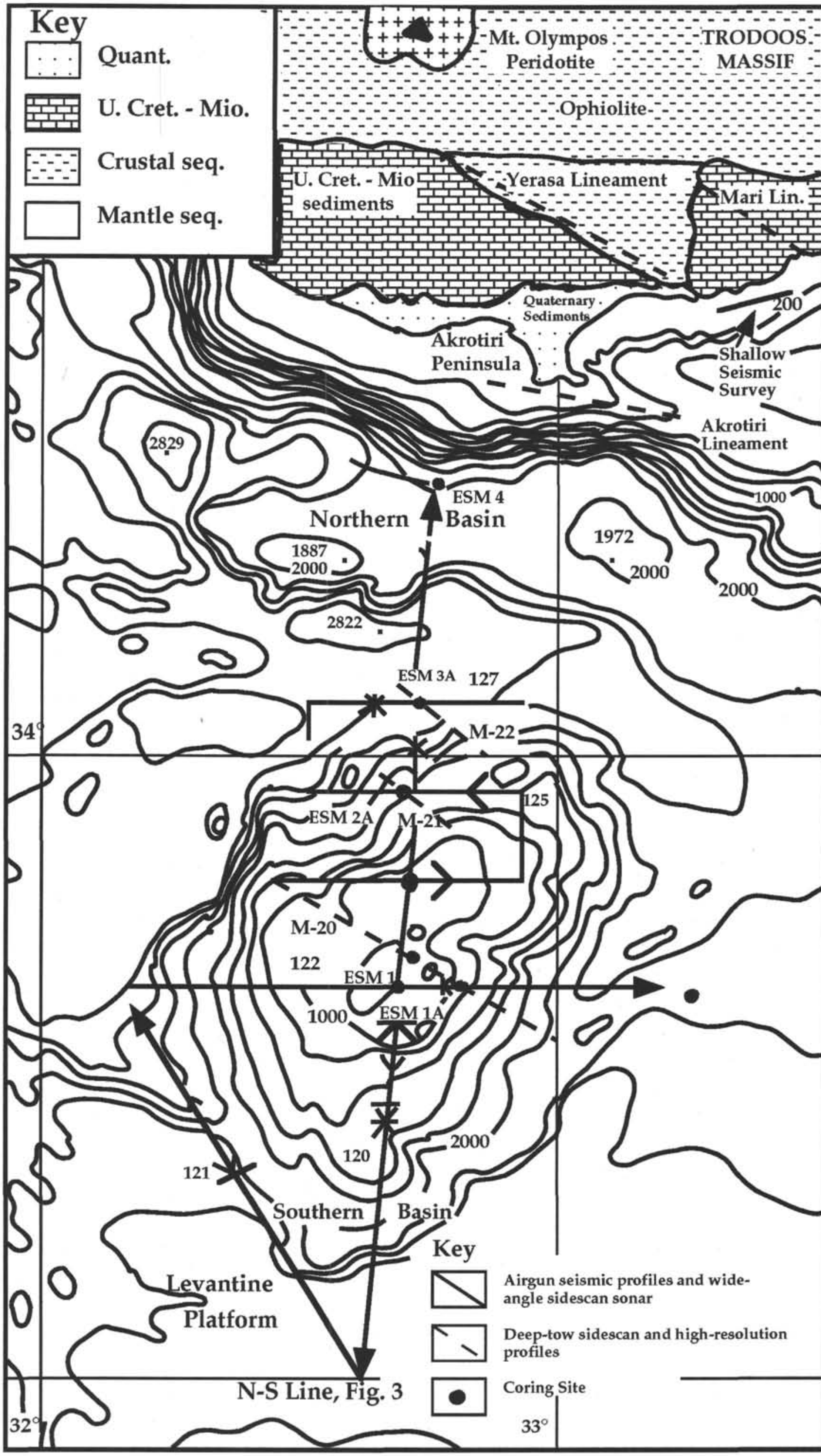

ESM-1
ESM-1A
ESM-4A
LEVANTINE PLATFORM
ERATOSTHENES SEAMOUNT
ESM-2A
CYPRUS TRENCH
CYPRUS MARGIN
Plio-Quaternary pelagics on Messinian ? erosion surface
Young extensional faults
Faulting and gravity reworking
ESM-3A
Northern basin filled with Plio-Quaternary turbidites ?
Miocene ? compression
Compression and incipient salt diapirism
Southern basin, young and rapidly subsiding turbidite infill
Slump scar
Small young basin (folds)
Upthrust crustal sliver
Messinian evaporites
M
S
Ca. 10km
N

Figure 3



Key
Quant.
U. Cret. - Mio.
Crustal seq.
Mantle seq.
Mt. Olympos
Peridotite
TRODOOS
MASSIF
Ophiolite
U. Cret. - Mio
sediments
Yerasa Lineament
Mari Lin.
Quaternary
Sediments
200
Akrotiri
Peninsula
Shallow
Seismic
Survey
Akrotiri
Lineament
2829
ESM 4
Northern
Basin
1000
1887
2000
1972
2000
2000
2822
ESM 3A
127
34°
M-22
125
ESM 2A
M-21
M-20
122
ESM 1
ESM 1A
1000
2000
120
121
Southern
Basin
Key
Levantine
Platform
Airgun seismic profiles and wide-angle sidescan sonar
Deep-tow sidescan and high-resolution profiles
Coring Site
N-S Line, Fig. 3
32°
33°

Figure 4

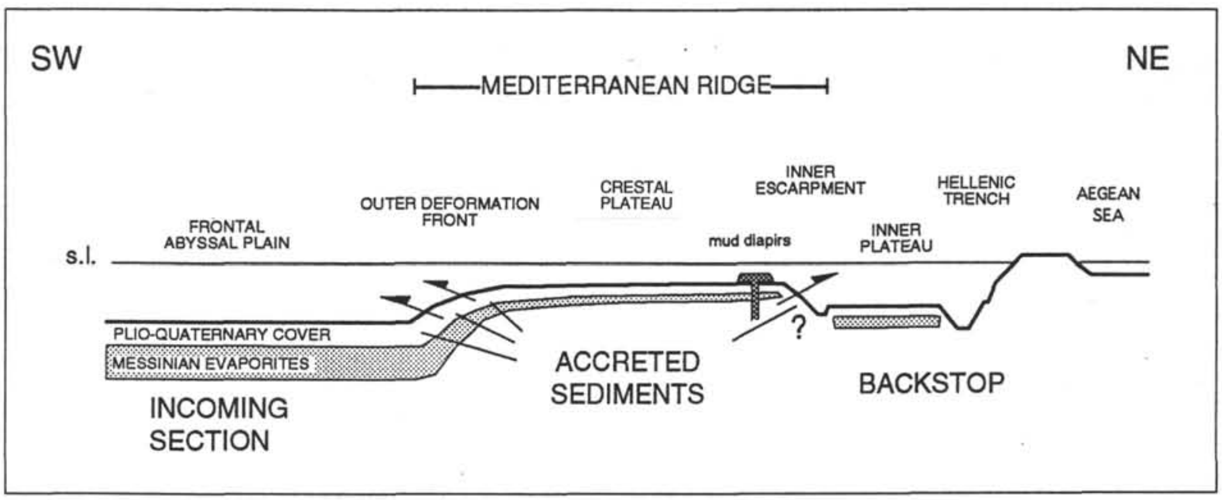

SW
NE
MEDITERRANEAN RIDGE
FRONTAL ABYSSAL PLAIN
OUTER DEFORMATION FRONT
CRESTAL PLATEAU
INNER ESCARPMENT
HELLENIC TRENCH
AEGEAN SEA
INNER PLATEAU
mud diapirs
s.l.
PLIO-QUATERNARY COVER
MESSINIAN EVAPORITES
INCOMING SECTION
ACCRETED SEDIMENTS
BACKSTOP
?

Figure 5

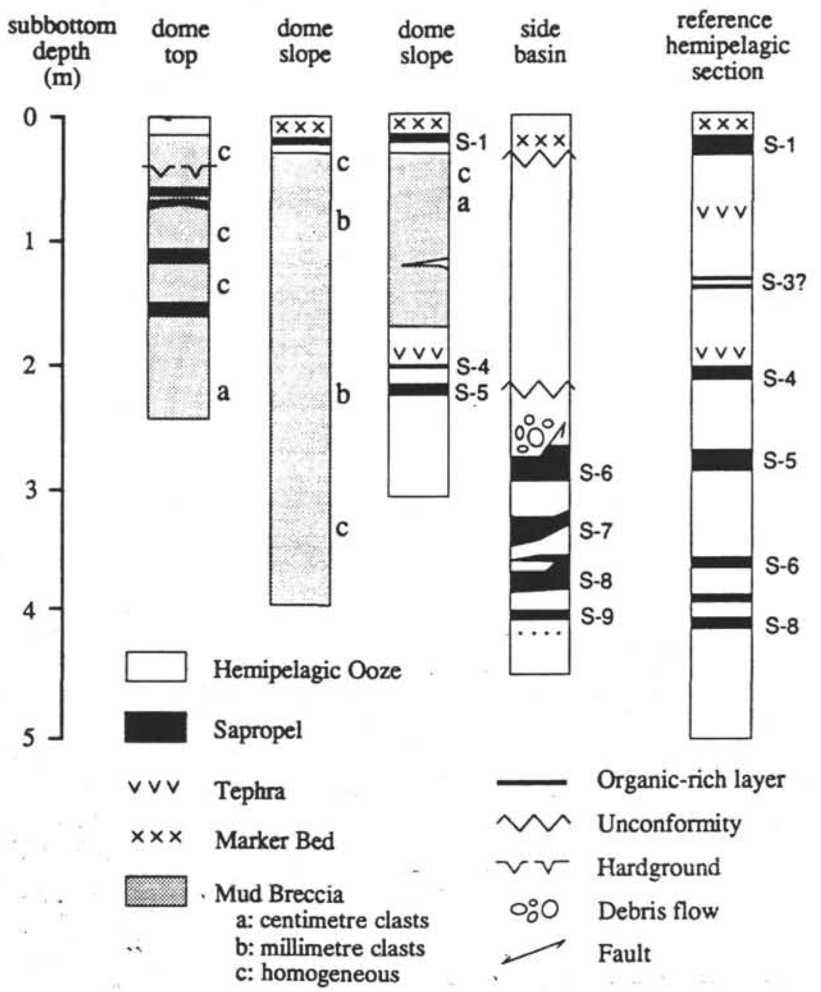

subbottom depth (m)
dome top
dome slope
dome slope
side basin
reference hemipelagic section
0
1
2
3
4
5
c
c
c
a
c
b
b
c
S-1
c
a
S-4
S-5
S-6
S-7
S-8
S-9
S-1
S-3?
S-4
S-5
S-6
S-8
Hemipelagic Ooze
Sapropel
Tephra
Marker Bed
Mud Breccia
a: centimetre clasts
b: millimetre clasts
c: homogeneous
Organic-rich layer
Unconformity
Hardground
Debris flow
Fault

Figure 6

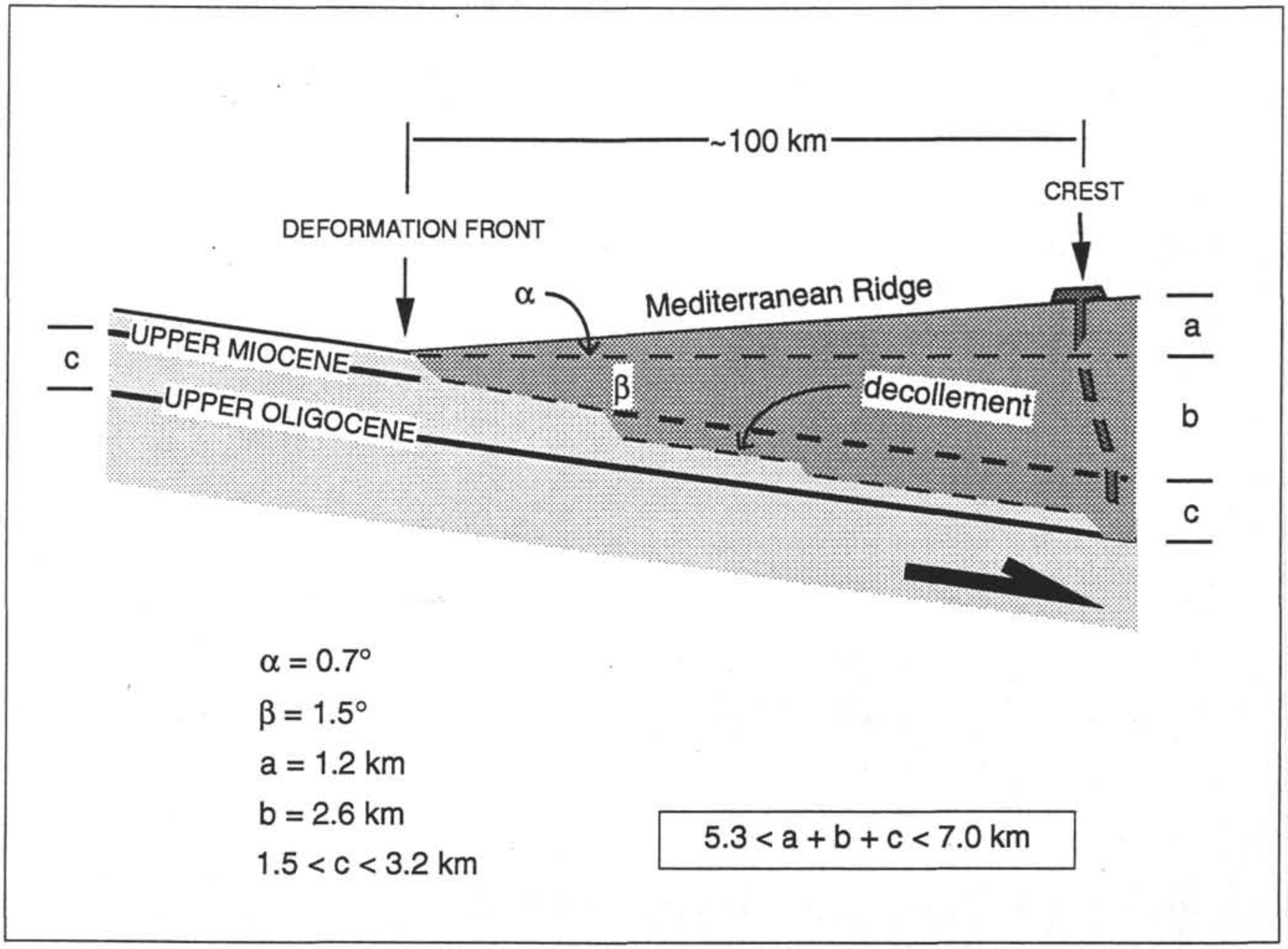

~100 km
CREST
DEFORMATION FRONT
α
Mediterranean Ridge
UPPER MIOCENE
UPPER OLIGOCENE
β
decollement
a
b
c
c
α = 0.7°
β = 1.5°
a = 1.2 km
b = 2.6 km
1.5 < c < 3.2 km
5.3 < a + b + c < 7.0 km

Figure 7

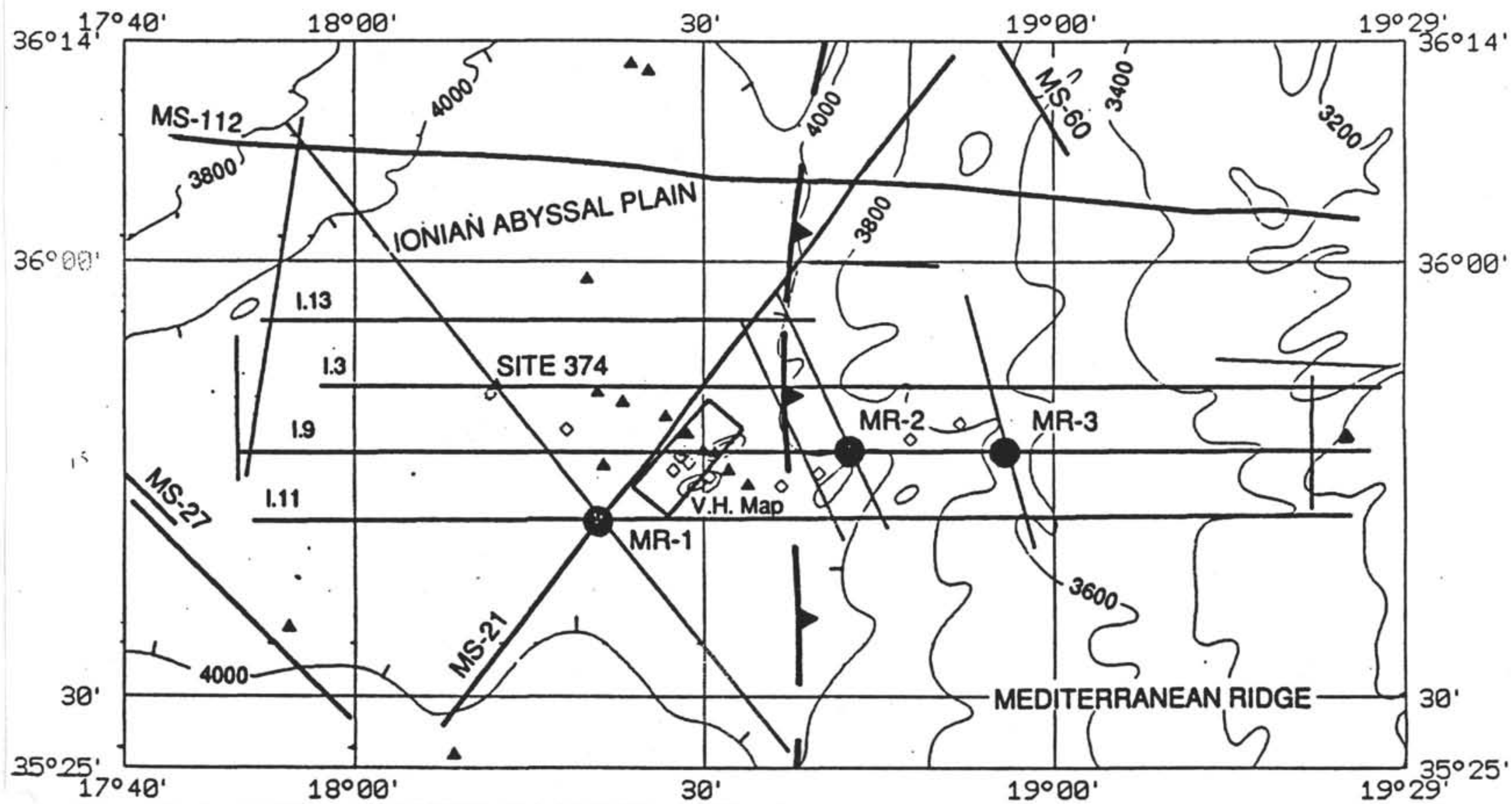
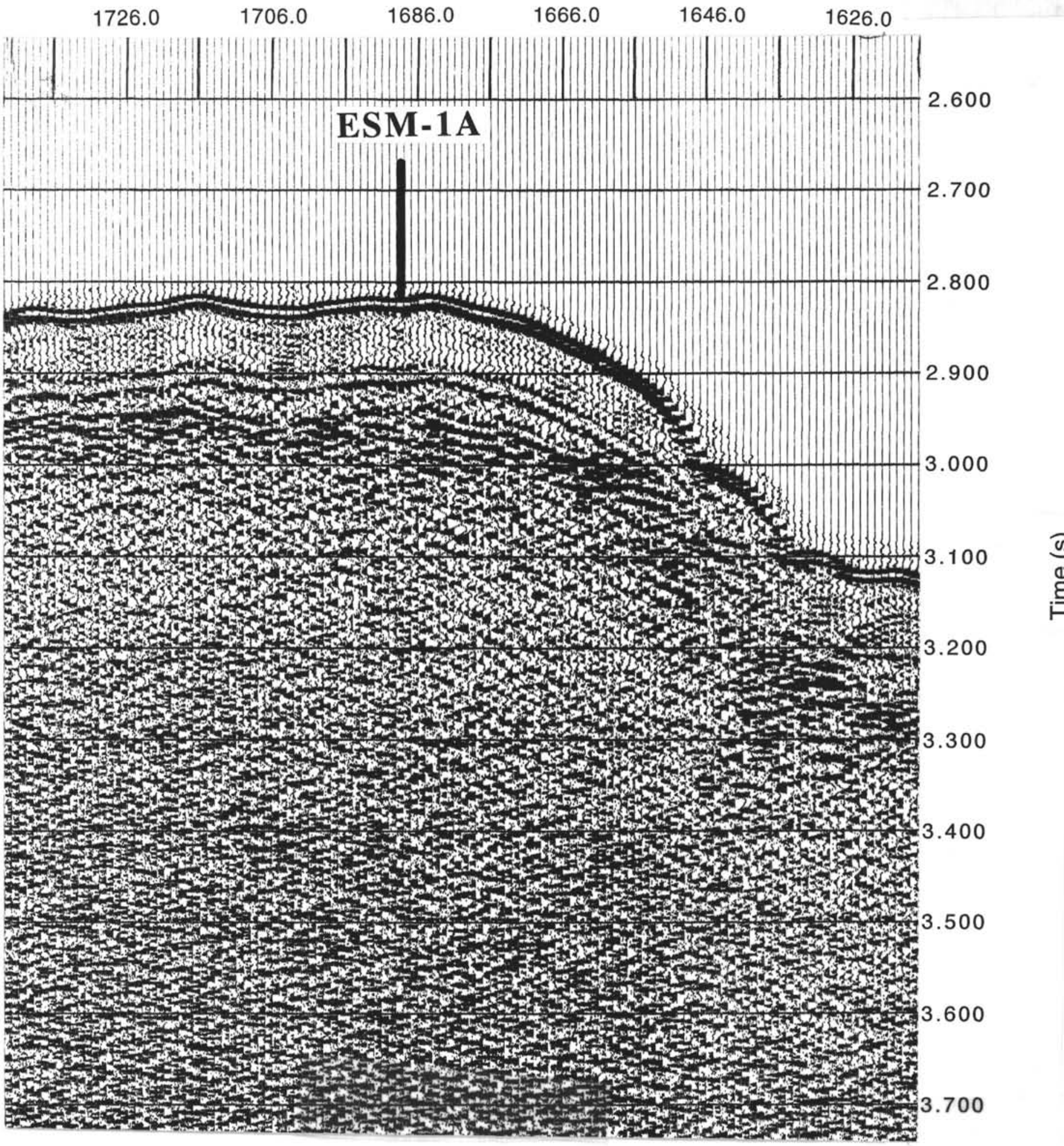

17°40'
18°00'
30'
19°00'
19°29'
36°14'
36°00'
30'
35°25'
MS-112
MS-60
MS-27
MS-21
4000
3800
3400
3200
3600
IONIAN ABYSSAL PLAIN
I.13
I.3
I.9
I.11
SITE 374
MR-1
MR-2
MR-3
V.H. Map
MEDITERRANEAN RIDGE

Figure 8


1726.0
1706.0
1686.0
1666.0
1646.0
1626.0
ESM-1A
2.600
2.700
2.800
2.900
3.000
3.100
3.200
3.300
3.400
3.500
3.600
3.700
Time (s)

Site: ESM-1A/MEDSAP-1D

Priority: 1

Position: 33°47.8'N, 32°42.1'E

Water Depth: 750 m

Sediment Thickness: 1000+ m

Total Penetration: 150 m

Seismic Coverage: Strakhov lines 31 and 32, TREDMAR 3 SCS lines 120-122; also MCS line MS 54

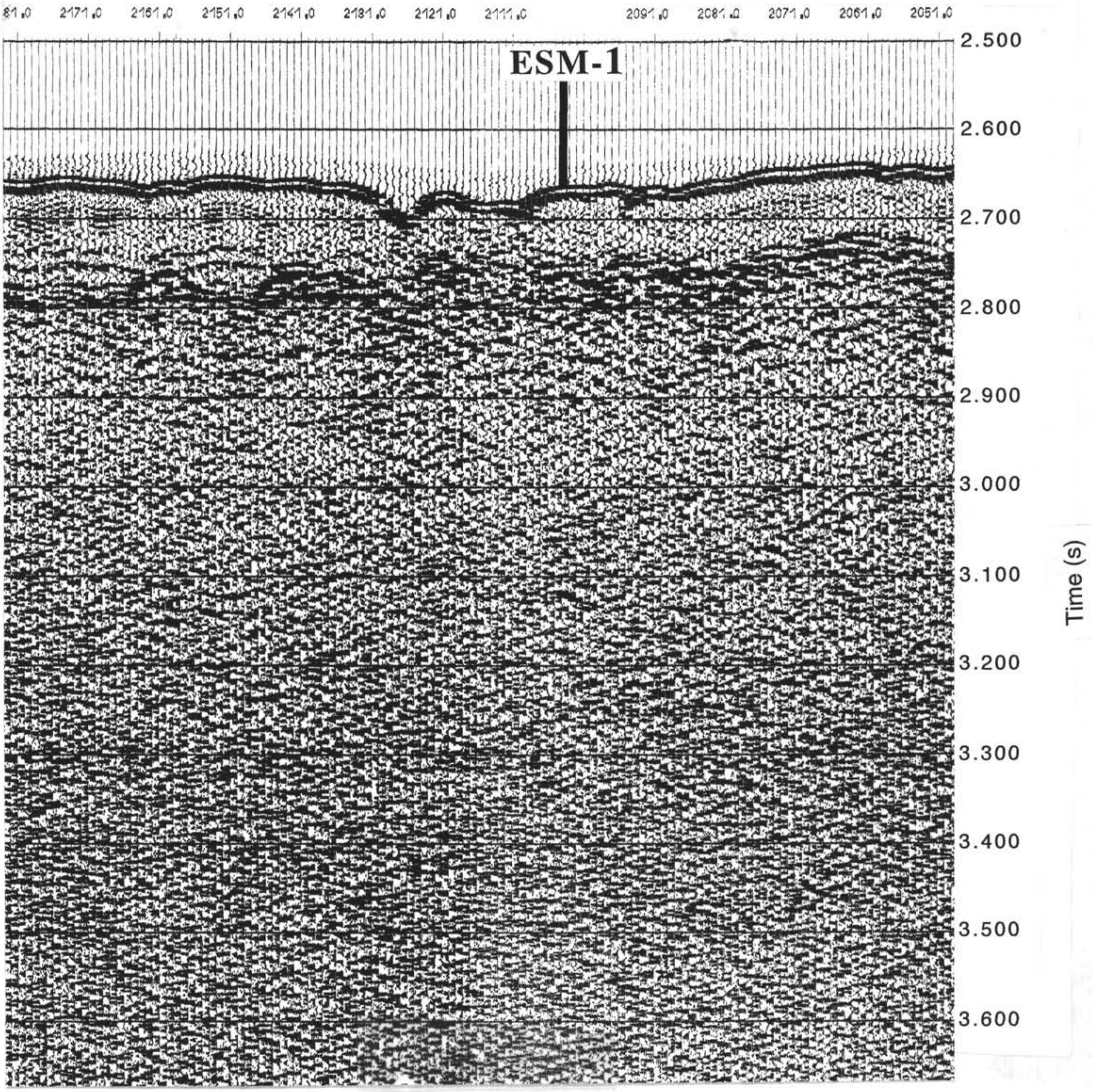
Objectives: To document the paleoceanography of the area by providing a complete record of Plio-Quaternary (or even older) sapropels in this part of the Eastern Mediterranean; tephra layers could help chart the volcanic history of the region (e.g., early development of the Aegean volcanic arc); sedimentological analysis, particularly of the wind-blown clastic component, will shed light on Plio-Quaternary climatic variation; to determine the subsidence history related to the collapse of the Seamount; to determine the nature of the prominent reflector at the base of the inferred Plio-Quaternary succession; paleomagnetic determinination whether the Seamount has undergone any tectonic rotation about a vertical axis that could be related to collision; to determine the relation of Messinian features to the Messinian salinity crisis and the bathymetric position of Eratosthenes; to determine the nature and age of the crust below the inferred unconformity surface.

Drilling Program:

1. APC coring until refusal, estimated at 150 mbsf, followed by continued deepening of the A-hole to 170 mbsf by XCB.
2. APC coring of the B-hole (oriented) and the C- and D-holes (standard) to refusal. The D-hole will be deepened by RCB coring to 350 mbsf. The entire hole below the casing will then be logged.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical, and FMS).

Nature of Rock Anticipated: Oozes, marls, sapropels, and tephra layers; evaporites or limestones at base.


81.0
2171.0
2161.0
2151.0
2141.0
2131.0
2121.0
2111.0
2091.0
2081.0
2071.0
2061.0
2051.0
ESM-1
2.500
2.600
2.700
2.800
2.900
3.000
3.100
3.200
3.300
3.400
3.500
3.600
Time (s)

Site: ESM-1/MEDSAP-1D

Priority: 2

Position: 33 °38'N, 32°40'E

Water Depth: 750 m (drill estimates: 650 m)

Sediment Thickness: ?

Total Penetration: 350 m

Seismic Coverage: MS-54 s.p., TREMAR-3 SCS line 120

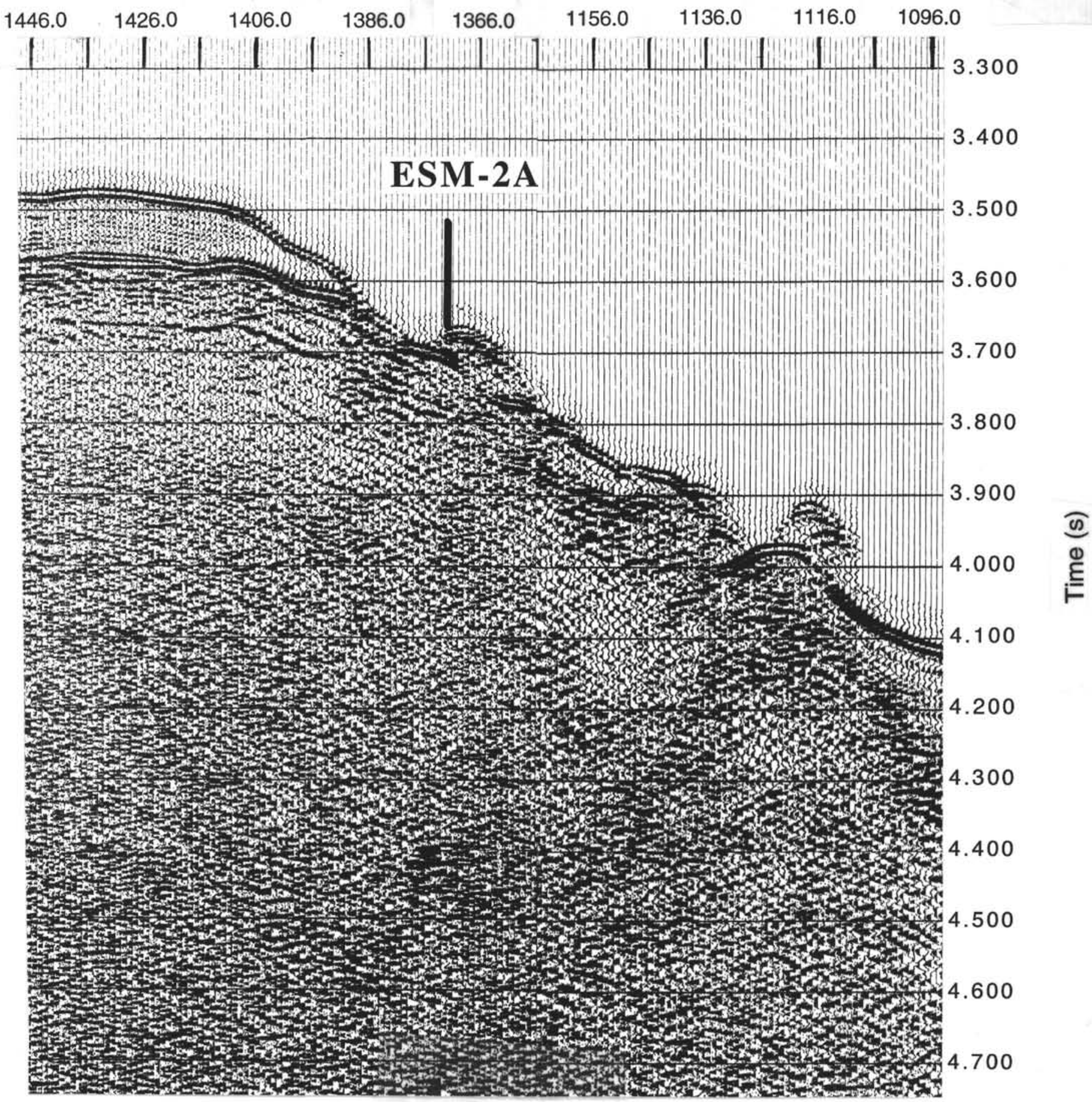
Objectives: To document the paleoceanography of the area by providing a complete record of Plio-Quaternary (or even older) sapropels in this part of the Eastern Mediterranean; tephra layers could help chart the volcanic history of the region (e.g., early development of the Aegean volcanic arc); sedimentological analysis, particularly of the wind-blown clastic component, will shed light on Plio-Quaternary climatic variation; to determine the subsidence history related to the collapse of the Seamount; to determine the nature of the prominent reflector at the base of the inferred Plio-Quaternary succession; paleomagnetic determinination whether the Seamount has undergone any tectonic rotation about a vertical axis that could be related to collision; to determine the relation of Messinian features to the Messinian salinity crisis and the bathymetric position of Eratosthenes; to determine the nature and age of the crust below the inferred unconformity surface.

Drilling Program:

1. APC coring until refusal, estimated at 100 mbsf, followed by continued deepening of the A-hole to 120 mbsf by XCB.
2. APC coring of the B-hole (oriented) and the C- and D-holes (standard) to refusal. The D-hole will be deepened by RCB coring to 350 mbsf. The entire hole below the casing will then be logged.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical). FMS may be run if time permits.

Nature of Rock Anticipated: Plio-Pleistocene unconsolidated sediments (oozes, marls, sapropels, and tephra layers) and evaporites or limestones at base.


1446.0
1426.0
1406.0
1386.0
1366.0
1156.0
1136.0
1116.0
1096.0
ESM-2A
3.300
3.400
3.500
3.600
3.700
3.800
3.900
4.000
4.100
4.200
4.300
4.400
4.500
4.600
4.700
Time (s)

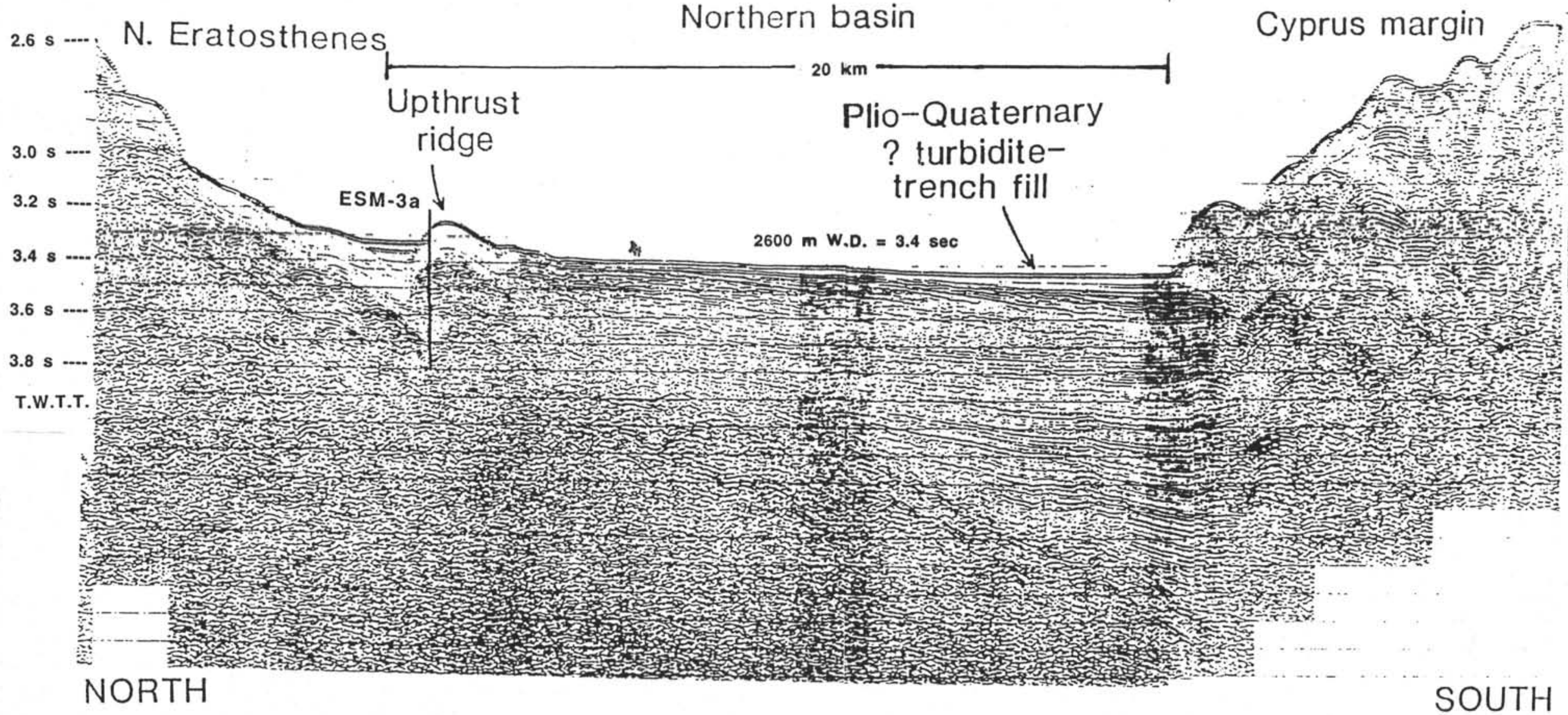
Site: ESM-2A
Priority: 1
Position: 33°55.1'N, 32°42.8'E
Water Depth: 1500 m
Sediment Thickness: 50 m
Total Penetration: 250 m
Seismic Coverage: MS-54 s.p., TREMAR-3 SCS lines 120, 125

Objectives: To penetrate the Eratosthenes basement in an area of minimal sediment cover, and compare this with basement units drilled at ESM 1A (or ESM 1) and ESM 3A. Specifically, faulting and mass wasting might allow relatively deep stratigraphic levels of the seamount to be penetrated at relatively shallow depths; to carry out strain and paleomagnetic analysis of the units below the Plio-Quaternary with a view to shedding light on the processes of collapse and breakup of the seamount; to determine processes of any gravity reworking (slumping and mass flow) that has affected any remaining Plio-Quaternary sedimentary cover. In addition the potential exists to correlate any Plio-Quaternary sediments with the pathways of downslope gravity transport revealed by the TREDMAR high-resolution seismic record. ESM-2A is the first of the sites to be drilled at the Eratosthenes seamount.

Drilling Program:
1. APC coring of the A (oriented) and B (standard) holes until refusal, estimated at 50 mbsf, followed by continued deepening of the B-hole to 70 mbsf by XCB.
2. Heat flow measurement.
3. Drill of the C hole to 50 mbsf and deepen by RCB coring to 250 mbsf. The entire hole below the casing will then be logged.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical). FMS may be run if time permits.

Nature of Rock Anticipated: Plio-Pleistocene unconsolidated sediments and Miocene rock.


N. Eratosthenes
Northern basin
Cyprus margin
20 km
Upthrust ridge
ESM-3a
Plio-Quaternary ? turbidite-trench fill
2600 m W.D. = 3.4 sec
2.6 s
3.0 s
3.2 s
3.4 s
3.6 s
3.8 s
T.W.T.T.
NORTH
SOUTH

Site: ESM-3A

Priority: 1

Position: 34°04.01'N, 32°43.52'E

Water Depth: 2750 m

Sediment Thickness: 135 m

Total Penetration: 300 m

Seismic Coverage: MS-54 s.p. 450, TREMAR-3 SCS lines 120, 127

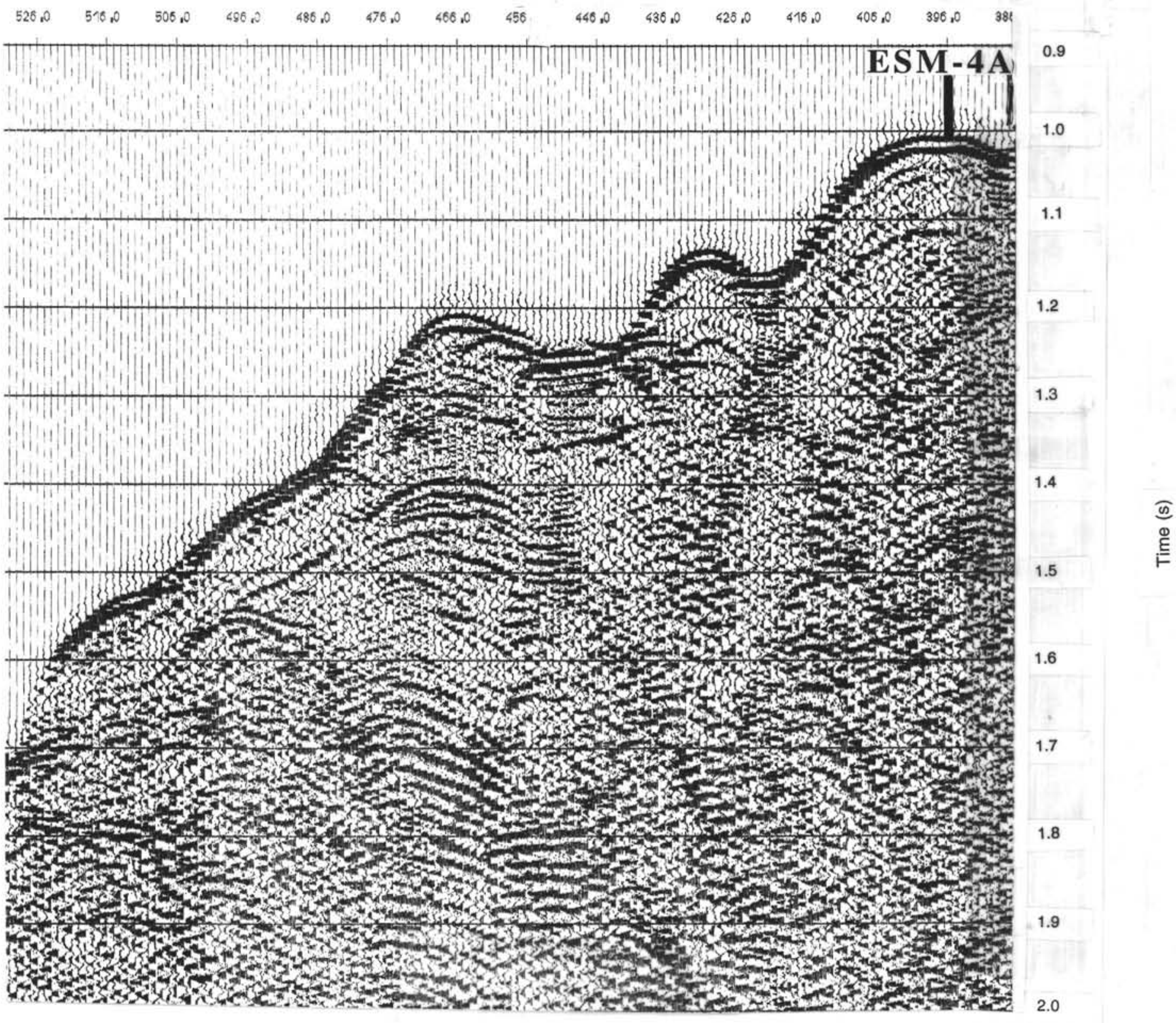
Objectives: To sed some light on the hypothesis that a sliver of Eratosthenes is in the process of being detached and accreted within an incipient collision zone, if possible by drilling through the inferred décollement plane; to analyze kinematically the strain related to detachment and accretion of an Eratosthenes crustal sliver; if possible to collect and analyze fluids within the décollement zone bearing on the geochemical mass-balance of subduction environment; to determine the crustal nature of the inferred accreted crustal sliver, in relation to rocks expected to be cored at ESM 1 beneath the inferred Plio-Quaternary succession; to infer the timing and processes of uplift of the footwall above the décollement to form the present low-standing ridge; to provide successions of deep-sea sediments (including mud turbidites) that can be compared with a more condensed succession on the crest of the Seamount. We also hope to determine if sapropels and/or tephra can be identified in deep-water sites that are potentially subject to gravity reworking and turbiditic deposition.

Drilling Program:

1. APC coring of the A (oriented) and B (standard) holes until refusal, estimated at 135 mbsf, followed by continued deepening of the B-hole to 155 mbsf by XCB.
2. Heat-flow measurement.
3. Drilling of the C hole to 135 mbsf and deepening by RCB coring to 300 mbsf. The entire hole below the casing will then be logged.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical, and FMS).

Nature of Rock Anticipated: Plio-Pleistocene unconsolidated sediments overlying mesozoic carbonates (?).


526,0
516,0
506,0
496,0
486,0
476,0
466,0
456
446,0
436,0
426,0
416,0
406,0
396,0
ESM-4A
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Time (s)

Site: ESM-4A

Priority: 1

Position: 34°19.9'N, 32°45.3'E

Water Depth: 2000 m

Sediment Thickness: 5000+ m

Total Penetration: 300 m (Plio-Quaternary sediments)

Seismic Coverage: TREMAR-3 SCS line 120

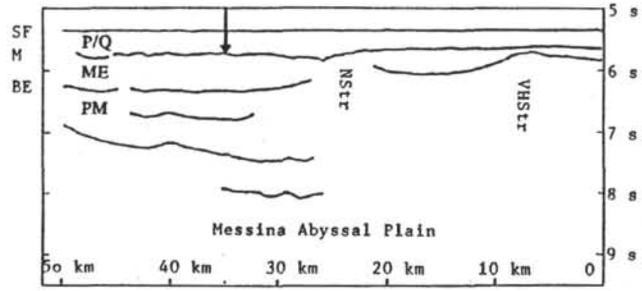
Objectives: To sample the sedimentary succession of the Cyprus slope to the north of the sediment-filled trough, and to compare the history of vertical motion with that of the Eratosthenes sites; also to allow detailed comparison with the onshore geology of southern Cyprus.

Drilling Program:

1. Double APC to 200 mbsf. Hole A will be oriented, hole B will be deepened by the XCB to 300 mbsf.
2. Heat-flow measurement will be carried out in hole C.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical, and FMS).

Nature of Rock Anticipated: Plio-Pleistocene muds and mudstone.



SF ———— Seafloor

P/Q = Pliocene + Quaternary

M reflector ———— Top of ME

ME = Messinian evaporites

BE reflector ———— Base of ME

PM = Pre-Messinian sediments

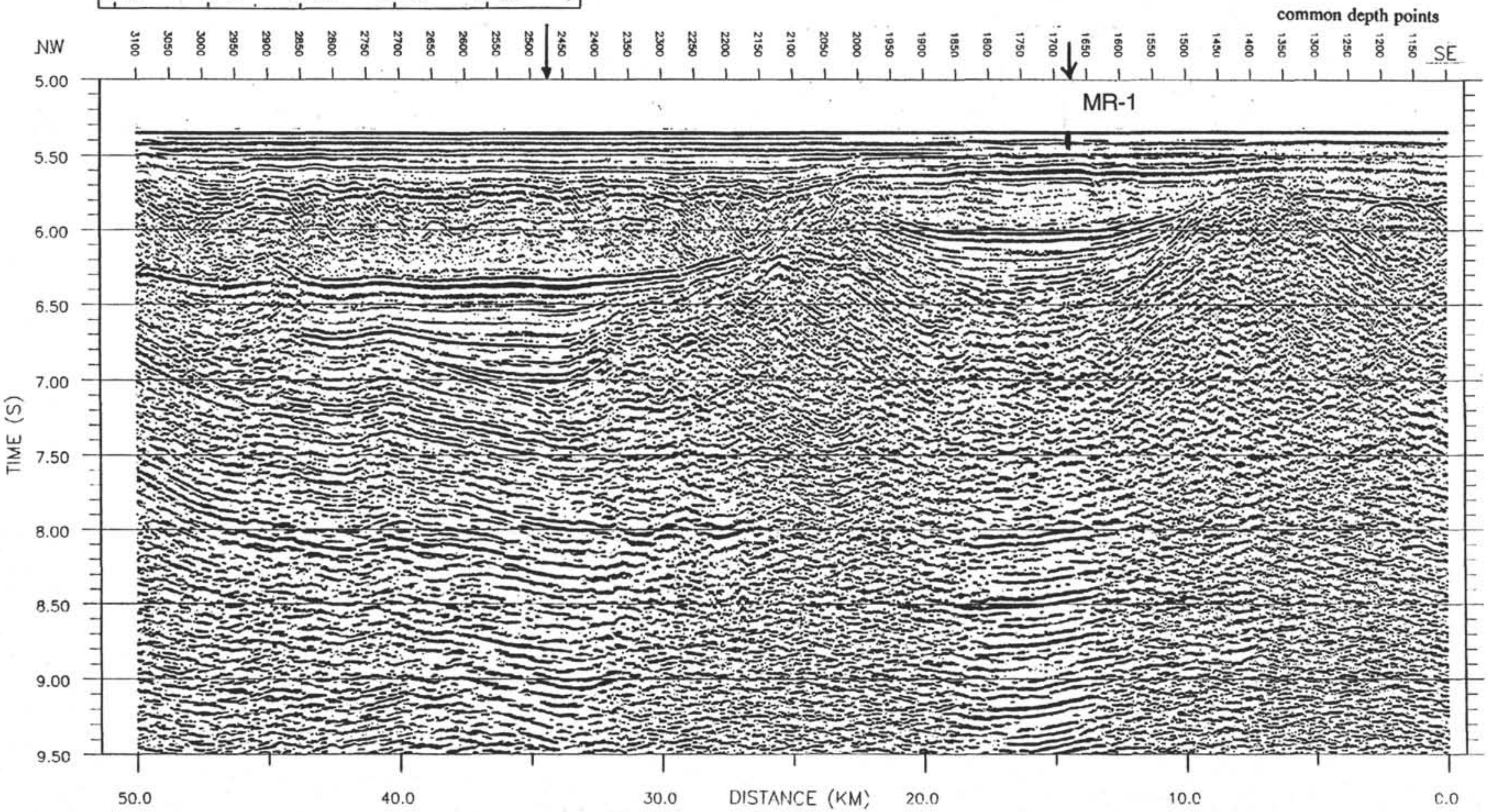
Figure 6

Profile 1.7 - Messina Abyssal Plain - Migrated time section and line drawing

For location see Figure 1

NStr = Nathalie Structure
VHStr = Victor Hensen Structure

↓ = position DSDP Site 374



Site: MR-1

Priority: 1

Position: 35°42.1'N, 018°21.2'E

Water Depth: 4100 m

Sediment Thickness: 5000+ m

Total Penetration: 300 m

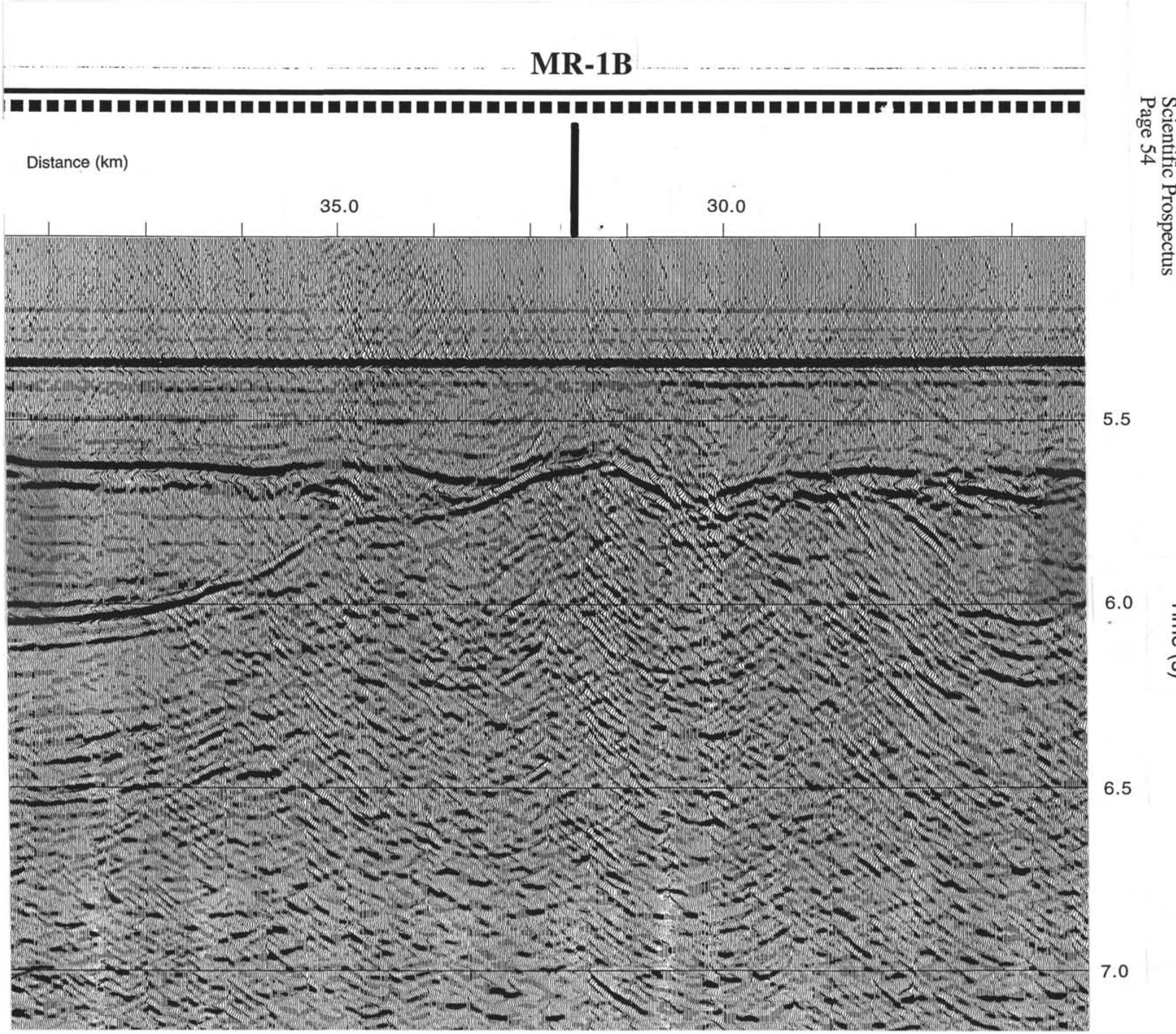
Seismic Coverage: at the intersection of lines 1.11 (at CDP 1676) and 1.7 (at CDP 4436)

Objectives: First of three shallow holes as part of a transect across the deformation front of the Mediterranean Ridge where nearly orthogonal plate convergence is taking place. It is intended to sample the sediment that is being incorporated into the Mediterranean accretionary wedge.

Drilling Program: Oriented APC hole to 200 mbsf. The hole will be deepened by the XCB to 300 mbsf. Heat-flow measurement. A second APC hole to 200 mbsf will be drilled if time permits.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Ooze, clay, sand, and mudstone.


MR-1B
Distance (km)
35.0
30.0
5.5
6.0
6.5
7.0
Time (s)

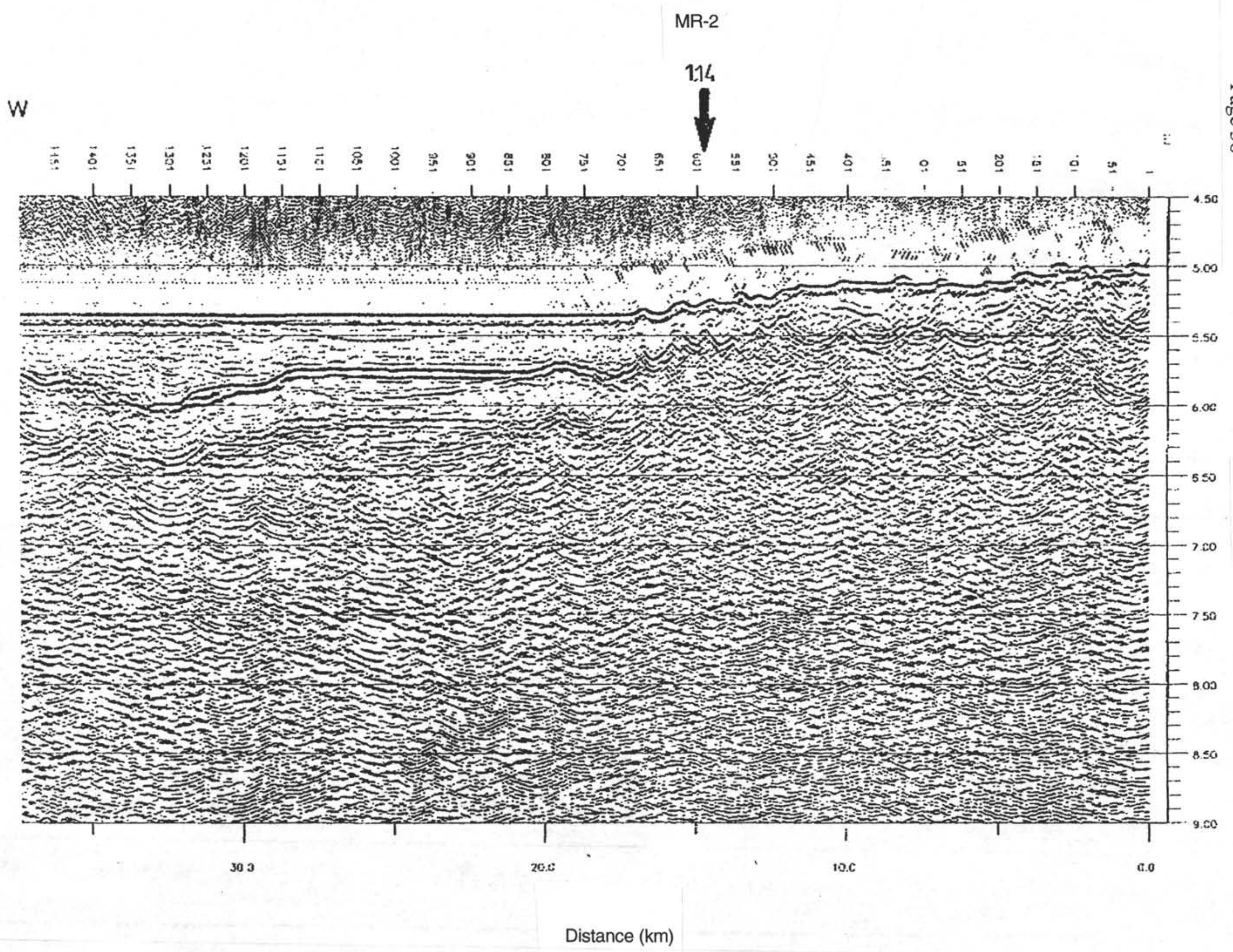
Site: MR-1B
Priority: 2
Position: 35°41.99'N, 018°25.76'E
Water Depth: 4100 m
Sediment Thickness: 5000+ m
Total Penetration: 350 m
Seismic Coverage: MCS line MS-21 at CDP 495 and SCS line 1.11 at CDP 4110

Objectives: First of three shallow holes as part of a transect across the deformation front of the Mediterranean Ridge where nearly orthogonal plate convergence is taking place. It is intended to sample the sediment that is being incorporated into the Mediterranean accretionary wedge.

Drilling Program: Oriented APC hole to refusal. The hole will be deepened by the XCB to 350 mbsf. Heat-flow measurement. A second APC hole to refusal will be drilled if time permits.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Plio-Quaternary muds, intercalated with turbidites.


MR-2
114
W
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
Time (s)
30.0
20.0
10.0
0.0
Distance (km)

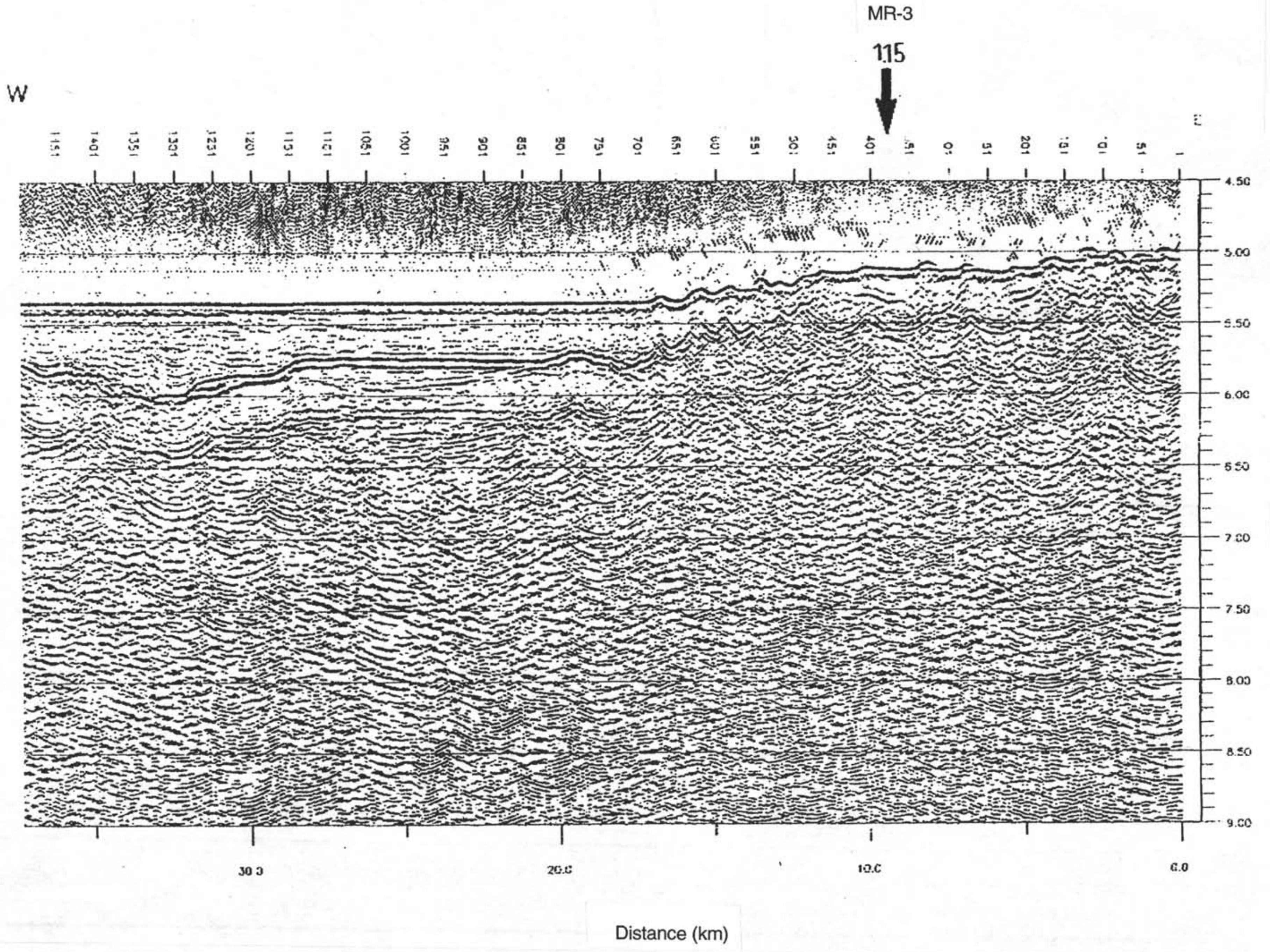
Site: MR-2
Priority: 1
Position: 35°46.8'N, 018°42.8'E
Water Depth: 3590 m
Sediment Thickness: 5000+ m
Total Penetration: 200 m
Seismic Coverage: at the crossing of p1.15 with p1.9

Objectives: Second of three shallow holes as part of a transect across the deformation front of the Mediterranean Ridge where nearly orthogonal plate convergence is taking place. It is intended to shed light on the age and structure of uplifted sediment directly behind the deformation front; to calculate the rates of uplift; to determine from the composition of interstitial fluids if any evaporites have been involved in the décollement at depth and have found their way upward as fluids to high levels along the décollement to the tip of the deformation front prior to or during uplift.

Drilling Program: Oriented APC hole to 200 mbsf. A second APC hole to 200 mbsf will be drilled if time permits.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Ooze, clay, and sand.


MR-3
115
W
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
Time (s)
30.0
20.0
10.0
0.0
Distance (km)

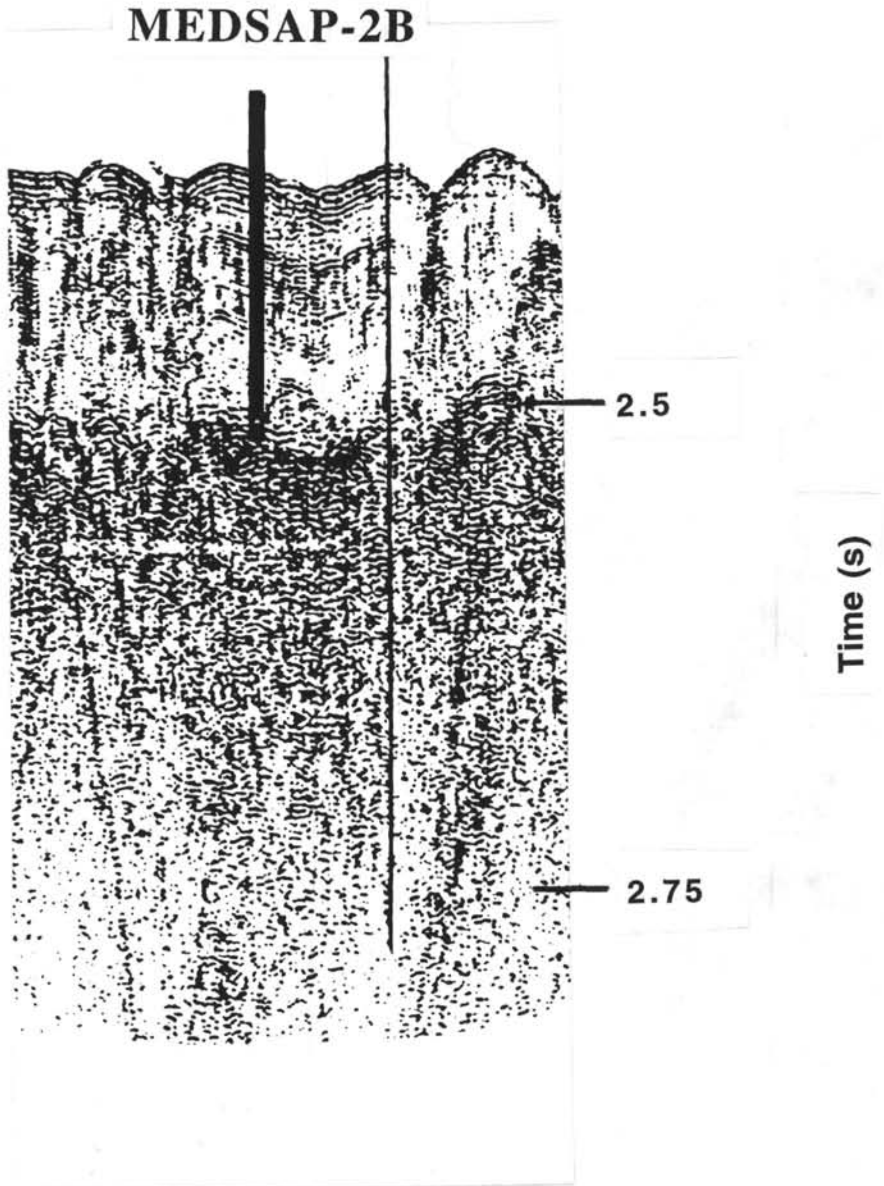
Site: MR-3
Priority: 1
Position: 35°46.8'N, 018°56.8'E
Water Depth: 3700 m
Sediment Thickness: 5000+ m
Total Penetration: 200 m
Seismic Coverage: The position in the July 1992 proposal is the crossing of p1.17 with p1.9

Objectives: Third of three shallow holes as part of a transect across the deformation front of the Mediterranean Ridge where nearly orthogonal plate convergence is taking place. It is intended to shed light on the age and structure of uplifted sediment directly behind the deformation front; to calculate the rates of uplift; to determine from the composition of interstitial fluids if any evaporites have been involved in the décollement at depth and have found their way upward as fluids to high levels along the décollement to the crest of the deformation front prior to or during uplift.

Drilling Program: Oriented APC hole to 200 mbsf. A second APC hole to 200 mbsf will be drilled if time permits.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Ooze, clay, and sand.


MEDSAP-2B
2.5
2.75
Time (s)

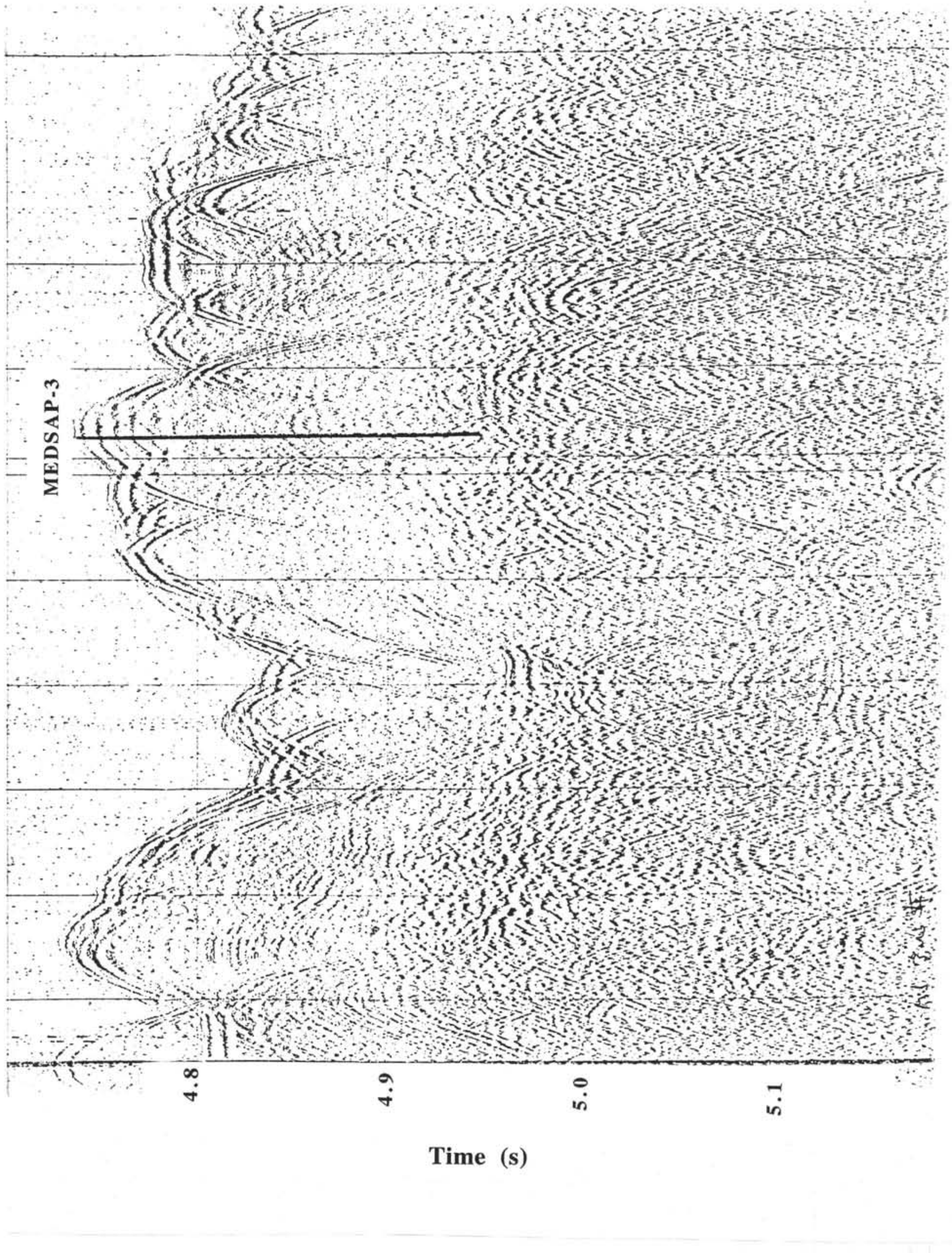
Site: MEDSAP-2B
Priority: 1
Position: 33°51'N, 24°53.9'E
Water Depth: 2200 m
Sediment Thickness: 1000+ m
Total Penetration: to APC refusal
Seismic Coverage: TREDMAR-3 and Ban-89a Line 0/33 kHz

Objectives: To retrieve a complete Quaternary succession on a structural high extending back at least through the Quaternary and hopefully through at least part of the Pliocene. This site represents the central tie-point of the paleoenvironmental transect.

Drilling Program: 4 holes to APC refusal. The first hole will be oriented; heat-flow measurements at the last hole.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Calcareous muds and oozes, sapropels and tephra layers; evaporites below 120 mbsf.


MEDSAP-3
4.8
4.9
5.0
5.1
Time (s)

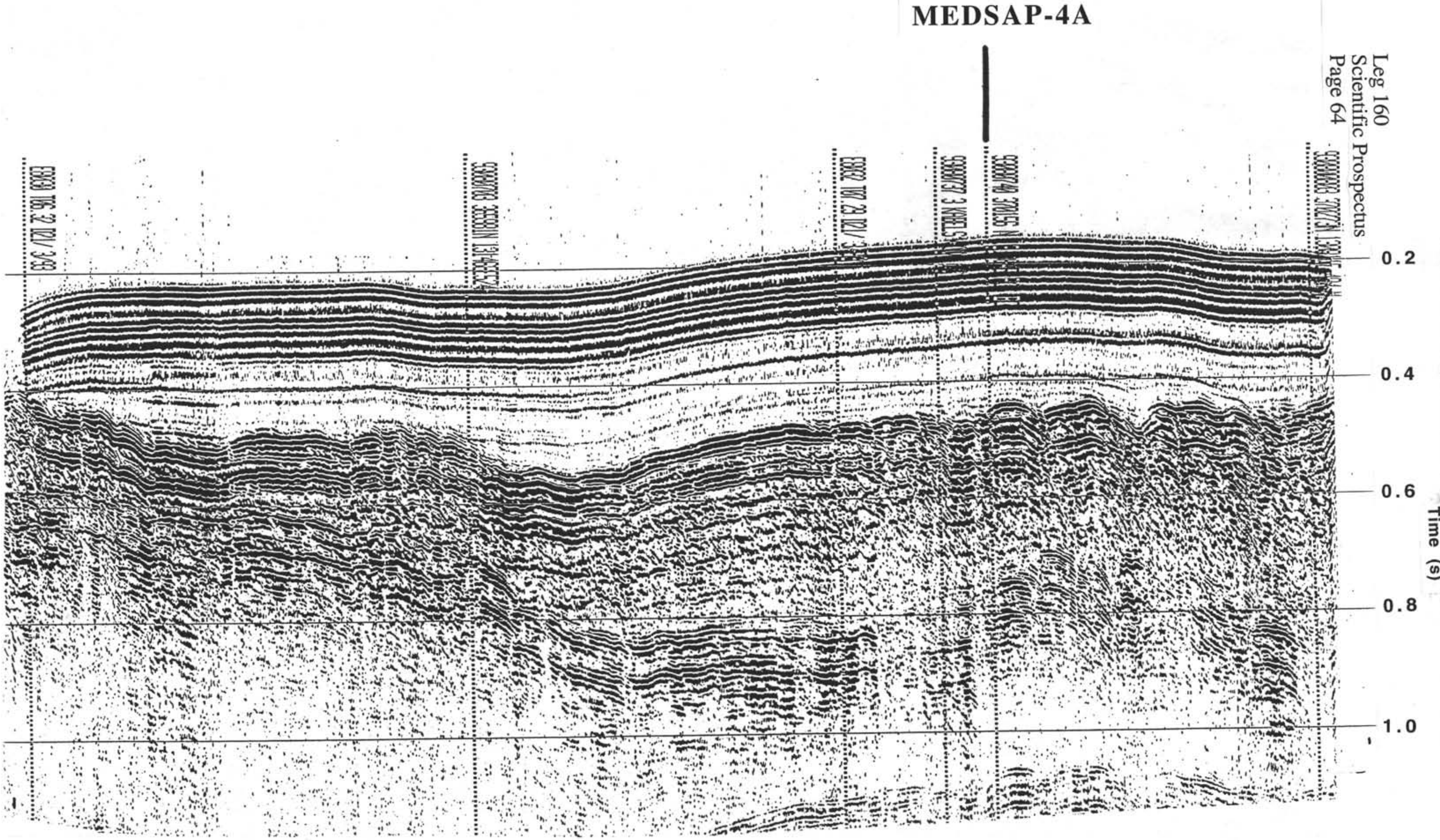
Site: MEDSAP-3
Priority: 1
Position: 36°15.3'N, 17°44.3'E
Water depth: 3640 m
Sediment Thickness: 5000+ m
Total Penetration: 100 m
Seismic Coverage: N/O URANIA

Objectives: This site is at the Calabrian Ridge on the Pisano Plateau between Beato Angelico Trough and Raffaello Basin and is a crucial site for establishing land-sea correlations (exposures in Calabria). Deep coring has recovered at least 15 sapropel intervals and 3 magnetic reversals in the topmost 32 m.

Drilling Program: 4 APC holes to 100 mbsf. The first hole will be oriented; heat-flow measurements in the last hole.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Calcareous muds and oozes, turbidites, tephra, and sapropels.


MEDSAP-4A
0.2
0.4
0.6
0.8
1.0
Time (s)

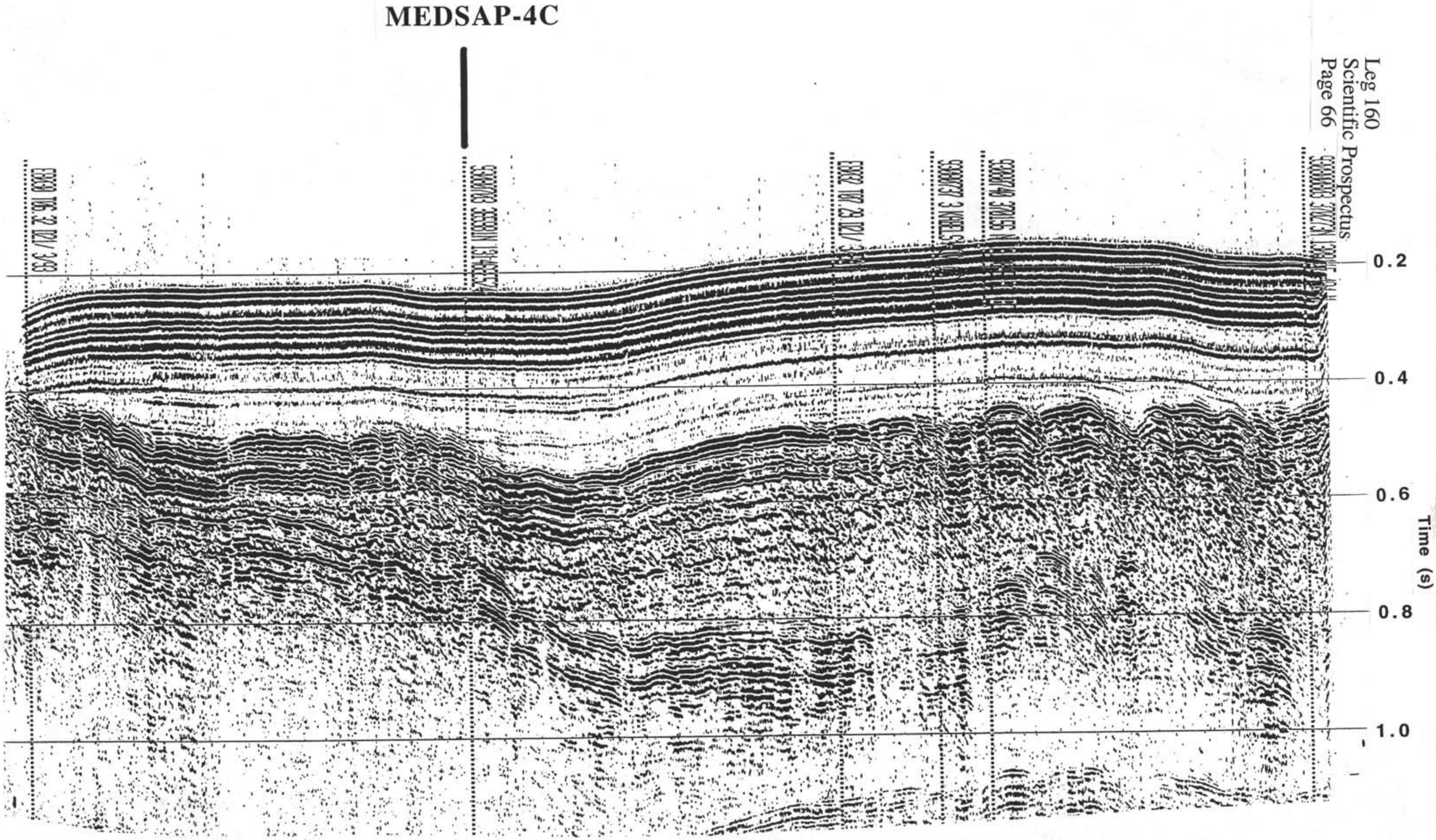
Site: MEDSAP-4A
Priority: 1
Position: 37°1.9'N, 13°10.9'E
Water Depth: 470 m
Sediment Thickness: 200 m
Total Penetration: 300 m
Seismic Coverage: Tyro Lines SC4, MT7, MT9, MCS G82-142 and -121C

Objectives: To be used as the watchdog for water-mass exchange between the eastern and western Mediterranean basins. The Sicily Channel marks the border between the two water masses in the east and west Mediterranean basins. Any current influence of sapropel deposition would be of particular interest. The site is also crucial for land-sea correlation (early Pliocene exposures of Capo Rosello on Sicily) and establishment of current regimes across the Strait of Sicily during sapropel deposition.

Drilling Program: 4 APC holes to 200 mbsf. The first hole will be oriented; heat-flow measurements in the last hole.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Calcareous muds and oozes, turbidites, tephra, and sapropels.


MEDSAP-4C
0.2
0.4
0.6
0.8
1.0
Time (s)

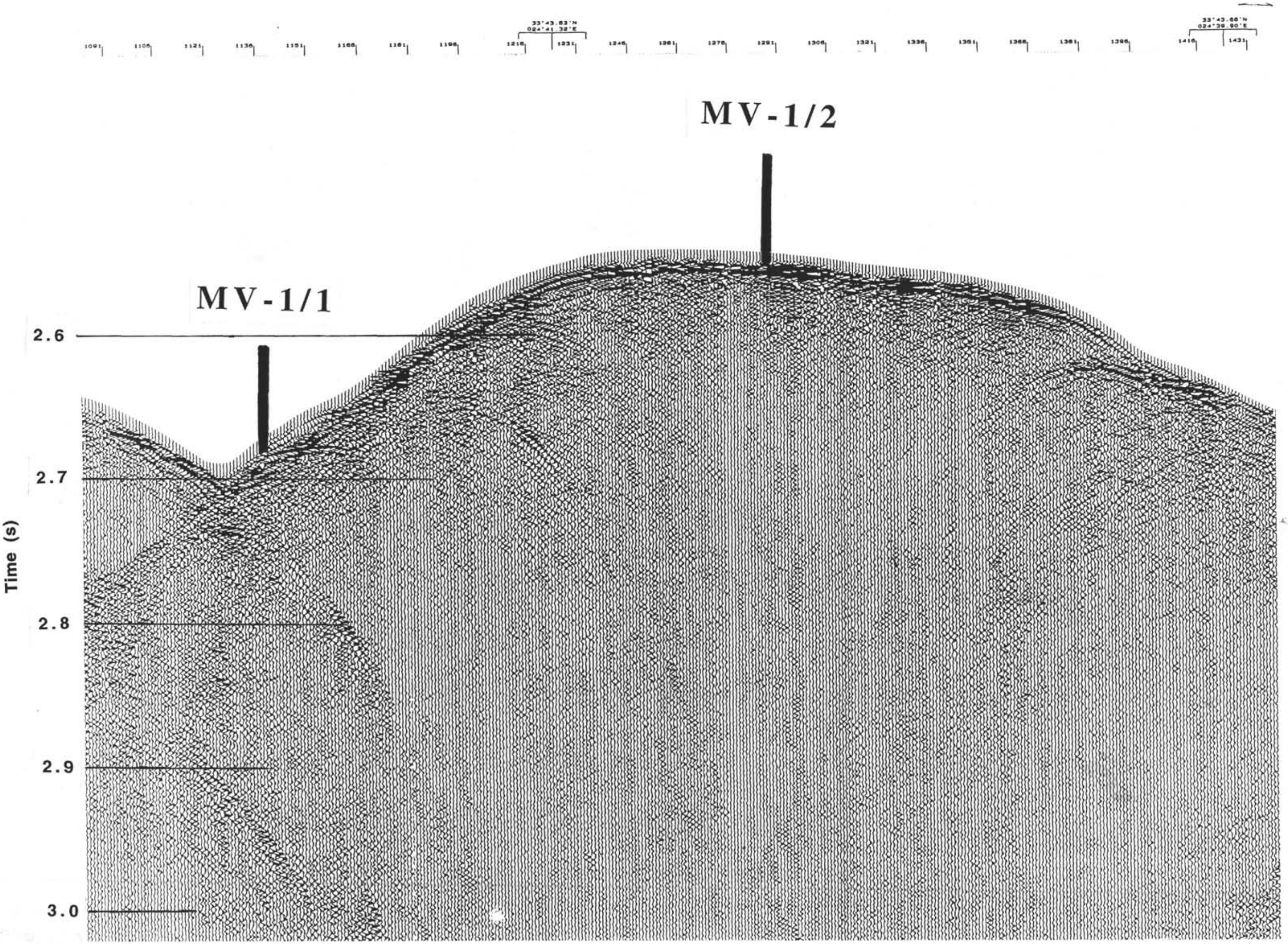
Site: MEDSAP-4C
Priority: 2
Position: 37°3.9'N, 13°15.3'E
Water Depth: 502 m
Sediment Thickness: 450 m
Total Penetration: 200 m
Seismic Coverage: Tyro Lines SC4, MT7, MT9, MCS G82-142 and -121C

Objectives: To be used as the watchdog for water-mass exchange between the eastern and western Mediterranean basins. The Sicily Channel marks the border between the two water masses in the east and west Mediterranean basins. Any current influence of sapropel deposition would be of particular interest. The site is also crucial for land-sea correlation (early Pliocene exposures of Capo Rosello on Sicily) and establishment of current regimes across the Strait of Sicily during sapropel deposition.

Drilling Program: 4 APC holes to 200 mbsf. The first hole will be oriented; heat-flow measurements in the last hole.

Logging and Downhole Operations: None.

Nature of Rock Anticipated: Calcareous muds and oozes, turbidites, tephra, and sapropels.


33°43.63'N
024°41.32'E
1216
1231
1246
1261
33°43.66'N
024°39.90'E
1416
1431
MV-1/2
MV-1/1
2.6
2.7
2.8
2.9
3.0
Time (s)

Site: MV-1/1, MV-1/2

Priority: 1

Position: 33°43.7'N, 24°41.8'E

Water Depth: 1980 m

Sediment Thickness: 10,000+ m

Total Penetration: 200 m

Seismic Coverage: lines Bannock-89 and-91 (dormed) and Gelendzhik-1993/106

Objectives:

Site MV-1 will be located on the Eastern flank of the Napoli Mud Volcano (Olimpi mud diapir field). Drilling 200 m of sediment section will permit:

1) Sample extensively and date mud sills propagating radially away from the central mud breccia conduit.

2) Obtain a detailed section of the physical properties of the mud breccia.

3) Obtain information on the chemical composition of the interstitial fluids of the mud breccia in order to evaluate depth of origin, migration paths, and diagenetic alterations.

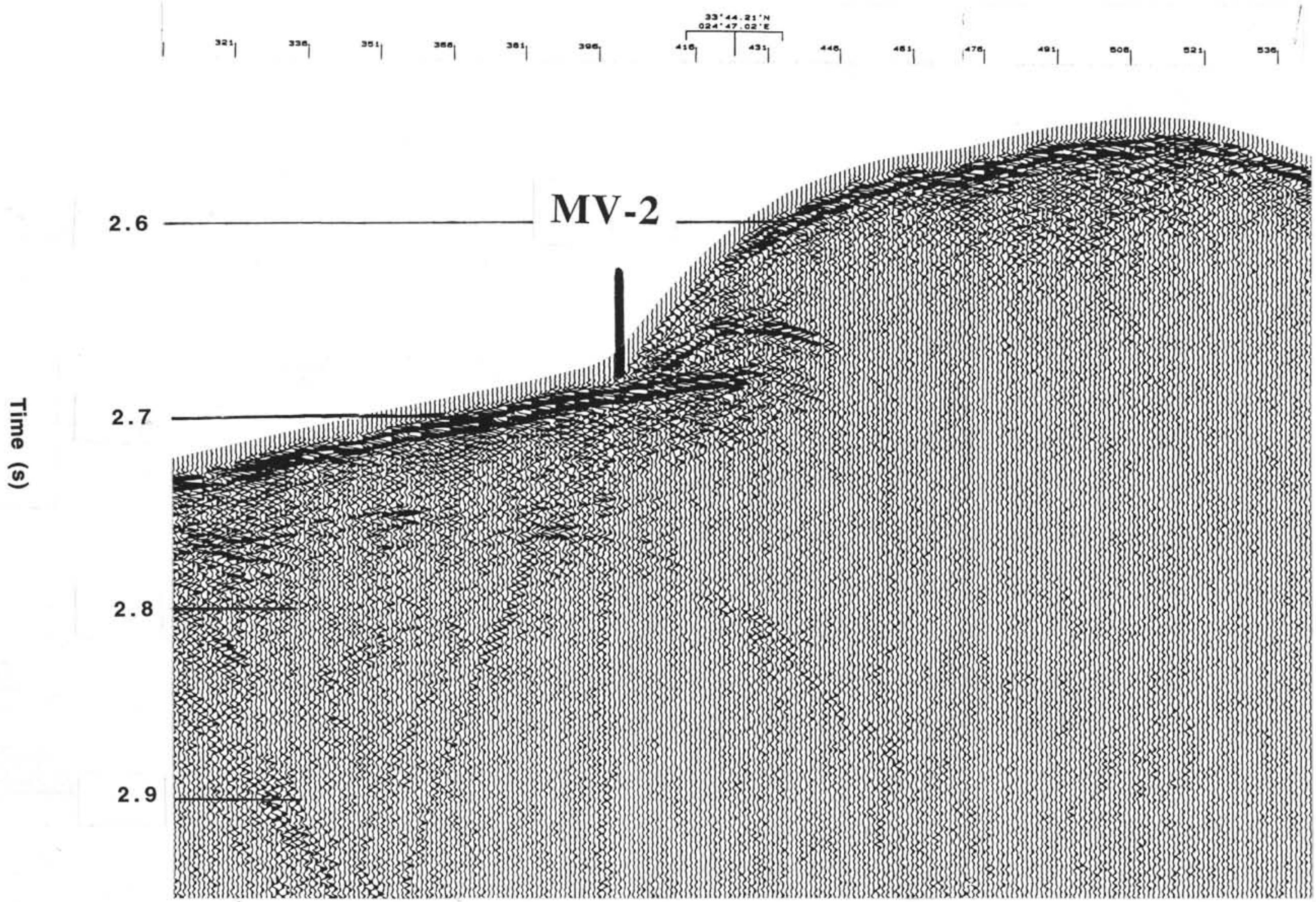
Site MV-1 is conceived as a multiple-hole site (MV-1/1, MV-1/2), composed of a transect of three holes spaced 50-100 m across the flank. This strategy will permit sampling, including possible "mud sills" that could be produced by the interfingering of host hemipelagic sediments and the diapiric mud.

Drilling Program:

1. Three standard APC holes will be drilled to 200 m on the flank of the mud volcano. Heat-flow measurements and logging will be carried out in the last hole.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical).

Nature of Rock Anticipated: alternations of mud breccia and hemipelagic sediments.


33°44.21'N
024°47.02'E
321
336
351
366
381
396
416
431
446
461
476
491
506
521
536
MV-2
2.6
2.7
2.8
2.9
Time (s)

Site: MV-2
Priority: 2
Position: 33°44.1'N, 24°47.1'E
Water Depth: 1990 m
Sediment Thickness: 10,000+ m
Total Penetration: 200 m
Seismic Coverage: Bannock-89/14/82, Bannock-91 (dormed)

Objectives:
Site MV-2 will be located on the eastern flank of the Milano Mud Volcano (Olimpi mud diapir field). Drilling 200 m of sediment section will permit:
1) Sample extensively and date mud sills propagating radially away from the central mud breccia conduit.
2) Obtain a detailed section of the physical properties of the mud breccia.
3) Obtain information on the chemical composition of the interstitial fluids of the mud breccia in order to evaluate depth of origin, migration paths, and diagenetic alterations.

Site MV-2 is conceived as a multiple-hole site (MV-2), composed of a transect of three holes spaced 50-100 m in a radial direction away from the center of the mud volcano. This strategy will permit sampling, including possible "mud sills" that could be produced by the interfingering of host hemipelagic sediments and the diapiric mud. We expect to encounter alternations of mud breccia and hemipelagic sediments at all holes. The seismic stratigraphy and the flank material is better imaged that at MV-1.

Drilling Program:
1. Three standard APC holes will be drilled to 200 m on the flank of the mud volcano. Heat-flow measurements and logging will be carried out in the last hole.
2. One standard APC hole at the tip of the mud volcano to 50 mbsf.

Logging and Downhole Operations: Standard strings (Quad combo, geophysical, geochemical).

Nature of Rock Anticipated: alternations of mud breccia and hemipelagic sediments.

SCIENTIFIC PARTICIPANTS

OCEAN DRILLING PROGRAM LEG 160

Co-Chief Scientist:

Kay-Christian Emeis
Institut für Ostseeforschung Warnemüende
Seestrasse 15
18119 Warnemüende
Federal Republic of Germany
(E-mail: emeis@comserv.io-warnemuende.de)
Wk. Phone: 49-381-5197-394
Fax: 49-381-5197-352

Co-Chief Scientist:

Alastair H.F. Robertson
Grant Institute of Geology
University of Edinburgh
West Mains Road
Edinburgh EH9 3JW
United Kingdom
(E-mail: ahfr@glg.ed.ac.uk)
Wk. Phone: 44-31-650-8546
Fax: 44-31-668-3184

Staff Scientist:

Carl Richter
Ocean Drilling Program
1000 Discovery Drive
Texas A&M University Research Park
College Station, Texas 77845-9547
U.S.A.
(E-mail: Richter@tamu.edu)
Wk. Phone: (409) 845-2522
Fax: (409) 845-0876

Sedimentologist:

Marie-Madeleine Blanc-Valleron
Laboratoire de Géologie du Muséum National d'Histoire Naturelle
URA 723 - CNRS
43 rue Buffon
75005 Paris, France
(E-mail: valleron@mnhn.fr)
Wk. Phone: 33 (1) 40-79-34-73
Fax: 33 (1) 40-79-37-39

Sedimentologist: Adrian Cramp
Marine Geosciences
Dept. of Geology
U.W.C.C.
P.O. Box 914
Cardiff, United Kingdom
(E-mail:geology@cardiff.ac.uk)
Wk. Phone: 44 (222) 874-335
Fax: 44 (222) 874-326

Sedimentologist: Eve M. Arnold
University of Rhode Island
Graduate School of Oceanography
Narragansett, Rhode Island 02882
U.S.A.
(E-mail:ema@gsosun1.gso.uri.edu)
Wk. Phone: (401) 792-6921
Fax: (401) 792-6811

Sedimentologist: Tatsuhiko Sakamoto
Division of Earth and Planetary Sciences
Graduate School of Science
Hokkaido University
Sopporo, 060
Japan
(E-mail: tats@s2.hines.hokudai.ac.jp)
Wk. Phone: 81 011-706-2726
Fax: 81-5351-6438

Sedimentologist: Floyd McCoy
University of Hawaii/Windward College
Kaneohoe, Hawaii 96744
U.S.A.
(E-mail: n/a)
Wk. Phone: (808) 235-7316
Fax: (808) 247-5362

Sedimentologist: Alan E.S. Kemp
Dept. of Oceanography
University of Southampton
Southampton, SO17 1BJ
United Kingdom
(E-mail: n/a)
Wk. Phone: 44 703 592 788
Fax: 44 703 593 059

Sedimentologist: TBN

Organic Geochemist:

Jürgen H. Rullkötter
Institut für Chemie und Biologie
des Meeres (ICBM)
Universität Oldenburg
Postfach 2503
D-26111 Oldenburg
Federal Republic of Germany
(E-mail: n/a)
Wk. Phone: 49-441-798-3262
Fax: 49-441-798-3384

Organic Geochemist:

Ioanna Bouloubassi
Dept. of Geology and Oceanography
University of Bordeaux I
Avenue des Facultés
33405 Talence Cedex
France
(E-mail: bertrand@geocean.u-bordeaux.fr)
Wk. Phone: 33 56-84-83-59
Fax: 33 56-84-08-48

Inorganic Geochemist:

Hans-Jürgen Brumsack
ICBM
University of Oldenburg
P.O. Box 2503
D-26111 Oldenburg
Federal Republic of Germany
(E-mail: n/a)
Wk. Phone: 49 441-798-3384

Inorganic Geochemist:

Gert J. De Lange
Dept. of Geochemistry
Institute for Earth Sciences
Budapestlaan 4
3584 CD Utrecht
Netherlands
(E-mail: gdelange@earth.ruu.nl)
Wk. Phone: 31-30-535034
Fax: 31-30-535030

Structural Geologist:

Rachel Flecker
Dept. of Geology and Geophysics
Edinburgh University
West Mains Road
Edinburgh, EH9 3JW
United Kingdom
(E-mail: flecker@castle.ed.ac.uk)
Wk. Phone: 44 31 650 5918
Fax: 44 31 668 3184

Structural Geologist:

Achim Kopf
Institut für Geowissenschaften
Universität Giessen
Senckenbergstrasse 3
D-35390 Geissen
Federal Republic of Germany
(E-mail: achim.kopf@geo.uni-giessen.de.)
Wk. Phone: 49 641 7028367
Fax: 49 641 39265

Paleontologist (diatoms):

Itaru Koizumi
Division of Earth and Planetary Sciences
Graduate School of Science
Hokkaido University
Sopporo, 060
Japan
(E-mail: n/a)
Wk. Phone: 81 (011) 706-2733
Fax: 81-5351-6438

Paleontologist (foraminifera):

Michael W. Howell
SCAMP
College of Sciences and Mathematics
University of South Carolina
Columbia, South Carolina 29208
(E-mail: howell@psc.psc.scarolina.edu)
Wk. Phone: (803)777-2164
Fax: (803)777-2451

Paleontologist (nannofossils):

Enrico Di Stephano
Dept. of Geology and Geodesy
Palermo University
Corso Tukory, 131
Italy
(E-mail: n/a)
Wk. Phone: 39-91-6512019
Fax: 39-91-6516070

JOIDES Logger/Geophysicist:

John M. Woodside
Geomarine Centre
Free University
De Boelelaan 1085
1081 HV Amsterdam
Netherlands
(E-mail: wooj@geo.vu.nl)
Wk. Phone: 31-20-548-5587
Fax: 31-20-646-2457

Physical Properties:

Brian M. Whiting
Dept. of Geological Sciences
University of Kentucky
Lexington, Kentucky 40506-0053
(E-mail: bmw@lithos.gly.uky.edu)
Wk. Phone: 606-257-7214
Fax: 606-323-1938

Physical Properties:

Daniel Pribnow
Dept. of Geology and Geophysics
717 Browning Bldg.
Salt Lake City, Utah 84112
U.S.A.
(E-mail: dpribnow@mines.utah.edu)
Wk. Phone: (801) 581-3588
Fax: (801) 581-7065

Physical Properties:

Yossi Mart
Leon Recanati Center for Marine Studies
University of Haifa
Mt. Carmel
Haifa 31905
Israel
(E-mail: yossi.mart@uvm.haifa.ac.il)
Wk. Phone: 972-4-240-600
Fax: 972-4-240-493

Paleomagnetist: TBN

Paleomagnetist: TBN

LDEO Logger:

Marie-Jose Jurado
Institute of Earth Sciences-Jaume Almerc
C.S.I.C.
Martí i Franqués s/n
08028-Barcelona
Spain
(E-mail: mjjurado@ija.csic.es)
Wk. Phone: 34-3-490-05-52
Fax: 34-3-411-00-12
Address after 1/1/95
Institute for Geophysics
University of Karlsruhe
Hertzstrasse 16
76187 Karlsruhe
Federal Republic of Germany
Fax: 49-721-71173

LDEO Logging Trainee:	Alain Rabaute Les Jardins du Château, Apt. 34 38, rue Pierre Cochereau 34000 Montpellier France
Schlumberger Engineer:	Steve Kittridge Schlumberger Offshore Services 369 Tristar Dr. Webster, Texas 77598 U.S.A.
Operations Manager:	Eugene Pollard Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A. (E-mail: pollard@nelson.tamu.edu) Wk. Phone: (409) 845-2161 Fax: (409) 845-2308
Laboratory Officer:	Bill Mills Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A. (E-mail: Mills@nelson.tamu.edu) Wk. Phone: (409) 845-2478 Fax: (409) 845-2380
Assistant Lab. Officer/X-ray:	Kuro Kuroki Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/ Curatorial Representative:	Erinn McCarty Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.

Marine Computer Specialist/System Manager:	Barry Weber Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Computer Specialist/System Manager:	John Eastlund Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/ Storekeeper:	Greg Lovelace Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/X-ray:	Jaque Ledbetter Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/Chemistry:	Robert Kemp Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/Chemistry:	Anne Pimmel Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/Magnetics:	Margaret Hastedt Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.

Marine Laboratory Specialist/Phys. Props.:	TBN Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Electronics Specialist:	Mark Watson Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Electronics Specialist:	Bill Stevens Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/Photo:	Randy Ball Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/Yeoperson:	Jo Ribbens Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist/UWG:	Monty Lawyer Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.
Marine Laboratory Specialist /DHL/FANTAIL	Tim Bronk Ocean Drilling Program Texas A&M University Research Park 1000 Discovery Drive College Station, Texas 77845-9547 U.S.A.

TECH STAFF SUBJECT TO CHANGE.