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ABSTRACT

Leg 161 was the second in a two-leg ODP program to address both tectonic and paleoceanographic objectives in the Mediterranean Sea. The paleoceanographic program concentrated on reconstructing Atlantic-Mediterranean water exchange and the paleoceanography of the western Mediterranean during the late Cenozoic. Tectonic studies focused on the origin and tectonic evolution of the Alboran Sea as a well-defined example of an extensional basin developed in a collisional setting.

The main focus of the paleoceanographic program during Leg 161 was documentation of the timing of sapropel formation in the Tyrrhenian Sea and of circulation patterns in the western Mediterranean, as well as monitoring of the Atlantic-Mediterranean water exchange. Secondary objectives were to determine environmental conditions during the onset of evaporitic conditions and the reestablishment of open-marine conditions during the earliest and latest Miocene, and the evolution of the Mediterranean’s hydrography during the onset of Northern Hemisphere glaciation, about 3.0 m.y. ago. Because the Mediterranean is a semi-enclosed, landlocked basin with only restricted water exchange with the open ocean, the composition of these sediments is especially sensitive to climate change, and environmental signals are preserved in great detail. To achieve these goals, three drill sites where chosen: Site 974 in the Tyrrhenian Sea, Site 975 on the Menorca Rise, and Site 976 in the western Alboran Sea. Sites 977, 978, and 979 in the eastern and southern Alboran Sea were primary tectonic sites but also included paleoceanographic objectives.

APC and XCB drilling at multiple offset holes ensured continuous recovery of Pliocene-to-Pleistocene sequences at these sites. In the Alboran Sea, major unconformities were observed in the Pliocene and Miocene sections. Sedimentation rates varied between 3 and 4 cm/k.y. in the Tyrrhenian and southern Balearic seas, and 15 and 30 cm/k.y. in the Alboran Sea. At Sites 974 and 975, we recovered up to 38 organic-rich layers (ORL’s), which resemble the type sapropels found in the eastern Mediterranean in that they are discrete, dark layers with sharp upper and lower boundaries. Total organic carbon concentrations of these layers varies between 0.8% and 2.5%; maximum concentrations of >6% are reached in the Tyrrhenian Sea. At the Alboran sites, more than 40 ORL’s were found, but here they are more dispersed and have gradational upper and lower contacts. In addition, some are more than 3 m thick, reflecting higher sedimentation rates. Interstitial- water profiles show that brines were present in the deepest parts at all sites. In the Tyrrhenian and Balearic seas, these brines likely are derived from dissolution of evaporites that are known to occur below the cored sediments. No major evaporite series are known in the Alboran Sea, however, and the brines there are preliminarily interpreted as a paleo-fluid of Messinian age or

represent a lateral flow of brines resulting from dissolution of evaporites in other parts of the area. At Site 975 on the Menorca Rise, we retrieved an upper Miocene evaporite sequence that consists of finely laminated gypsum, limestone, and marls. This sequence, together with sediments from the Miocene/Pliocene transition in the Alboran Sea, is important for establishing the transition from restricted to open-marine conditions.

The prime tectonic objective of the Alboran Sea drill sites was to develop a better understand the dynamics, kinematics, and deformation of continental lithosphere margins. The following problems were explored: the origin of extensional basins developed on former collisional orogens; the dynamics of the collapse of collisional ridges which result in extensional basins surrounded by arc-shaped orogenic belts; and a determination of the actual or sub-actual collisional processes.

Sites 976, 977, 978, and 978 in the Alboran Sea focused on the tectonic goals. Site 976, in the western Alboran Basin, penetrated through the Pleistocene and Miocene sedimentary cover and recovered 258.97 m of high-grade metamorphic basement, yielding information on the origin and evolution of the Alboran Sea. Metamorphic conditions indicate that these rocks underwent a significant decrease in pressure, accompanied by constant, or possibly increasing, temperature. Sites 977 and 978, in the eastern Alboran Basin, yielded information on the late Miocene to Holocene subsidence history and rifting evolution of the basin. Site 979 penetrated a zone of syn- and post-sedimentary folds on the flank of the Alboran Ridge (the main compressional feature of the Alboran Sea), yielding information on the age and nature of the later stages of compressional tectonic reorganization of the Alboran Basin.

INTRODUCTION

Early in scientific drilling, the Mediterranean attracted the interest of the earth science community. In 1970, the first expedition of *Glomar Challenger* (Leg 13; Ryan, Hsü, et al., 1973) to the Mediterranean investigated the “Messinian salinity crisis,” which led to the deposition of the famed evaporitic sequences. Leg 42 (1975; Hsü, Montadert, et al., 1978) and Leg 107 (1985; Kastens, Mascle, Auroux, et al., 1987) provided important information on the pre-Messinian environmental history and tectonic evolution of the Mediterranean.

Leg 161 in the western Mediterranean was the second in a two-leg ODP program to address both tectonic and paleoceanographic objectives in the Mediterranean Sea. During Leg 161, *JOIDES Resolution* drilled a transect of five sites across the western Mediterranean (Fig. 1) from the

Tyrrhenian Sea to the Alboran Sea, immediately east of the Strait of Gibraltar. Sites 974 and 975 in the Tyrrhenian Sea and on the Menorca Rise, respectively, were dedicated to paleoceanographic studies. Sites 976, 977, 978, and 979 in the Alboran Sea focused on tectonic goals, but also involved paleoceanographic objectives.

The ODP Leg 160 paleoceanographic investigation in the eastern Mediterranean was devoted to obtaining Pliocene-Pleistocene records containing a detailed record of sapropel deposition. Leg 161 was designed to retrieve time-equivalent sedimentary sequences that would allow documentation of the Miocene-through-Pleistocene paleoceanography of the western Mediterranean and a determination of the Mediterranean-wide circulation patterns at times of sapropel formation in the east. Site 974, in the Tyrrhenian Sea, was chosen, as it represents the westernmost documented occurrence of sapropels in the Mediterranean. Site 975, in the southern Balearic Sea, was selected to document the hydrography of western Mediterranean surface and deep waters. The paleoceanographic goals at the Alboran Sea sites included study of the late Cenozoic history of Atlantic-Mediterranean water exchange and the development of biological productivity patterns. The paleoceanographic and tectonic objectives in the Alboran Sea are related in that the paleogeographic evolution of the western Mediterranean gateway is a central theme for understanding the Messinian desiccation and circulation in the western Mediterranean Sea.

For tectonic studies in the western Mediterranean, the Alboran Sea was chosen as the optimum area to study the origin of Neogene extensional basins in collisional settings. Among the Mediterranean convergent boundaries, the collision between the Eurasian and the African plates at the westernmost Mediterranean Sea has resulted in a broad region of distributed deformation rather than a discrete plate boundary. This broad region comprises the Betic, Rif, and Tell cordilleras, which are linked across the Gibraltar Arc, and includes the extensional basins that form the Alboran and South Balearic seas (Fig. 2). The apparent paradox of extensional basin formation and crustal stretching during the collision of the Eurasian and Africa plates has been a long-standing problem in Mediterranean tectonics.

The Alboran Basin was formed during the early to middle Miocene by extension at the site of a former collisional orogen. The basin, which is floored by extended continental crust and surrounded by a thrust belt that was tectonically active during basin extension, closely resembles the northern Tyrrhenian Sea or the Panonnian Basin in that there is no geological or geophysical evidence that oceanic lithosphere subduction was associated with basin extension. The extension directions in the basin, and those of the coeval thrusting in the surrounding orogenic arc, are not clearly related to the Eurasian-African relative motion.

The prime tectonic objective of the Alboran Sea drill sites was to determine the response of the crust to compressional and extensional forces, and to better understand the kinematics and deformation of the Mediterranean continental lithosphere. Furthermore, the continental rift system that led to the development of the Alboran Basin provided an opportunity to examine the nature of brittle and ductile deformation of the crust, the role of magmatism in rifting processes, and the role of upper mantle in crustal modification and lithosphere evolution. The young, and tectonically active Alboran Sea is an ideal natural laboratory where these active tectonic processes can be investigated. The Alboran Sea drilling results are expected to have immediate applications in establishing geodynamic models for the origin and evolution of Mediterranean-type backarc extensional basins.

In summary, the primary paleoceanographic objectives of Leg 161 were as follows.

(1) To investigate the timing of sapropel formation in the Tyrrhenian Sea. At the time Leg 161 was being planned, this was the westernmost documented occurrence of sapropels in the Mediterranean.

(2) To investigate the circulation pattern in the western Mediterranean during periods of sapropel formation in the east. A determination of the hydrographic patterns across the entire Mediterranean was needed to better define the various factors that may have contributed to the formation of sapropels (i.e., basinwide anoxia vs. biological productivity).

(3) To understand environmental conditions during the onset of evaporitic conditions and to investigate the reestablishment of open-ocean conditions during the earliest and latest Miocene.

(4) To investigate Atlantic-Mediterranean water exchange and its influence on the Mediterranean's hydrography during the onset of Northern Hemisphere glaciation, about 3.0 m.y. ago. Monitoring hydrographic paleo-gradients across the Mediterranean, as well as vertical paleo-gradients between surface- and deep-water hydrographic proxies, was an important objective of Leg 161.

The primary tectonic objectives of Leg 161 were as follows.

(1) To investigate the dynamics, kinematics, and deformation of the continental lithosphere margins, including the development of extensional basins on collisional orogens, the dynamics of the collapse of collisional ridges, which result in extensional basins surrounded by orogenic belts, and collisional processes affecting continental margins.

(2) To determine the nature of the Mediterranean crust to develop a lithosphere model for the Alboran Sea rifting; to establish models for Miocene rifting on the basis of the nature of the basement and the geometry of rifting; to examine the magnitude and timing of extensional faulting; to examine syn-rift vs. post-rift subsidence and the pattern of total tectonic subsidence; and to determine the timing and role of magmatism during extension.

(3) To investigate post-rift deformation, in particular the late Miocene to Holocene contractive reorganization, recent strike-slip tectonics, the role of volcanism, and the recent collapse of the Alboran Basin.

To address these topics, six sites were selected for drilling in the western Mediterranean (Figs. 1, 2, 3, and 4).

Site 974 (proposed site MedSap-5) is located in the Tyrrhenian Sea and reoccupies ODP Leg 107 Site 652, which recovered eight sapropels and several volcaniclastic deposits (Kastens, Mascle, Auroux, et al., 1987). The primary objective of Site 974 was to obtain a continuous Pliocene-Pleistocene record of organic-rich sedimentary events and a comprehensive record of volcaniclastic sedimentation that could be tied into the paleoceanographic and tephrochronologic concepts of the Mediterranean.

Site 975 (proposed site MedSap-6A), on the South Balearic Margin, was chosen, as it is located in a key position to monitor the history of inflowing Atlantic waters on their passage east, and of outflowing Mediterranean waters on their passage west to the Alboran Sea. Site 975 is a central tiepoint along the trans-Mediterranean drilling transect, which was drilled during Legs 160 and 161.

Site 976 (proposed site Alb-2A) is located in the western Alboran Sea on a structural high at the southern Spanish margin. The site’s primary objective was to penetrate through the Pleistocene and Miocene sediment cover and to recover hard rock samples at least 200 m into basement to yield information on the origin and evolution of the Alboran Sea as a typical “Mediterranean backarc” basin. A primary paleoceanographic objective was to monitor the Atlantic-Mediterranean water exchange during the late Cenozoic.

Sites 977 and 978 (proposed sites Alb-4A and Alb-4, respectively) are located in the eastern Alboran Sea and lie in small sub-basins south and north of the Al-Mansour Seamount. At Sites 977 and 978, we aimed to drill through a sequence of tilted and hummocky seismic reflectors, likely representing syn-rift sedimentary structures, that may yield information on the subsidence history and tectonic evolution of the eastern Alboran Basin. Paleoceanographic objectives included an investigation of the Miocene-through-Pleistocene history of the Atlantic-Mediterranean water exchange, and of productivity patterns in the eastern Alboran Sea in relation to climatically driven circulation changes.

Site 979 (proposed site Alb-3A), in the southern Alboran Sea, is located on the southern flank of the Alboran Ridge, about 45 km north of Cabo Tres Forcas. The main objective was to penetrate through a zone of syn-sedimentary deformation on the flank of the ridge, which is depicted in seismic reflection profiles across the site, to yield the age and nature of folding, faulting, and associated unconformities. Ultimately, information obtained from this site will provide the database needed to establish the history of subsidence and/or uplift of the southern Alboran Basin and of the later contractive reorganization of the Alboran Basin as a whole.

RESULTS

The objectives of Leg 161 required recovery of a continuous sedimentary sequence. Drilling multiple holes at each site, with coring intervals offset in depth, helped to ensure that intervals missing within a single hole were recovered in adjacent holes. During Leg 161, the continuity of the recovered sedimentary sequence was confirmed by development of composite depth sections at the multiple-cored sites. Figure 5 shows an example of a composite depth section. A litho-stratigraphic summary of Leg 161 drill sites in the Tyrrhenian, Balearic, and Alboran seas is shown in Figure 6. The Holocene to Miocene sediment-accumulation history for all sites is shown in Figure 7.

Site 974

Site 974 is located in the central Tyrrhenian Sea on the lowermost eastern continental margin of Sardinia. The site lies in a north-south trending, small, deep basin, between the Tyrrhenian Central Fault and the De Marchi Seamount. The basin is underlain by thinned continental crust, which surrounds areas of Pliocene and Pleistocene oceanic crust (the Vavilov and Marsili basins) to the south and southeast. Site 974 lies about 300 m west-northwest of Site 652, which was drilled during ODP Leg 107 in 1986 (Fig. 8).

The objectives at Site 974 were to obtain a complete Pleistocene-through-Pliocene sedimentary sequence that would contain a continuous record of organic-rich depositional events (sapropel intervals) in the Tyrrhenian Sea, and to retrieve a comprehensive record of the coeval volcaniclastic deposits within this sequence. At Site 974, we recovered 198 m (Hole 974B) and 202.2 m (Hole 974C) of Pleistocene-Pliocene sediments. At the base of the sedimentary sequence in Hole 974B (203.7 mbsf) and Hole 974C (204.5 mbsf), sediments of latest Miocene age were reached. Recovery of a continuous sedimentary sequence was achieved at Site 974 by triple APC coring to 165 mbsf, and by double XCB coring to total depth. This drilling strategy proved successful in ensuring complete stratigraphic coverage.

Cores recovered at Site 974 contain abundant, mostly well-preserved Pleistocene to earliest Pliocene/latest Miocene calcareous nannofossil and foraminiferal assemblages. Abundance and preservation of nannofossils and foraminifers are poor in sediments at the base of Holes 974B and 974C; this may reflect a transition from nonmarine to marine environment during the latest Miocene (Messinian). Benthic foraminifers were rare to absent. The biostratigraphic data indicate that sedimentation rates at this site steadily increased with age, from 30.7 m/m.y. during the early Pliocene to over 34.1 m/m.y. during the late Pliocene to 45.4 m/m.y. during the Pleistocene/ Holocene.

Sediments at Site 974 are subdivided into four lithostratigraphic units, based primarily on nannofossil (carbonate) content. Unit boundaries were clearly correlated among Holes 974A, 974B, 974C, and 974D.

> Unit I (Hole 974B, 0-88.9 mbsf; Hole 974C, 0-90.1 mbsf; Hole 974D, 0-89.8 mbsf) consists of Pliocene-to-Pleistocene nannofossil-rich clay to nannofossil-rich silty clay. Carbonate contents within this unit average 29% by weight. The sediments are locally bioturbated and exhibit thin to medium color banding.
>
> A total of 36 sapropels, ranging in thickness from 2 to 20 cm, were identified within Unit I. Total organic carbon (TOC) contents of the sapropels reach up to 6.4%. Some of these layers are thin beds (1-2 cm) with less than 2% TOC. Organic matter atomic C/N ratios and Rock-Eval analyses indicate that the sapropels mostly consist of partially

degraded (oxidized) Type II algal and microbial material. At the base of Unit I, some sapropels have been faulted and deformed; reverse faulting has repeated some of these intervals in Hole 974D, whereas normal faulting may have removed some others in Holes 974B and 974C.

Numerous crystal-rich and vitric ash layers are present in Unit I. Ash and volcaniclastic layers range from a few millimeters to about 12 cm in thickness. Several ash layers are normally graded and faintly laminated, showing medium to high bioturbation. Rounded pumice grains are present in a few of these layers. From shipboard observations, it is difficult to determine whether all volcaniclastic intervals are primary, or if they consist of reworked material. Ash beds are locally altered to zeolite (phillipsite and analcime?) and clay minerals. Cemented, ash-rich, zeolitic concretions were found at the top of several ash layers. The boundary between Units I and II is located in a zone where slumping intervals alternate with undisturbed sediments.

Unit II (Hole 974B, 88.9-199.32 mbsf; Hole 974C, 90.1-200.14 mbsf; Hole 974D, 89.8-163 mbsf) consists of Pliocene nannofossil clay and nannofossil ooze, with minor amounts (1%-5%) of foraminifers. Ash beds are few and are locally altered to clay minerals and zeolites. Carbonate contents within the nannofossil clay and nannofossil ooze intervals average 50%. A few sapropels are present in the lower part of Unit II.

The sediments of Units I and II correspond to deposits that accumulated in an open-marine environment with periodic influx of pyroclastic material. The shift from more pelagic deposits in Unit II to more hemipelagic sediments in Unit I may reflect greater terrigenous input during the Pleistocene.

Unit III (Hole 974B, 199.32-200.47 mbsf; Hole 974C, 200.14-200.97 mbsf) is a very thin, variegated, brownish-gray to blackish-red, transitional unit that separates Pliocene marine sediments from the Messinian sequence. The unit is characterized by horizontally laminated to cross-laminated(?) silt to silty clay with local clay interbeds. The Unit II/Unit III boundary was placed at the Miocene/Pliocene age boundary, based on the last occurrence of in-situ planktonic foraminifers.

Unit IV (Hole 974B, 200.47-203.86 mbsf; Hole 974C, 200.97-202.48 mbsf) consists of a single graded(?), gray, siliciclastic interval, comprising a basal coarse-to-medium sand that grades upward into cross-laminated, very fine sand to cross- or parallel-laminated silt. The sandy and silty fraction is formed of carbonate and siliciclastic grains and possibly includes gypsum.

Structural features of primary significance include changes in bedding dips and the presence of microfaults and slumps. Dips of up to ~15° in coherent sections are interpreted to reflect tectonic tilting of the sedimentary sequence. Microfaults with normal-sense displacements of 1 cm, or less, are abundant from about 30 mbsf downward, with dips mainly in the range of 45°-60°. Between 90 and 110 mbsf, intervals of slump folding, on scales from 5 cm to 2 m, and disrupted and contorted bedding, including slump-related reverse-faults, have been identified in all holes. Slumping and tectonic deformation at this site suggest that the area was tectonically active during the Pliocene and Pleistocene.

Natural remanent magnetization (NRM) was strong in all cores (about 100 mA/m), i.e., far above the noise level of the cryogenic magnetometer. After 25 mT alternating field (AF) demagnetization, the values decreased to about 10 mA/m. Inclinations throughout the cores are close to present-day values at the site (+60˚). The consistently positive inclinations appear to have been caused by drill string overprinting, which makes magnetostratigraphy difficult at this site. Declination was obtained by reorienting the cores, using Tensor tool measurements. The large scatter observed for declination is likely the result of spurious secondary magnetization. The apparent spurious declination is not removed after 25 mT demagnetization. Additional measurements on working and archive halves of some cores, as well as on discrete samples, confirmed that the bulk magnetization is perpendicular to the split section in the core. Similar observations during Leg 154 were used to infer "pervasive radial remagnetization" (PRR), possibly induced by the cutting shoe, but the processes which produce PRR remain unclear.

Physical property measurements (thermal conductivity, index properties, and natural gamma radiation) all showed good hole-to-hole correlation, with due allowance for variation on short vertical scales and variances in sampling locations. High-resolution (2-10-cm-scale) profiles of GRAPE density, magnetic susceptibility, and color reflectance were used to construct a composite depth section from Holes 974B, 974C, and 974D. Distinctive features in each of the cores were aligned, using a common depth scale. Shifted positions of the cores were used to splice together a composite section. This composite section provides the most complete and least disturbed stratigraphic record at this site.

Downhole temperature measurements were made with the ADARA temperature tool at five depths in Hole 974B. The temperature data were reduced to in-situ values and combined with the thermal conductivity measurements to determine heat flow. The best-fitting linear regression to the data has a slope of 157 mW m^{-2} (n=5, R=0.998), which is virtually identical with the 160 mW m^{-2} value obtained at Site 652 during ODP Leg 107, also at this location. These values fit well with a young age for the Tyrrhenian Basin.

Interstitial water profiles at Site 974 show steady increases with depth in salinity, chlorinity, calcium, strontium, ammonium, and lithium values. Evaporites, especially halite, anhydrite, and gypsum, known to occur below the sediments cored at Site 974, can provide the source for these variables. Potassium and, to a certain extent, pH and alkalinity steadily decrease with depth. The downhole increase in calcium and strontium is most likely the result of an interaction of Messinian brines with background carbonates. High lithium concentrations suggest the presence of late-stage evaporitic brines. Ammonium concentrations are generally low, reflecting limited decomposition of organic matter. The sulfate concentration indicates that organic matter degradation at this site occurs mainly by sulfate reduction.

Logging in Hole 974C included the quad-combo, formation microscanner (FMS), and geochemical tool (GLT). Two main log units were identified in close correspondence with lithostratigraphic Units I and II. High log variability in Log Unit I (36.0-90.0 mbsf; Pleistocene-Pliocene hemi-pelagic sediments) indicates relatively heterogeneous lithologies. High variations in thorium content in this unit appear to be related to ash layers. Uranium content is likely related to the ORL's. Log Unit II (90.0-186.0 mbsf; Pliocene pelagic to hemipelagic sediments) shows a homogeneous response of all three tools.

Site 974 successfully achieved its goals in that we obtained a continuous sequence of Pliocene-Pleistocene sediments that contain a striking record of sapropel deposition in the Tyrrhenian Sea. Within this sequence, substantial volcaniclastic deposits have been found. Further studies, which will combine biostratigraphy, tephrochronology, geochemistry, and isotope stratigraphy at Site 974, will focus on developing a latest Cenozoic-to-Holocene paleoceanographic model at this site. This will allow us to constrain the timing and origin of sapropels in the Tyrrhenian Sea, and to compare the pattern of sapropel occurrence in the western Mediterranean with that in the eastern Mediterranean.

Site 975

Site 975 is located on the South Balearic Margin between the Balearic Promontory (Menorca and Mallorca islands) and the South Balearic-Algerian Basin. The site was drilled at the edge of a small basin perched on the east-dipping slope of the Menorca Rise, at a water depth of 2415 m (Fig. 9). Upon approaching the site location, navigation, bathymetric, seismic reflection, and 3.5-kHz data were collected to verify the position of the drill site.

The primary objective at Site 975 was to continuously core the Pliocene-Pleistocene sedimentary sequence on the Menorca continental rise to obtain a complete stratigraphic section that would allow us to document the history of surface- and deep-water variations in the western Mediterranean. Site 975 is located in a key position to monitor the history of eastbound inflowing Atlantic waters, and of westbound outflowing Mediterranean waters. The site, which is a central tiepoint along the trans-Mediterranean paleoceanographic drilling transect, will allow us to correlate environmental conditions in the eastern Mediterranean and western Mediterranean.

Triple APC and double XCB coring was chosen to ensure continuous sediment recovery at Site 975. The two deepest holes recovered 317.1 m (Hole 975B) and 313.7 m (Hole 975C).

The stratigraphic sequence at Site 975 ranges from uppermost Pleistocene/Holocene (Subzone NN21b) to uppermost Miocene (Zone NN12). The sediments contain abundant and well-preserved Pleistocene to lower Pliocene foraminiferal assemblages. Upper Miocene samples (*G. conomiozea* Zone) contain poor to moderately well-preserved foraminifers. The biostratigraphic data indicate that sedimentation rates at Hole 975B were 70.5 m/m.y for the Pleistocene/Holocene, 48.9 m/m.y. for the upper Pliocene, and 53.8 m/m.y. for the lower Pliocene.

Sediments at Site 975 have been divided into three lithostratigraphic units, based on downhole changes in lithology and sedimentary facies.

> Unit I (Hole 975A, 0.0-9.5 mbsf; Hole 975B, 0.0-305.2 mbsf; Hole 975C 0.0-306.3 mbsf; Hole 975D, 0.0-0.149.9 mbsf) consists of Pliocene-to-Pleistocene nannofossil or calcareous clay, nannofossil or calcareous silty clay, and nannofossil ooze. The carbonate content of these sediments varies between 30% and 70% (average 47%) and increases slightly with depth. Nannofossils are the major component of the carbonate fraction; locally, foraminifers and micrite may each constitute up to 30% of carbonate sediments. The terrigenous sediment fraction includes clay minerals, quartz, and minor amounts of feldspar and accessory minerals. Color banding and bioturbation are common throughout Unit I, but are especially prominent below 150 mbsf. Graded and/or laminated foraminiferal-rich sandy or silty layers were found throughout the unit.

In Unit I, we encountered 38 sapropels of Pleistocene-to-Pliocene age, containing up to 2.8% TOC. These sapropel layers are well correlated between all holes at Site 975. Organic C/N ratios of the sapropels average 12.7, implying that the sapropels likely contain algal material that has been partially degraded during sinking to the seafloor. Rock-Eval analyses of sapropels suggest that their organic matter consists of a mixture of partially oxidized Type II algal material and Type III land-plant material.

Unit II (Hole 975B, 305.2-307.0 mbsf; Hole 975C, 306.3-306.9 mbsf) consists of Pliocene/Miocene(?) light-colored, carbonate-rich sediments. The major lithologies are finely interlaminated to thinly interbedded gray micrite and greenish-gray, micritic, silty clay. Rare thin beds of graded, calcareous, silty sand contain abundant foraminifers and bioclasts. Mineral assemblages encountered in these silty sands include quartz, feldspar, micritic calcite, clay minerals, and minor amounts of dolomite, glauconite, chlorite, celestite, and gypsum. Sedimentary structures and composition strongly suggest an intertidal origin for sediments of Unit II.

Unit III (Hole 975B, 307.0-317.1 mbsf; Hole 975C, 310.7-313.7 mbsf) is composed of 4.4 m and 1.6 m of an upper Miocene evaporite sequence at Holes 975B and 975C, respectively. The major lithology is light, olive-gray to moderate olive-brown gypsum, which occurs as nodular, finely laminated, and coarse crystals in a micrite matrix. Thin (1-2 cm) intervals of grayish-green clay to micrite-rich clay are present as a minor lithology. The evaporites of Unit III are composed of two broad cycles, which begin with a clay or micrite-rich clay interval, overlain by thinly bedded, gypsiferous chalk.

The sediments of Unit I are interpreted to have been deposited in an open-marine environment. The gradual decrease in carbonate content toward the sediment surface may reflect a shift from dominantly hemipelagic to pelagic conditions from the Pliocene to the Pleistocene. The finely laminated beds in the lower intervals of Unit I may reflect periodic fluctuations of terrigenous input. The boundary between Units I and II likely marks the change from a shallow, intertidal environment during the latest Miocene(?) to open-marine conditions during the Pliocene.
The wavy laminations of the micritic intervals in Unit II are indicative of algal or microbial mat layering. Calcareous, silty, sand intervals at the base of Unit II may have formed in a beach or channel environment. The evaporite sequence in Unit III is consistent with deposition in a supratidal environment. Unit III can be correlated with the top of the Messinian evaporite sequences (just below the M reflector) that are known elsewhere in the Mediterranean.

Meter-scale slump folds occur at 114.5 and 143 mbsf in Hole 975B. Slumping may have been related to the very gentle east-northeast dip of the entire Neogene and Pleistocene sequence, which is visible in seismic profiles at the site. Steeply dipping, conjugate fractures in laminated, micritic, silty clay and micrite at 305.6 mbsf in Hole 975B appear to have been affected by pressure solution, producing stylolites; vertical stylolites are visible at exactly the same level in Hole 975C. Brittle boudins occur in a sand layer within micrite at 306.4 mbsf. Neither of these features is likely to have any regional tectonic significance. The lack of tectonic deformation and the paucity of slump structures suggest that Site 975 was tectonically inactive during Pliocene- Pleistocene times.

A strong magnetic overprinting made it difficult to determine the primary magnetization at Site 975. The magnetic overprint is characterized by high intensities of natural remanent magnetizations, high coercivity, strong positive inclinations close to the present field (60°), and a PRR. Intervals of shallow and negative inclinations are tentatively correlated among the four holes. A very short interval of negative inclination is found at ~10 mbsf. Negative inclinations are recorded between 25 and 45 mbsf for Holes 975B, 975C, and 975D. A third interval of negative inclination occurs between 50 and 100 mbsf in Holes 975B and 975C, and between 50 to 80 mbsf in Hole 975D. The third interval of negative inclination may be the Brunhes/Matuyama boundary, which, according to the sedimentation rates as defined by biostratigraphic datums, should be at ~60 mbsf.

P-wave velocity increases with depth from 1.5 km s^{-1} at the surface to 4.8 km s^{-1} at 310 mbsf in the evaporitic sequence.

Individual cores were correlated between the four holes using magnetic susceptibility, GRAPE, and 550-nm spectrophotometer data. Excellent results were achieved from the seafloor to approximately 150 mbsf, the limit of APC coring. Above 150 mbsf, a continuous record is readily identifiable using intervals in Holes 975A, 975B, 975C, and 975D. Independently correlated sapropel layers on the depth-shifted core data yielded composite depths of the layers that were generally within 20 cm of each other.

Downhole temperature data measured at five depths in Hole 975C, combined with thermal conductivity data, indicate a heat flow of 81 mW m^{-2}.

Interstitial water profiles at Site 975 are strongly influenced by the presence of the evaporitic sequence at the base of Site 975. Interstitial calcium and sulfate profiles both exhibit a gentle decrease between the sediment/water interface and 46.55 mbsf, and then increase to near linear gradients toward the base of the hole. Dissolution of gypsum in the Messinian evaporites provides the deep source for the calcium and sulfate and explains why sulfate depletion does not occur at this site, even though bacterial sulfate reduction is the main diagenetic process. Calcium, and particularly strontium, may also originate from interactions of the Messinian brines with biogenic carbonates. The high, interstitial-lithium concentrations suggest the presence of late-stage brines in the evaporites, and the decrease in potassium with depth indicates an absence of potassium-bearing salts. The interstitial-water sulfate gradient suggests that organic-matter degradation below 5.55 mbsf occurs mainly by sulfate reduction. Between the sediment/water interface and 5.55 mbsf, organic-matter degradation is occurring by aerobic degradation and manganese reduction, as evidenced by the manganese-mobilization peak at 5.55 mbsf.

Samples containing at least 1% TOC were selected from Hole 975B for extraction and analysis of C_{37} alkenone biomarkers and for calculation of sea-surface paleotemperatures. Sea-surface paleotemperatures have fluctuated over a 7°C range in the Balearic Sea during the Pleistocene. A similar record of fluctuating paleotemperatures was established for the eastern Mediterranean during Leg 160. The paleotemperatures calculated for the Balearic Sea are consistently ~5°C cooler than those estimated at times of sapropel deposition in the eastern areas.

Hole 975C was logged between 42.0 and 309.0 mbsf, using the quad-combo, FMS, and GLT tool strings. The resistivity profile is homogeneous throughout the section, with values increasing from 0.7 Ωm at the top of the hole to 1.0 Ωm at the bottom of the hole. Caliper data from the quad-combo and the FMS show erratic variations in hole diameter from 150 mbsf downward, where drilling switched from APC to XCB coring.

Site 975 achieved three significant results. First, by multiple APC and XCB coring at offset holes, a continuous Pliocene-Pleistocene sedimentary sequence was retrieved, which will enable high-resolution documentation of paleoceanographic conditions in the western Mediterranean. Second, 38 sapropel layers were recovered at this site; Site 975 thus extends the geographic limit of documented sapropel occurrence farther west, from the Tyrrhenian Sea to the central western Mediterranean Basin. Discovery of sapropels at Site 975 warrants revision of the paleoceano-graphic concepts that relate the formation of sapropels to paleoceanographic changes in the eastern Mediterranean. Third, a well-preserved sequence of uppermost Messinian evaporites and early Pliocene hemipelagic-to-pelagic sediments was retrieved in two holes at Site 975. The high-quality XCB cores will enable a detailed study of the environmental transition from restricted Messinian conditions to open-marine conditions during the early Pliocene.

Site 976

Site 976, located in the western Mediterranean (Alboran Sea), 60 km off the southern Spanish coast and about 110 km east of the Strait of Gibraltar, is situated on the lower part of a gentle slope that dips to the south from the Spanish margin toward the western Alboran Basin. The site is located in a water depth of 1108 m and is 8 km northeast of DSDP Site 121.

Site 976 (Fig. 10) is the first of three Leg 161 sites that were planned to address tectonic objectives in the western Mediterranean Sea. It is the westernmost site of the trans-Mediterranean drilling transect, which was designed to refine paleoceanographic models for sapropel formation. The main tectonic question in the Alboran Basin deals with the long-standing problem of understanding convergent plate boundaries, i.e., the development of extensional basins in collisional settings. Paleoceanographic objectives at Site 976 focused on monitoring late Cenozoic Atlantic-Mediterranean water exchange with special emphasis on periods of sapropel deposition.

Five holes were drilled at Site 976. Except for Hole 976A, which was used to determine the mud line, these holes were dedicated to distinct scientific objectives. Hole 976B continuously cored the entire 650 m-thick sedimentary sequence and penetrated 267 m into metamorphic basement, thus meeting our highest priority tectonic objective. Hole 976C was dedicated to paleoceanographic objectives and cored down to the Pleistocene/Pliocene boundary at 375 mbsf. Hole 976D was dedicated to high-resolution, interstitial-water geochemistry and was cored to a depth of 30 mbsf. Hole 976E was designed to fill gaps in recovery around major unconformities within the sedimentary sequence and to sample and log the sediment-basement transition.

The stratigraphic interval cored and sampled at Site 976 ranges from uppermost middle Miocene (Zone NN7, *N. continuosa/G. Siakensis* Zone) to uppermost Pleistocene/Holocene (Subzone NN21b, *G. truncatulinoides excelsa* Zone). The Pliocene/Pleistocene boundary is between 357.92 and 361.01 mbsf. Three major hiatuses were recorded: between the late and early Pliocene (Zanclean and Piacenzian), between the early Pliocene and latest Miocene (Zanclean and Messinian), and within the late Miocene (Tortonian). Sedimentation rates were calculated as 205 m/m.y for the Pleistocene/ Holocene, 341 m/m.y. for the late Pliocene, 167 m/m.y. for the early Pliocene, and 33 m/m.y. for the late Miocene.

Sediments at Site 976 were subdivided into four lithostratigraphic units.

Unit I (Hole 976A, 0-5.9 mbsf; Hole 976B, 0.0-362.1 mbsf; Hole 976C, 0.0-362.8 mbsf; Hole 976D, 0.0-30.0 mbsf) contains a Holocene-Pleistocene, open-marine, hemipelagic facies of nannofossil-rich clay, nannofossil clay, and nannofossil silty clay. Continuous and discontinuous, clayey, silt laminae occur irregularly throughout the unit. Carbonate content averages 28%. The carbonate fraction consists of nannofossils, foraminifers, bioclasts, micrite, inorganic calcite, and dolomite. Laminated beds of diatomaceous ooze, up to 5 cm thick, can be correlated between holes. Downhole variations in detrital siliciclastic grains suggest that Unit I contains three major cycles of upward-increasing terrigenous input.

Twenty eight ORL’s occur in five discrete intervals within Unit I. These ORL’s, which consist mainly of nannofossil clay to nannofossil-rich clay and generally contain 0.9 to 1.3% TOC (background is 0.5% TOC), are identified by low magnetic susceptibilities and subtle color changes. The ORL’s range in thickness from <20 cm to >2 m. Examination of the smear slides reveals an amorphous organic component, as well as terrigenous plant fragments and spores.

Unit II (Hole 976B, 362.1-518.3 mbsf; Hole 976C, 362.8-379.7 mbsf) consists of Pliocene sand, silt, calcareous silty clay, and nannofossil clay. Core recovery was low (12%), probably because poorly consolidated sand intervals were washed during drilling. Average carbonate content is 33%. Where recovered, the sand consists mainly of quartz and shell fragments, with minor components of rock fragments (including schist and serpentinite), feldspar, micas, heavy minerals, plant fragments, and traces of glauconite.

Unit III (Hole 976B, 518.3-660.2 mbsf; Hole 976E, 543.8-652.0 mbsf) is Miocene/Pliocene in age and consists of grayish-olive, nannofossil and nannofossil-rich clay and claystone. Hiatuses/unconformities occur between the early and late Pliocene, at the Miocene/Pliocene boundary, and within the Tortonian. The average carbonate content is 37%. Bioturbation is extensive, and *Chondrites* and *Zoophycos* ichnofacies are found throughout the unit. Laminations are present in a few intervals and, in places, are delineated by aligned organic matter. At Hole 976 E, immediately above Unit IV, the clays of Unit III exhibit a well-defined fissility (shale).

Unit IV (Hole 976B, 660.2-669.73 mbsf; Hole 976E, 651.95-652.08 mbsf) immediately overlies basement in both holes. In Hole 976B, Unit IV consists of coarse-grained, poorly sorted, coarse pebbly sand. The pebbly sand, which is Serravallian in age, is of marine facies and composed of quartz, biotite, feldspar, and rock and shell fragments. Rounded, gravel-sized, metamorphic clasts are present as minor components throughout the sandy interval. In Hole 976E, Unit IV is composed of a 15 cm-thick interval of glauconite-rich, sandy-silty claystone, also Serravallian in age.

Beneath the sedimentary sequence, we cored 259 m (669.7-928.7 mbsf) and 50.53 m (652.08-702.5 mbsf) of high-grade metamorphic rocks in Holes 976B and 976E, respectively. The contact between basement and the middle Miocene sediments is sharp and has an irregular topography, possibly produced by faulting. Faulting of the basement is indicated by breccia throughout the basement in Holes 976B and 976E. In the upper 40 m of basement, some fault breccias are formed by highly angular metamorphic clasts in a matrix with a Miocene sedimentary component.

The high-grade metamorphic basement rocks of the Alboran Basin at Site 976 are formed of the following lithotypes.

(1) High-grade schist: dark-gray graphitic schist with biotite, sillimanite aggregates, with andalusite and garnet porphyroblasts in some places.

(2) Gneiss: medium-gray felsic gneiss, commonly with biotite, feldspar, plagioclase, sillimanite, andalusite porphyroblasts up to 1 cm, inky blue or blue-green cordierite porphyroblasts up to 1 cm, and locally some muscovite. In places, the gneiss grades, with increasing biotite content, into high-grade schist, and with increasing felsic component, into migmatitic gneiss.

(3) Migmatitic gneiss: medium-gray, felsic biotite-cordierite-sillimanite-andalusite gneiss with irregular veins and patches of light-gray, weakly foliated or unfoliated granite, with biotite and tourmaline. The granitic material forms veins parallel to, or cutting across, the foliation. Associated coarse-grained quartz veins with tourmaline are abundant. In places, the granitic material contains cordierite.

(4) Marble: very pale green, gray, or white crystalline dolomite marble and calcite marble with minor amounts of phlogopite and chlorite. The calcite marble near the top of the basement in Hole 976E is interlayered, on a small scale, with calc-silicate rock and biotite-sillimanite schist.

(5) Calc-silicate rock: banded rocks with thin layers of calcite or dolomite, garnet, plagioclase, green calc-silicate minerals, including diopside and calcic amphibole, and serpentine(?) after forsterite(?). These minerals commonly occur as reaction zones between marble and schist.

(6) Granite: discrete pieces of light gray-to-white, fine-grained, hypidiomorphic, granular leucogranite occurs throughout the sequence, probably in the form of dikes. The granite has small amounts of biotite and tourmaline.

With the exception of the leucogranite dikes and the granitic leucosomes, all basement rock types show a well-developed foliation. These rocks also show evidence of penetrative ductile deformation, which produced a suite of small-scale structures and fabrics, followed by extensive brittle fracturing. At least three sets of ductile fabrics and structures can be systematically distinguished. The metamorphic sequence is also cut by numerous zones of fault breccia and fault gouge, which mark zones of brittle faulting. Marble occurs as layers dispersed throughout the sequence, and the dolomitic marble, in particular, is commonly associated with zones of brecciation and faulting. At the bottom of Hole 976B, samples include a large amount of well-cemented fault breccia. Some left-lateral oblique slip along discrete faults is suggested by striae on the subvertical fault planes that cross-cut the basement rocks.

First estimates of P-T conditions of metamorphism, based on data published by Spear (1993, and references therein), suggest that the high-grade schist underwent a significant decrease in pressure accompanied by constant, or possibly increasing, temperature. Migmatite gneiss and gneiss also indicate a late superimposed high-T metamorphism under low-P conditions associated with granite formation. The metamorphic history of basement rocks at Site 976 is most easily explained by tectonic exhumation of middle crustal rocks accompanied by substantial heating (Fig. 11).

The basement rocks recovered from Holes 976B and 976E closely resemble high-grade metamorphic rocks belonging to the Alpujarride Complex of the western Betic Cordillera (Spain), which have early Miocene radiometric ages, particularly those neighboring the Ronda peridotite massif. In that region, the high-T/low-P metamorphism is dated at 18-22 Ma (Zeck et al., 1992; Monié et al., 1994), i.e., early Miocene.

Site 976 sediments average 0.5% TOC with maximum values up to 1.6%. C/N ratios of samples containing a minimum of 1% TOC average 15.5 and indicate that the organic carbon-rich sediments contain a mixture of partially degraded algal material and continental organic matter. T_{Max} values are relatively low, showing that organic matter is thermally immature with respect to petroleum generation. Concentrations of headspace methane are high at Site 976 and are probably derived from in-situ microbial fermentation of the marine organic matter. Gas levels never became hazardous at Site 976.

Interstitial-water concentrations of salinity, chlorinity, sodium, and bromine increase downcore to approximately 2-3 times seawater concentrations. Calcium, magnesium, strontium, and lithium also increase linearly with depth. These profiles suggest the presence of a deep-seated brine, which is preliminarily interpreted to be either a Messinian-age paleo-fluid, or a brine originating from dissolution of salts in a deeper part of the basin. The circulation of this brine may be driven by compaction or by hydrothermal influx along the basement/sediment contact.

High-resolution (1.5 m-interval), interstitial-water sampling of the upper 30 m at Hole 976 revealed a classical sequence of diagenetic redox reactions driving organic-carbon degradation. The Mn- and Fe-reduction zones are located within the upper 1.5 m of the core. Sulfate decreases linearly and is depleted at 19.95 mbsf, indicating that organic-matter degradation above this depth is primarily sustained by sulfate reduction. Below 20 m, headspace methane concentration increases rapidly, marking the onset of bacterially mediated methanogenesis, which is responsible for organic-matter degradation in the absence of interstitial-water sulfate.

Downhole temperature measurements with the ADARA and WSTP temperature tools indicate a heat flow of 102 mW m^{-2} at this site, which is in excellent agreement with other values measured nearby (Polyak et al., in press). Remanent magnetization of the sediments at Site 976 is weak and exhibits a stepwise decrease, by about one order of magnitude, down to 50-60 mbsf. Declinations are scattered and inclinations dominantly positive with only a few negative inclinations above 360 mbsf for Holes 976B and 976C. Between 675 and 710 mbsf at Hole 976B, negative inclinations suggest a reversed interval. A strong magnetic overprinting makes magnetostratigraphy difficult. Reliable MST velocity and GRAPE measurements could not be made at Site 976, owing to high gas concentrations in the sediments. Velocities in basement samples range from 3.3 to 6.5 km/s and have 20%-30% anisotropy.

One of the most exciting results of Site 976 is the discovery that basement beneath the Alboran Basin is formed by rocks of continental origin that have undergone high-temperature metamorphism during exhumation and isothermal decompression. We cored a >250 m-thick section of high-grade metamorphic basement and obtained a spectacular suite of basement logs (quad-combo, FMS, BHTV, and GLT). Tectonic models that propose an early-to-middle Miocene continental extensional origin for the Alboran Basin postulated the existence of such metamorphic rocks at depth. Drilling results from Site 976 will significantly contribute to our understanding of the tectonic evolution of the Alboran Sea, as well as other backarc basins in the Mediterranean Sea. Integration of tectonic and paleoceanographic results from Site 976 will help to establish links between the paleogeographic history of the Atlantic-Mediterranean gateway and the evolution of Atlantic-Mediterranean water exchange since the Miocene.

Site 977

Site 977 is located south of Cabo de Gata in the eastern Alboran Basin, halfway between the Spanish and Algerian coasts, at a water depth of 1984 m. The site is situated south of the Al-Mansour Seamount in a 36 km-wide graben, which is bounded by the Yusuf Ridge to the south and the Maimonides Ridge to the north (Fig. 12). Seismic records at Site 977 show a lower sequence of tilted and hummocky reflectors with several internal unconformities. This sequence, which likely represents the earliest syn-rift sediments that filled the graben, is overlain by uniform, mostly horizontally layered, Pliocene-Pleistocene sediments. Our main objective at Site 977 was to penetrate ~650 m to sample the unconformity between these two seismic units; this unconformity was suspected to represent the seismic M-reflector.

Paleoceanographic objectives included documentation of Atlantic-Mediterranean water exchange from the Miocene to the Pleistocene and of productivity patterns in the eastern Alboran Sea. Productivity fronts develop today along the path of Atlantic water inflow and have possibly changed their position and intensity during the past as the pattern of water circulation changed.

Site 977 penetrated 598.5 m of Miocene(?)/Pliocene-to-Holocene sediments. The Pliocene/ Pleistocene boundary is at 266.95 mbsf. The lowermost section of Site 977 not only contains Pliocene planktonic foraminifer marker species, but also contains uppermost Miocene nannofossil marker species; thus, the biostratigraphic data are not conclusive as to whether the Miocene/ Pliocene boundary was reached at this site. A hiatus occurred in the lower Pliocene (Zones NN13, MPL3-MPL2) between 490.59 and 490.63 mbsf. Benthic foraminifers make up <1%-2% of the total foraminiferal assemblage. The presence of frequently abraded, shelf taxa suggests contamination through rare, downslope sediment transport. Average sedimentation rates at Site 977 are 148 m/m.y for the Pleistocene-Holocene, 98 m/m.y. for the upper to uppermost lower Pliocene, and 91 m/m.y. for the lower Pliocene.

The sedimentary sequence recovered at Site 977 was subdivided into two lithostratigraphic units, based on downhole changes in sedimentary structure and grain size.

Unit I (0-532.9 mbsf) contains Pliocene-Pleistocene sediments of an open-marine, hemipelagic facies. The sediments, which consist predominantly of nannofossil clay to nannofossil-rich, silty clay, are slightly to moderately bioturbated throughout the unit (*Chondrites*, *Planolites*, *Zoophycos*). Carbonate content ranges between 21% and 61%. The carbonate fraction consists of nannofossils (70%), micrite (19%), bioclasts (6%), and foraminifers (5%). Minor lithologies include diatom and nannofossil oozes and nannofossil-rich, diatomaceous, sandy, silty clay. Sand- and silt-rich layers are intercalated with the clay-rich sediments. Sharp basal contacts are common. Intervals of slumping are found throughout the unit.

Thirty-nine ORL's occur in Unit I, some of which resemble sapropels recovered at previous Sites 974 and 975. The ORL's are greenish in color and exhibit low magnetic susceptibilities. Organic carbon contents of the ORL's vary between 0.8% and 1.5%; carbon concentrations >2% were measured for some discrete ORL's (sapropels?). The appearance of ORL's at Site 977 is important, as it suggests that organic-rich sedimentation occurred basinwide in the western Mediterranean; organic carbon concentrations in some ORL's reach levels that are similar to those found in the eastern Mediterranean sapropels. Smear slide analysis shows that ORL's are enriched in opaque minerals and, locally, micrite. Fe-bearing, Mn-rich dolomite (kutnohorite, up to 30%) or siderite occurs at the top of many ORL's.

Unit I has been further subdivided into three subunits, based on changes in sedimentary structure.

> Subunit Ia (0.0-417.4 mbsf). Visible structure in Subunit Ia sediments is minimal. Five minor slump intervals occur in this subunit with two associated intraclastic breccias. The breccias show inverse to normal grading with angular to subrounded clasts ranging to pebble size. Color banding and mottling are developed in sediments above, and below, the slumped intervals.
>
> Subunit Ib (417.4-490.6 mbsf). This subunit contains parallel and cross-laminated to bedded clays with numerous slumps and intraclastic breccias. The subunit is Pliocene in age and represents an open-marine, hemipelagic facies. Zones of intense burrowing can be found throughout the unit, predominantly of *Zoophycos* and *Planolites*. Slumps

are recognized from folding of fine laminations. The base of this subunit is just below a hiatus, spanning at least lower Pliocene Zone NN13.

Subunit Ic (490.6-532.9 mbsf). This subunit contains few sedimentary structures; laminations are rare, and soft sediment deformation has not been recognized. Bioturbation (*Zoophycos*, *Chondrites*, *Planolites*) ranges from slight to intense.

Unit II (532.9-598.5 mbsf) is composed of partly cemented, sandy gravel, which is early Pliocene to Miocene(?) in age. Recovery was less than 1% with only 2 cm of granule-rich sand and 40 cm of gravel being recovered from a cored interval of 57.8 m. The gravel consists predominantly of volcanic clasts (rhyodacite and rare shoshonitic to calc-alkaline basalt/andesite) and few sedimentary clasts (dolomitic mudstone and quartz sandstone, cemented by quartz and chlorite). These clasts are coated by a calcareous cement, suggesting that the gravel has been derived from the partly cemented sandy gravel.

Log data at Site 977 were acquired using the quad-combo and FMS tools. From 140 to 323 mbsf, the borehole was out of caliper (washed out). The FMS was run below this interval and obtained excellent images in the lower part of the hole, including the transition zone between clays and sandy conglomerates. After post-cruise processing, the logs will provide information about the lithology and structure of the gravel/sand interval below 531 mbsf in which core recovery was extremely low.

Sediments at Site 977 average 0.5% TOC and may reach 2.5% in ORL's. Organic C/N ratios of 28 ORL's, containing a minimum of 1% TOC, average 10.1, which is a value intermediate between unaltered algal organic matter and fresh land-plant material. These organic carbon-rich sediments likely contain partially degraded algal material with some admixed continental organic matter. Rock-Eval and elemental-source characterization suggests that marine organic matter in ORL's has been heavily oxidized. Rock-Eval T_{Max} values indicate that organic matter in the upper section is thermally immature with respect to petroleum generation, whereas it is overmature in the deeper sediments; from this, we infer that heat flow at Site 977 was higher in the past.

Concentrations of headspace methane are high at Site 977. The source of the methane is probably in-situ microbial fermentation of marine organic matter. Concentrations of propane, iso-butane, and iso-pentane exceed those of ethane in sediments from about 200 to 450 mbsf. C_3, C_4, and C_5

gases were likely produced by thermal degradation of sedimentary organic matter during some former period of elevated heat flow at this site.

Interstitial-water profiles at Site 977 are dominated by organic-matter degradation and carbonate diagenesis. Rapid sediment-accumulation rates at this site ensured that organic matter was buried more rapidly than dissolved oxygen could diffuse from the overlying seawater. Calcium and magnesium decrease in a zone of increased alkalinity, suggesting that dolomite or high-magnesium calcite has precipitated from solution. Silica increases markedly in the upper few meters, then gradually decreases with depth, except for a peak at 103.45 mbsf, which likely comes from dissolution of a diatomaceous ooze at 117.50 mbsf. Pore-water salinity remains below seawater concentrations until 362.30 mbsf, then increases to 46 g/kg at 506.50 mbsf. Lithium concentrations increase from surface concentrations to 202 µM at 477.70 mbsf; this may reflect a lateral migration of evaporitic brines from another section of the basin.

Downhole temperature and shipboard thermal conductivity measurements give a heat flow of 102 mW m^{-2}. This value is comparable to the range of 97-112 mW m^{-2} in the region around Site 977.

Magnetic inclinations are mostly positive at Site 977. Some negative inclinations are recorded, but declinations remain constant in these sections compared to those with positive inclination, suggesting that a strong overprint obscures the magnetic signal at this site. Therefore, it was not possible to obtain a magnetostratigraphy at Site 977.

Changes in susceptibility in the upper 60 mbsf are possibly due to higher concentrations of terrigenous components. Thermal conductivity is between 1.0 and 1.5 W/m K. Bulk density, porosity, and void ratio increase rapidly with depth in the uppermost 50 mbsf and at a slower rate below 50 mbsf.

The post-Messinian stratigraphy established at Site 977 will provide time control on the seismic facies in the eastern Alboran Sea, yielding information on the timing of extensional structures identified in seismic data, and on the tectonic subsidence history of the basin. The seismic line acquired by *JOIDES Resolution* during the site approach shows that the Pleistocene deposits recovered at this site are faulted. The strong seismic reflector recognized in the area likely corresponds to the gravel-bearing interval that has been sampled to 598.5 mbsf. This seismic reflector correlates with the “M-reflector”, the top of Messinian evaporites at our previous Sites

974 and 975. Drilling results at Site 977 suggest that, in the eastern Alboran Basin, the M-reflector corresponds to a strong erosional event, possibly from flooding during the early Pliocene.

The recovery of ORL's at Site 977 is an intriguing discovery that documents intervals with organic carbon concentrations, which in some cases reach levels found in sapropels from the eastern Mediterranean, across the western Mediterranean Sea. Establishing the timing of these events and coeval environmental conditions at Site 977 in relation to those at previous Sites 974 and 975 in the Tyrrhenian and Balearic seas will yield information on physical and biogeochemical boundary conditions in the western Mediterranean during these periods.

Site 978

Site 978 is located in the eastern Alboran Basin, to the south of Cabo de Gata and 24 km north of Site 977. The site lies in a small, east-west-trending basin within the same 35 km-wide graben as Site 977, but north of the Al-Mansour Seamount (Fig. 12). Site 978 was selected because, like Site 977, seismic data showed a lower sequence that may represent the earliest syn-rift sediments that filled the eastern Alboran Basin. This tilted sequence is overlain by relatively uniform, mostly flat-layered sediments. Site 978 was drilled to complete objectives that were not achieved at Site 977. Our main interest was to penetrate below the same unconformity that was penetrated at Site 977, with the objective of sampling the underlying syn-rift sequence of the eastern Alboran Basin, and of determining the age and nature of these deposits, as well as the relative proportions of syn-rift and post-rift subsidence. In addition, Site 978 results will permit accurate seismic correlation between the Alboran Basin and the South Balearic Basin.

A continuous sequence of 485 m (from 213 to 698.0 mbsf) of upper Miocene (Zone NN11) to Pleistocene (Subzone NN19) sediments was recovered at Site 978. The Pliocene/Pleistocene boundary, as approximated by the first occurrence of *Gephyrocapsa oceanica,* is between 222.77 and 223.35 mbsf; the Miocene/Pliocene boundary occurs between 607.51 and 611.39 mbsf. All Miocene cores are assigned to Zone NN11 (Messinian or uppermost Tortonian). In the Pliocene interval, foraminifers are abundant and preservation is generally good. Miocene foraminifers are moderately to poorly preserved. Using foraminiferal and nannofossil ages and geomagnetic polarity events, sedimentation rates were calculated at 127 m/m.y. for the Pleistocene, 110 m/m.y for the late Pliocene, 122 m/m.y. for the early Pliocene, and 100 m/m.y. for the late Miocene.

The sedimentary sequence sampled at Site 978 was divided into three lithologic units.

Unit I (213.0-620.9 mbsf) consists of early Pleistocene-to-Pliocene, grayish-olive nannofossil clay to claystone, which is variably bioturbated. Foraminifers and shell fragments are dispersed throughout the unit. The carbonate fraction consists predominantly of nannofossils, micrite, bioclasts, and foraminifers. Terrigenous components include quartz, feldspar, mica, sedimentary and low-grade metamorphic rock fragments, and accessory minerals such as garnet and zircon. Minor amounts of organic debris (up to 5%) and diagenetic opaque minerals (up to 3%) are present.

Unit II (620.9-630.67 mbsf) consists of an upper Miocene, gravel-bearing interval, containing pebbles of volcanic and sedimentary rocks. The contact between Units I and II was not recovered. Some pebbles have smooth, rounded, weathered(?) surfaces and some are partly covered by a thin coating of microcrystalline calcareous material, zeolites, and smectite, possibly representing matrix or cement. The pebbles are formed of andesitic basalt to andesite, chert, limestone, quartzite, and metamorphic rocks.

Unit III (630.67-694.3 mbsf) consists of Miocene sandy and silty layers, which exhibit parallel and cross lamination and inverse to normal grading. Sparse bioturbation and in-situ brecciation and clastic dikes are observed throughout this unit.

Sediment bedding is mostly horizontal, and sporadic slump folding and small, syn-sedimentary faults occur. Slump folds are well preserved near the base of the Pliocene. Late Miocene sediments are significantly more consolidated than the overlying Pliocene sequence. Bedding in the Miocene section is also mostly horizontal, but some units are cut by numerous dilational fractures with irregular orientations. The fractures possibly represent hydraulic fractures formed by overpressured and underconsolidated zones within the sequence.

Carbonate content varies between 10% and >60% in the Pliocene sediments. Miocene sediments are distinctly lower in carbonate content. TOC averages 0.3% and reaches values up to 0.9% in some ORL’s. Organic C/N ratios are mostly between 4 and 8. From Rock-Eval analysis, it is inferred that the organic matter has been heavily oxidized, probably by microbial reworking.

Concentrations of headspace methane are high in sediments at Site 978. The source of the methane is probably in-situ microbial fermentation of marine organic matter. Concentrations of propane, iso-butane, and iso-pentane exceed, or equal, those of ethane in sediments from about 300 to

500 mbsf. These C_3, C_4, and C_5 gases were probably produced by thermal degradation of sedimentary organic matter.

Interstitial water salinity, chloride, sodium, and calcium increase downhole, with a steepening of the concentration gradients below 450 mbsf. Sulfate concentrations are close to zero to 450 mbsf and increase steeply below 500 mbsf. Because no halite salts are known at depth in this area, the high concentrations of these elements are likely due to trapped Messinian-age paleo-seawater or to lateral migration of saline fluids that are produced by dissolution from Messinian halite deposits that are present in the South Balearic Basin, about 30 km east of Site 978. The downhole lithium increase may also be partly related to evaporitic fluids. Alkalinity shows a maximum of 3.5 mM at 269.5 mbsf, which corresponds to the highest ammonia concentrations and indicates that organic-matter decomposition is most extensive at that depth. Magnesium concentrations are consistently below seawater concentrations, indicating precipitation of high-magnesium calcite or dolomite in the sediments. Strontium shows a maximum at 492.20 mbsf, likely indicating carbonate recrystallization.

At least 11 magnetic polarity zones were identified between 390 and 610 mbsf at Site 978. Correlation with biostratigraphic data suggests that these represent polarity subchron C2An.2n through subchron C3n.4n (3.22 to 4.98 Ma). A sharp increase in intensity occurs at 440 mbsf, about 50 m below the last well-defined polarity change. A similar increase in intensity was observed at 420 mbsf at Site 977, indicating good correlation between the two neighboring sites. Remanent directions, however, are substantially different between the sites, probably due to different coring techniques. RCB drilling at Site 978 resulted in the only reasonable magneto-stratigraphy obtained during Leg 161, as well as better preservation of sediment structures and less intense biscuiting than at Site 977, which was drilled using XCB.

The post-Messinian stratigraphy established at Site 978 supports our results and interpretations from Site 977, and an accurate correlation between the post-Messinian sequence at both sites is feasible. The uppermost Miocene, gravel-bearing interval, containing pebbles of volcanic rocks in Unit II and encountered at 620.9 mbsf at Site 978, can be seismically correlated with the gravel interval sampled at 598.5 mbsf at Site 977. This correlation confirms the correspondence between this gravel-bearing sedimentary interval and the M-reflector, and the fact that this reflector represents a strong erosional event in the eastern Alboran Basin, possibly from the early Pliocene flooding.

Drilling at Site 978 was successful in sampling the post-rift and the upper part of the syn-rift sequence of the eastern Alboran Basin and in determining that late, syn-rift sediments correspond to the upper Miocene (Tortonian). Post-cruise studies will help to clarify the paleodepth of deposition for this upper Miocene facies and will allow us to evaluate the rate of syn- to post-rift subsidence for the eastern Alboran Basin.

Site 979

Site 979 is located in the southern Alboran Basin, a narrow depression between Alboran Island and the Moroccan coast, about 45 km north of Cabo Tres Forcas, Morocco. The site is situated south of the northeast-southwest-trending Alboran Ridge. The ridge, which is >30 km wide and ~150 km long, rises ~1000 m above the surrounding basin floor and above sea level at Alboran Island. This site was located where seismic data indicated a zone of syn- and post-sedimentary deformation, including Pleistocene-Holocene deformation and tilting (Fig. 13). The deformation is expressed as a series of folds and faults that extend from the southern flank of the Alboran Ridge to the adjacent basin floor. Our main objectives were to determine the age and stratigraphy of the uppermost part of the basin fill and to constrain the age of the deformation, thought to represent later stages of contractive reorganization of the Alboran Basin.

Site 979 was drilled to a total depth of 580.9 mbsf, where drilling was terminated to allow time for logging operations before the end of the leg. After excellent recovery and core quality in the upper part of the section, APC coring was terminated at 134.5 mbsf. Recovery in the XCB-cored interval was high, but the cores were extensively biscuited. Unfortunately, the biscuiting destroyed a significant portion of the original sediment texture, severely limiting sedimentological and structural observations to short (<10 cm) pieces of cores. In addition, recovered cores were highly gassy, which also caused considerable disturbance.

The recovered stratigraphic interval ranges from upper Pliocene (Subzone NN16a, MPL5a) to uppermost Pleistocene/Holocene (NN21, *G. truncatulinoides excelsa* zone). The Pliocene/ Pleistocene boundary is approximated by the NN19B/NN19A Subzonal boundary (between 340.77 and 345.33 mbsf). Calcareous nannofossils and planktonic foraminifers are abundant and well preserved in most of the sequence. Zone MPL5a (upper Pliocene) is consistently present down to 569.78 mbsf, and Zone MPL4b was not reached. Benthic foraminifers suggest lower epibathyal (500-1300 m) to upper mesobathyal (1000-1800 m) depths for these sediments. Average sedimentation rates at Site 979 were calculated at 196 m/m.y. for the Pleistocene and

176 m/m.y. for the late Pliocene. A short hiatus within the upper Pliocene was recognized, below which the biostratigraphic age data suggest an increase in sedimentation rate to 696 m/m.y.

The sediments recovered at Site 979 were quite uniform. Only one lithological unit was recognized.

> Unit I (0-580.9 mbsf) is composed of Pleistocene-to-Pliocene, open-marine hemipelagic deposits with minor siliciclastic detrital layers. The dominant lithology is gray-to-green, nannofossil clay, which accounts for about 40% of the stratigraphic section. A typical composition of these hemipelagic facies is about 53% clay, 40% calcareous nannofossils, 6% micrite, 1% foraminifers, and trace amounts of detrital mica, opaque minerals, sponge spicules, and fecal pellets. Shell fragments and dispersed, silt-sized foraminifers are variably present. Disseminated grains, clusters, and rare nodules of pyrite are common throughout the unit, as well as trace amounts of glauconite. Bioturbation is common but varies in intensity throughout the entire sequence and includes *Chondrites*, *Planolites*, and *Zoophycos*. Minor lithologies include diatom-rich, silty-clay, ORL's, discrete sandy and silty layers, and intraformational breccia. Silty and sandy turbidites occur throughout the sequence. The unconformity identified by biostratigraphic data between 475.35 and 477.46 mbsf is marked by a weakly bioturbated to structureless nannofossil-rich clay with no obvious breaks in the sedimentary record.

The Pliocene-to-Pleistocene sediments recovered at Site 979 are for the most part horizontal, but there are local intervals of dipping beds that may have resulted from slump folding. Some intervals show a variably developed and variably oriented fissility oblique to the bedding and, in addition, they show fractures parallel to the core. The fissility appears to be an incipient disjunctive cleavage, and may be a response to deformation associated with the nearby Alboran Ridge.

The interstitial water profiles at Site 979 appear to be influenced by two main processes, early diagenesis of organic matter and the presence of a saline brine at depth. There are downhole linear increases in calcium, salinity, chlorine, sodium, and lithium which suggest a deep supply for these elements. Alkalinity peaks at 16 mM at 24.96 mbsf, and decreases to below seawater values toward total depth. Strontium concentrations increase from seawater concentrations at the top of the cored sequence to 3 mM at total depth, which is >30 times higher than seawater concentrations. Sulfate decreases from seawater concentrations to zero at 24.95 mbsf, which reflects bacterial degradation of organic matter through sulfate reduction.

Heat flow at Site 979 is 79 mW m^{-2}, which is significantly less than that reported at other sites in this area. Calculating heat flow using the shallowest measurement at 20.5 mbsf and its delta temperature (in situ minus mud line) of 2.04˚C, the result is 111 mW m^{-2}, close to the 118 ± 8 mW m^{-2} reported from nearby sites. This value suggests that there may have been a recent change in bottom-water temperature.

Concentrations of carbonate carbon vary up to 8.3% and are equivalent to 2% to 69% sedimentary $CaCO_3$. TOC fluctuates between 0% and 2.0%. Average TOC concentration is 0.7%, which is more than twice the deep-sea average of 0.3%. The elevated TOC concentrations of these sediments probably are a consequence of high sedimentation rates, which improve organic-matter preservation. Organic-matter C/N ratios reach as high as 20, but most are between 4 and 8, which is representative of algal organic matter. Rock-Eval analyses indicate that some marine organic matter has been oxidized, probably by microbial reworking.

Elevated amounts of headspace gas, including higher molecular-weight thermogenic gases, were encountered. High C_1/C_2 ratios indicate that the methane is biogenic in origin. Concentrations of propane exceed those of ethane in sediments below about 300 mbsf and exceed 100 ppm at the bottom of Hole 979A, suggesting that propane was produced by thermal degradation of sedimentary organic matter during some former period of elevated heat flow in the southern Alboran Basin.

Remanent magnetic directions seem to be extensively overprinted at Site 979. The overprint, which is almost antiparallel to the radial remagnetization observed at the other Leg 161 sites (Sites 974, 975, 976, and 978), points to an acquisition of anhysteretic remanent magnetization. Due to this overprinting, magnetostratigraphic polarity zones could not be identified at Site 979.

Physical property data indicate smooth variation in properties downhole. GRAPE data show several distinct changes in slope, which may be related to subtle changes in the sediments' strength. Velocity measurements were hampered by the gassy nature of the cores.

Quad-combo log data were acquired from 60.0 to 277 mbsf. The entire logged section appears to be rather homogeneous, as is reflected in the recovered cores. Between 157 and 168 mbsf, however, intervals with abrupt decreases in resistivity and acoustic velocity are found.

Site 979 results will allow us to constrain the age of the deformation in the southern Alboran Basin and around the Alboran Ridge. A comparison between seismic data and drilling results suggests that tectonic activity, including uplifting by folding and/or faulting of the Alboran Ridge, occurred from the late Pliocene to the Holocene. The high sedimentation rates suggest that active subsidence and sedimentation were coeval with the recent contractive reorganization of the Alboran Basin. No volcanic or volcaniclastic material was found at Site 979, indicating that the upper Pliocene-to-Pleistocene contractive reorganization was not accompanied by volcanic activity and implying that the volcanic Alboran Ridge was not active during these times. Although we terminated coring ~40 m before reaching a major angular unconformity visible on seismic profiles, extrapolation of our data indicates that the unconformity may correspond to the same erosional unconformity that was cored at Sites 977 and 978, and likely corresponds to the “M-reflector” in the southern Alboran Basin.

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FIGURES

Figure 1. Leg 161 drill sites in the western Mediterranean. SG: Strait of Gibraltar; AB: Alboran Basin; SB: South Balearic Basin.

Figure 2. The Alpine chains surrounding the Alboran Sea, general tectonic subdivision of crustal domains (from Balanyá and Garcia-Dueñas, 1987). Onshore distribution of these domains indicates that the continental basement beneath the Alboran Sea belongs to the Alboran Crustal Domain.

Figure 3. Bathymetric map of the Alboran Sea showing position of Leg 161 sites and DSDP Site 121. Contours in meters.

Map onshore. Stippled: Miocene marine sediments; Shaded: Alboran Crustal Domain (Metamorphic Complexes in Betics and Rif).

ACH: Alboran Channel; Al: Alboran Island in the Alboran Ridge; CHB: Chella Bank; EAB: Eastern Alboran Basin; SAB: South Alboran Basin; SBB: South Balearic Basin; WAB: West Alboran Basin; XB: Xauen Bank; YB: Yusuf Basin; YR: Yusuf Ridge.

Figure 4. Structural sketch of the Alboran Sea, based on interpretation of MCS profiles and the surrounding Betic and Rif chains (from Comas et al., 1992; Comas et al., 1993). Positions of Leg 161 drill sites and DSDP Site 121 within the structural setting are shown.

Figure 5a. Composite (“spliced”) section construction at multiple offset holes seeks to provide a complete, continuous, and undisturbed stratigraphic record, utilizing overlapping intervals of cores from the different holes. In this example, Site 974 high-resolution (2 cm) color reflectance data (550 nm) for four offset holes (Holes 974A, 974B, 974C, and 974D) is plotted against meters composite depth (mcd), with tie lines used to a construct composite depth section. Distinctive features were correlated between cores from each hole and depth-shifted to mcd to produce the single composite section. Shifts in core depths from mbsf to mcd were accomplished using color as well as magnetic susceptibility and GRAPE data.

Figure 5b. ODP Leg 161 drill sites and Pleistocene occurrences of sapropels and ORL’s in the western Mediterranean. Preliminary time scale is based on shipboard biostratigraphic data. In the Tyrrhenian and Balearic seas, sapropels are discrete layers up to 30 cm thick. In the Alboran Sea, ORL’s contain 0.8% to 2.5% organic carbon and are up to 3 m thick. These layers are more dispersed and thus do not resemble type sapropels. Yet, ODP Leg 161 drilling results suggest that organic-rich sedimentation occurred basinwide in the western Mediterranean.

Figure 6. Lithostratigraphic summary of Leg 161 drill sites in the western Mediterranean.

Figure 7. Summary sediment-accumulation-rate diagram for Leg 161 sites. Data were obtained from calcareous nannofossils and planktonic foraminifers. Water depths for each site are given in meters.

Figure 8. Close-up of seismic line ST01, showing the relative positions of Sites 652 and 974. Dipping reflectors at Site 974 are due to fault-block tilting of the sedimentary sequence.

Figure 9. Single-channel (80-in.^{3} air-gun source) seismic profile shot during site approach across the southern flank of the Menorca Rise over Site 975. The acoustic “M-reflector” was penetrated at a sub-bottom depth of 305 mbsf, and an evaporitic Messinian sequence (gypsum) was recovered.

Figure 10. Portion of *JOIDES Resolution* single-channel seismic profile across Site 976. Below a Pleistocene to middle Miocene sedimentary sequence, 258.97 m of metamorphic basement was recovered at this site, consisting primarily of high-grade schist and gneiss, and migmatitic gneiss, with lesser amounts of granite, marble, and calc-silicate rocks.

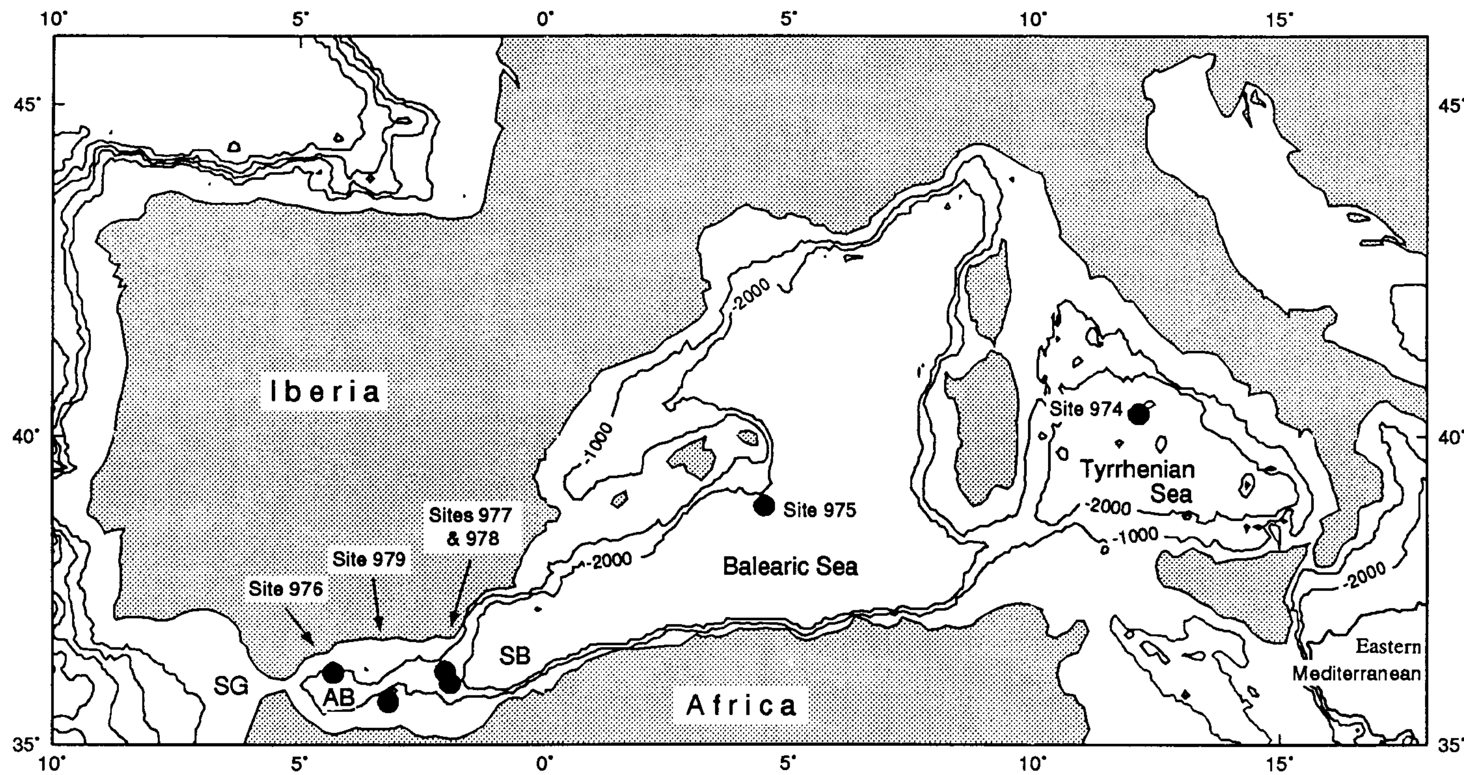
Figure 11. P-T diagram showing estimated conditions for the deformation in high-grade schist (light gray areas) and gneiss (dark gray areas). Uncertainties in boundary P-T conditions of the different deformations are shown by question marks. Approximate field of migmatite formation is also shown. P-T grid for pelites is in the KFMASH system, composed from Spear (1993) and references therein. Aluminum silicate triple point after Holdaway (1971). The minimum melting conditions for pelitic rocks and the H_2O contents (as X_{H2O} in melt) necessary to saturate the granitic liquid are from Le Breton and Thompson (1988). The garnet-plagioclase-rutile-ilmenite-quartz reaction is from Bohlen and Liotta (1986). The corundum-in and muscovite-out reactions are from Helgeson et al. (1978).

Mineral abbreviations: aluminosilicate (As); andalusite (And); biotite (Bt); chlorite (Chl); cordierite (Crd); corundum (Crn); garnet (Grt); ilmenite (Ilm); kyanite (Ky); muscovite (Ms); orthopyroxene (Opx); phlogopite (Phl); plagioclase (Pl); potassium feldspar (Kfs); quartz (Qtz); rutile (Rt); sillimanite (Sil); and staurolite (St).

Liquid (L) and vapor (V).

Figure 12. Location of Sites 977 and 978 on migrated multichannel seismic profile CONRAD 823. Al-Mansour Seamount divides the graben into two sub-basins in which Sites 977 and 978 were cored. The “M” Messinian reflector was penetrated at Site 978 and was just reached at Site 977. Submersible basement sampling of the northern flank of Al-Mansour Seamount recovered dacitic and rhyodacitic volcanic rocks.

Figure 13. Location of Site 979 on MCS profile RAY-36. Submersible basement sampling of the northern side of Alboran Ridge recovered rhyodacitic volcanic and volcaniclastic rocks.



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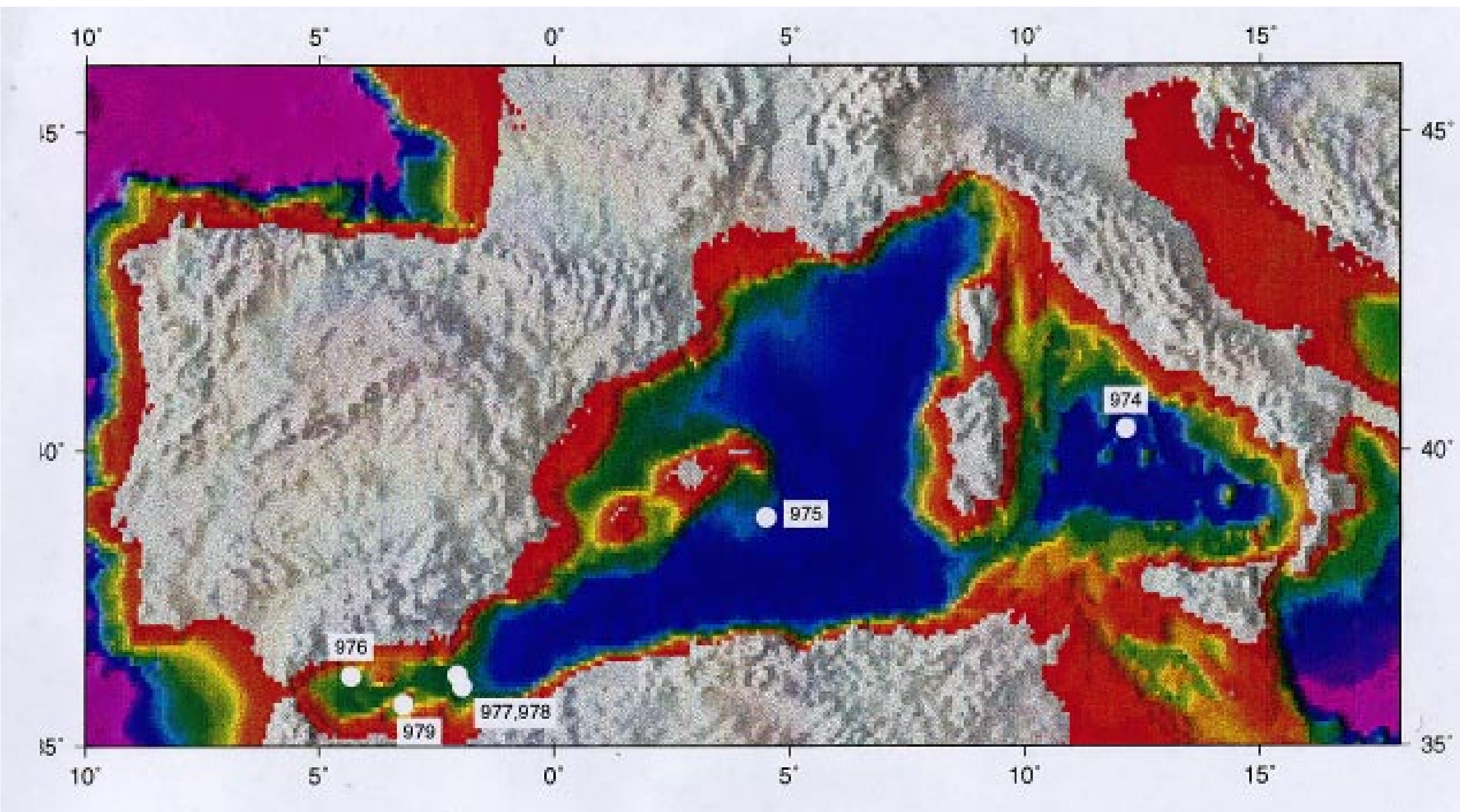
Site 979
Site 976
Balearic Sea
SG
AB
SB
Africa
Eastern Mediterranean

Figure 1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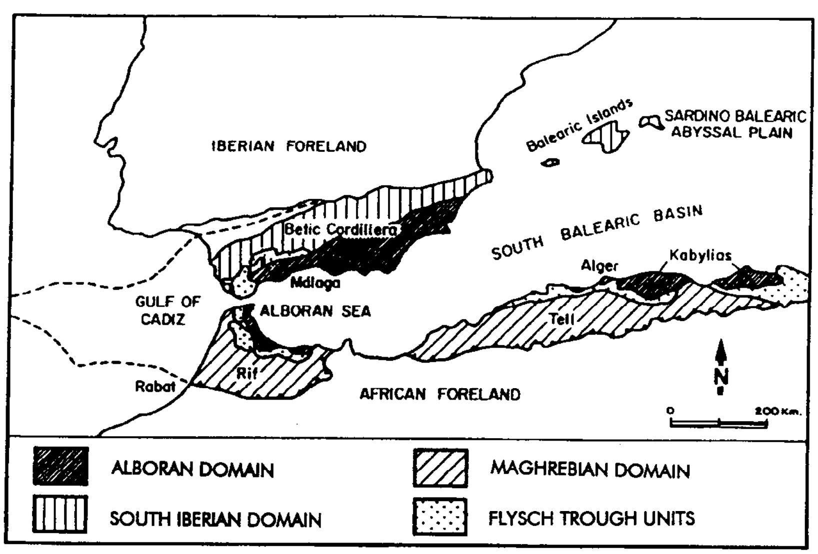
IBERIAN FORELAND
Balearic Islands
SARDINO BALEARIC ABYSSAL PLAIN
Betic Cordillera
SOUTH BALEARIC BASIN
Málaga
Alger
Kabylias
GULF OF CADIZ
ALBORAN SEA
Tell
Rif
Rabat
AFRICAN FORELAND
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ALBORAN DOMAIN
MAGHREBIAN DOMAIN
SOUTH IBERIAN DOMAIN
FLYSCH TROUGH UNITS

Figure 2

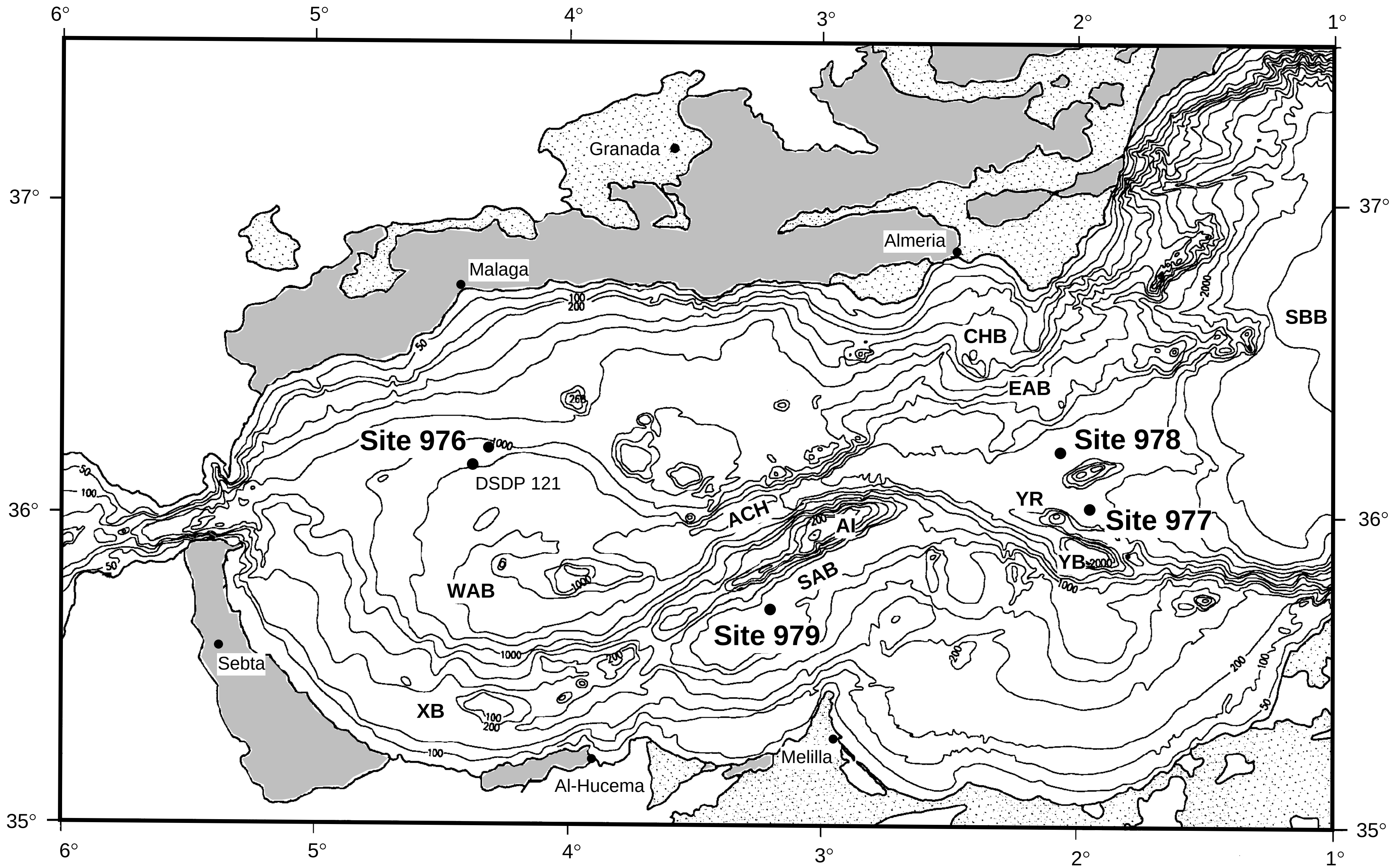


Fig. Prel. Rept-3

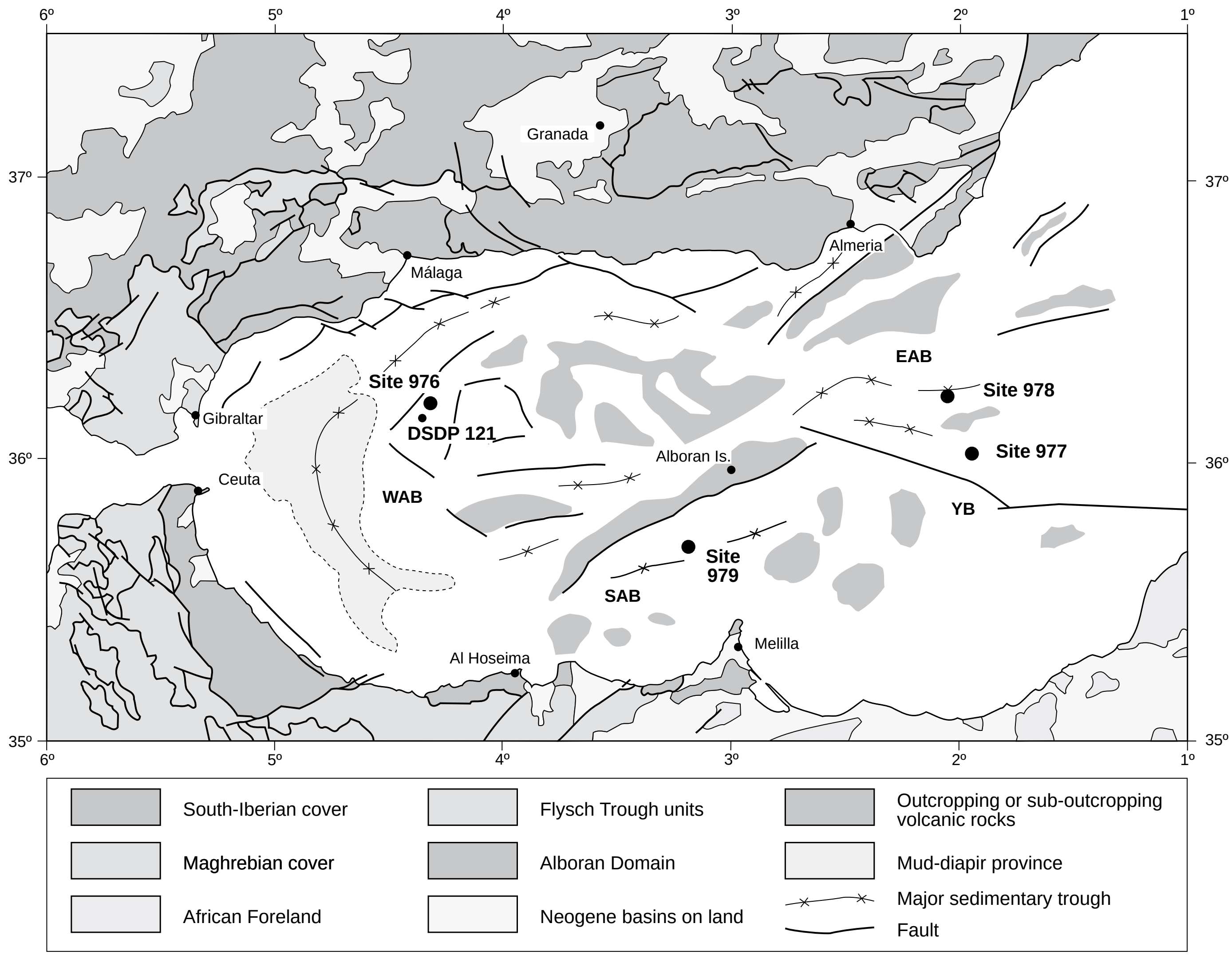


Fig. Prel. Rept- 4

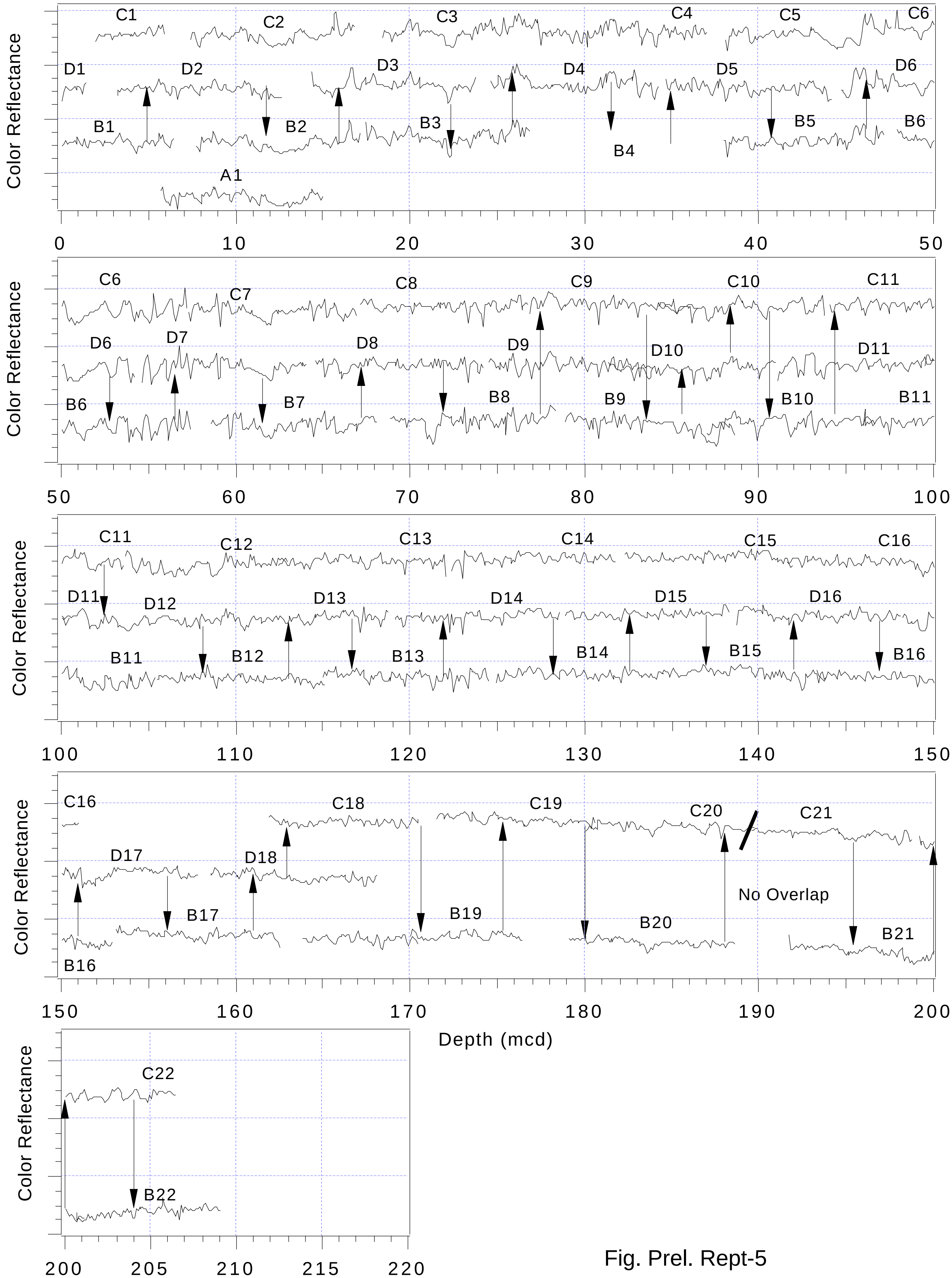
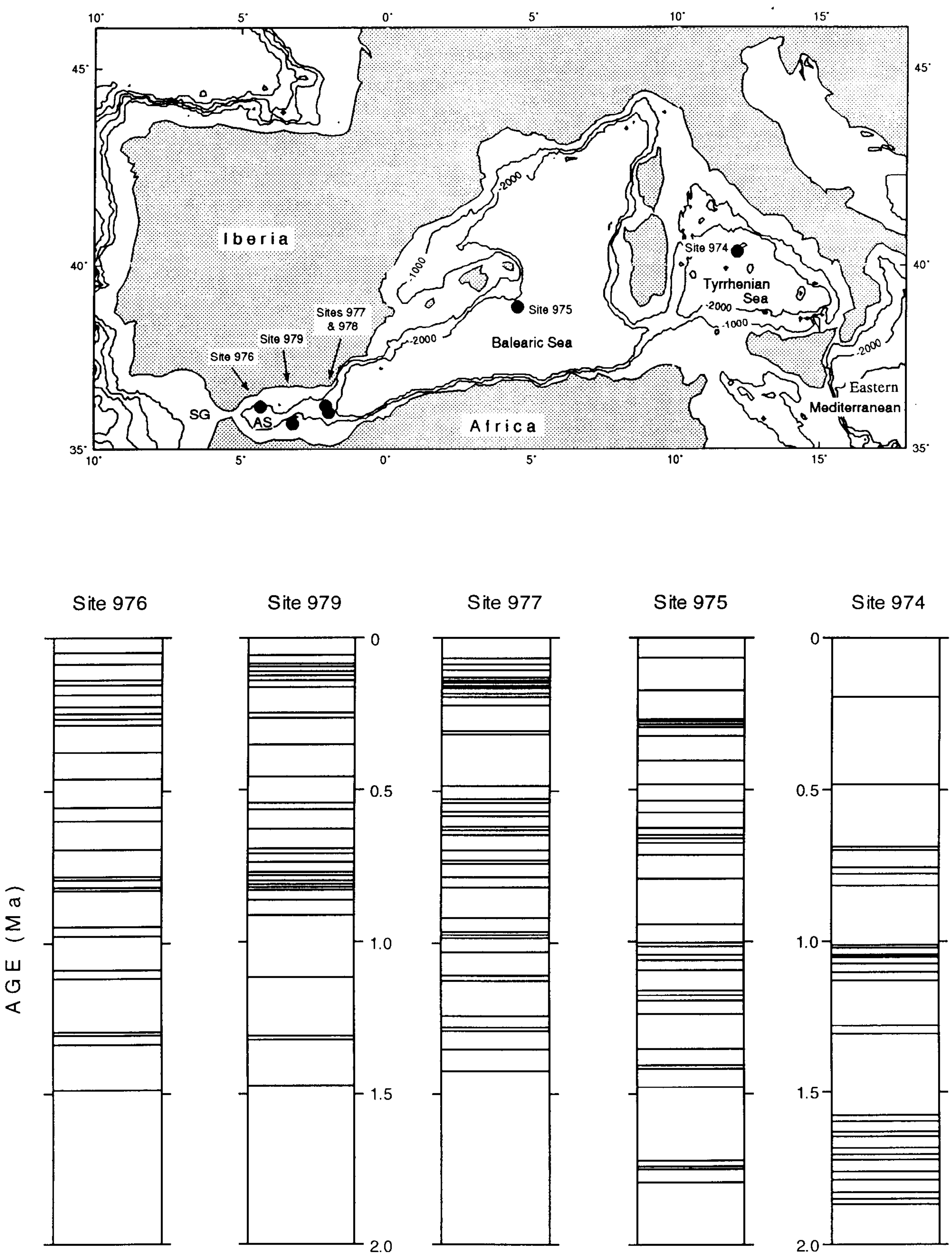


Fig. Prel. Rept-5



10°
5°
0°
5°
10°
15°
45°
40°
35°
Iberia
Africa
Balearic Sea
Tyrrhenian Sea
Eastern Mediterranean
Site 974
Site 975
Site 976
Site 979
Sites 977 & 978
SG
AS
-2000
-1000
Site 976
Site 979
Site 977
Site 975
Site 974
AGE (Ma)
0
0.5
1.0
1.5
2.0

Figure 5b

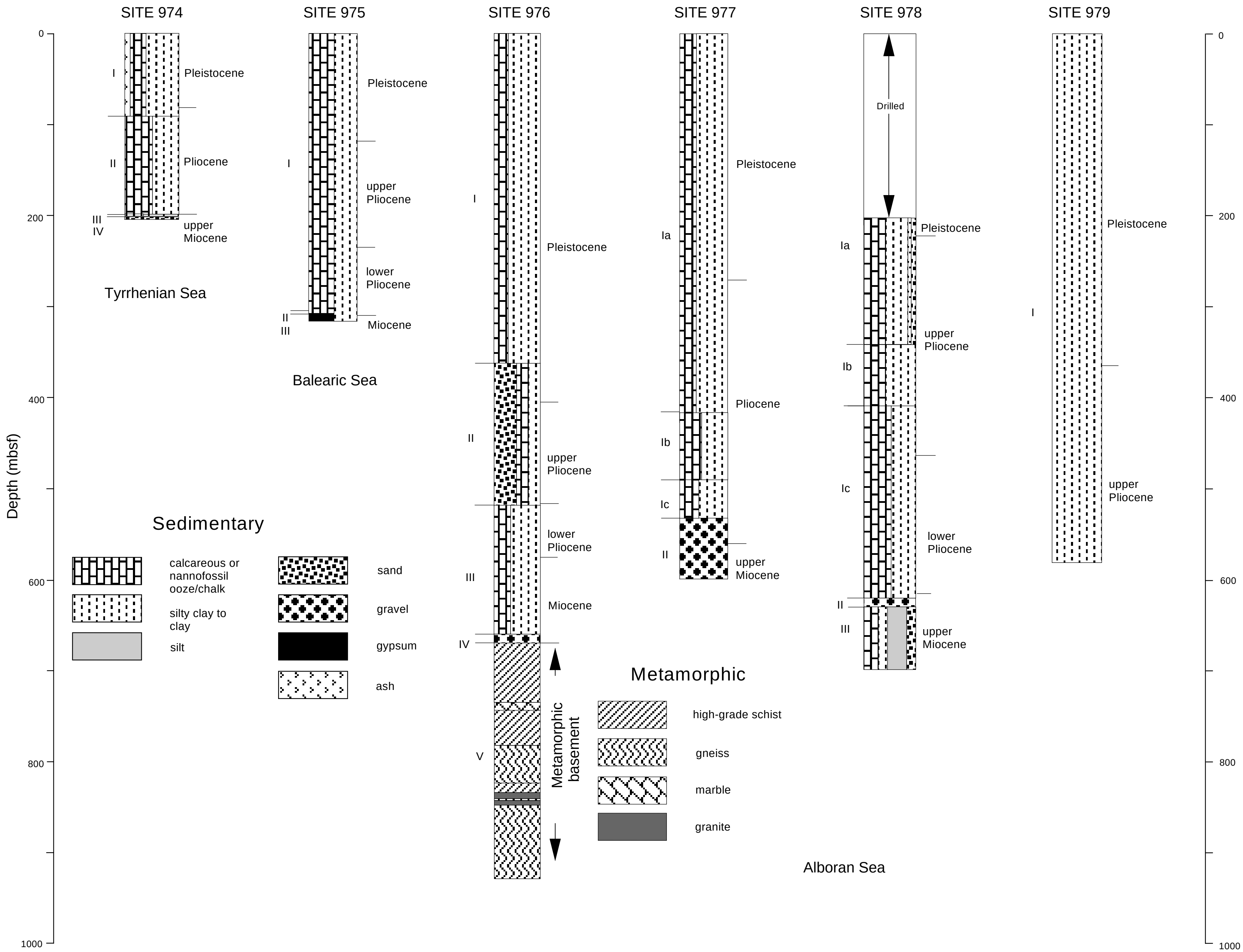


Figure Prel. Rept-6

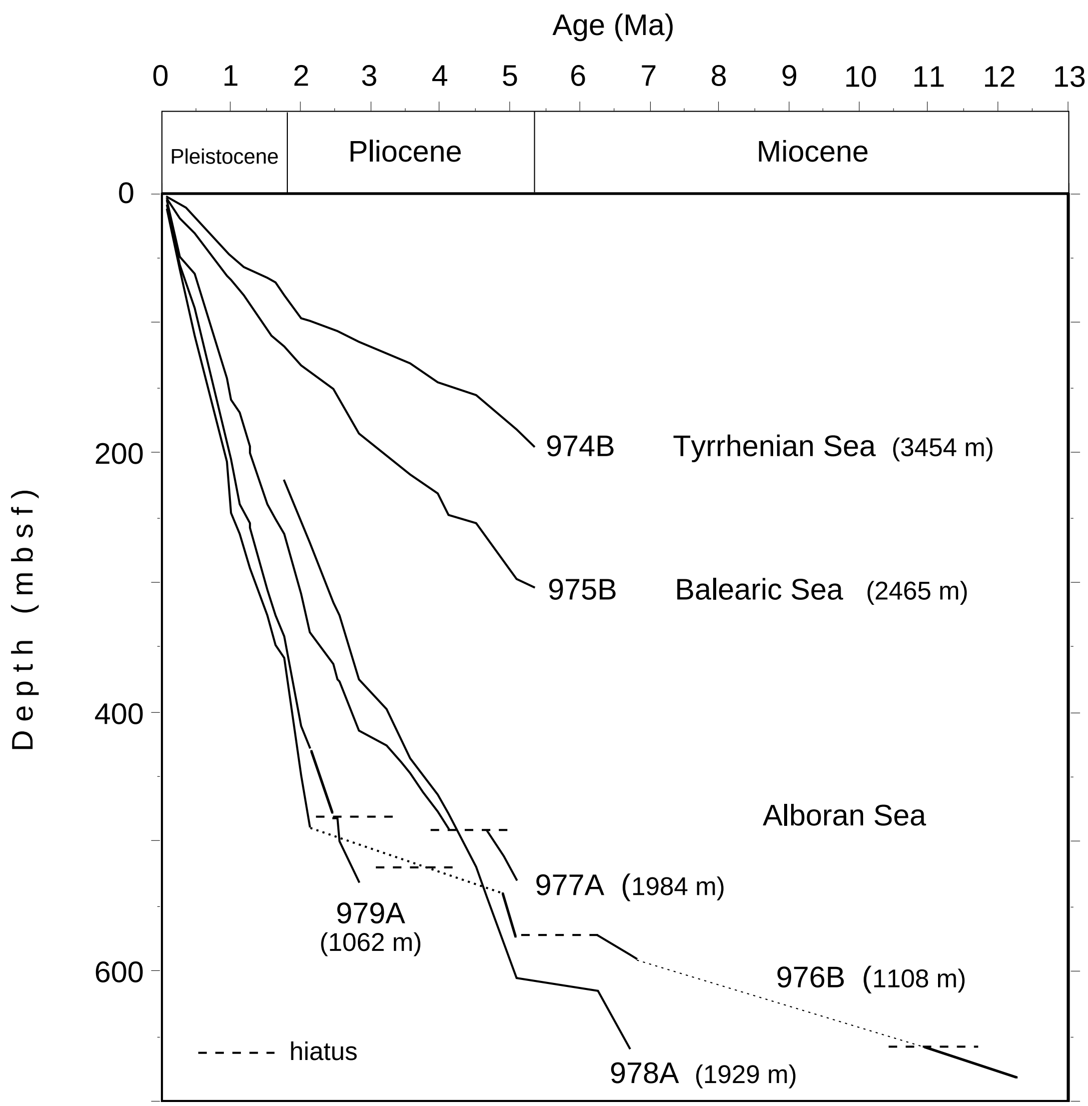


Figure Prel. Rept-7

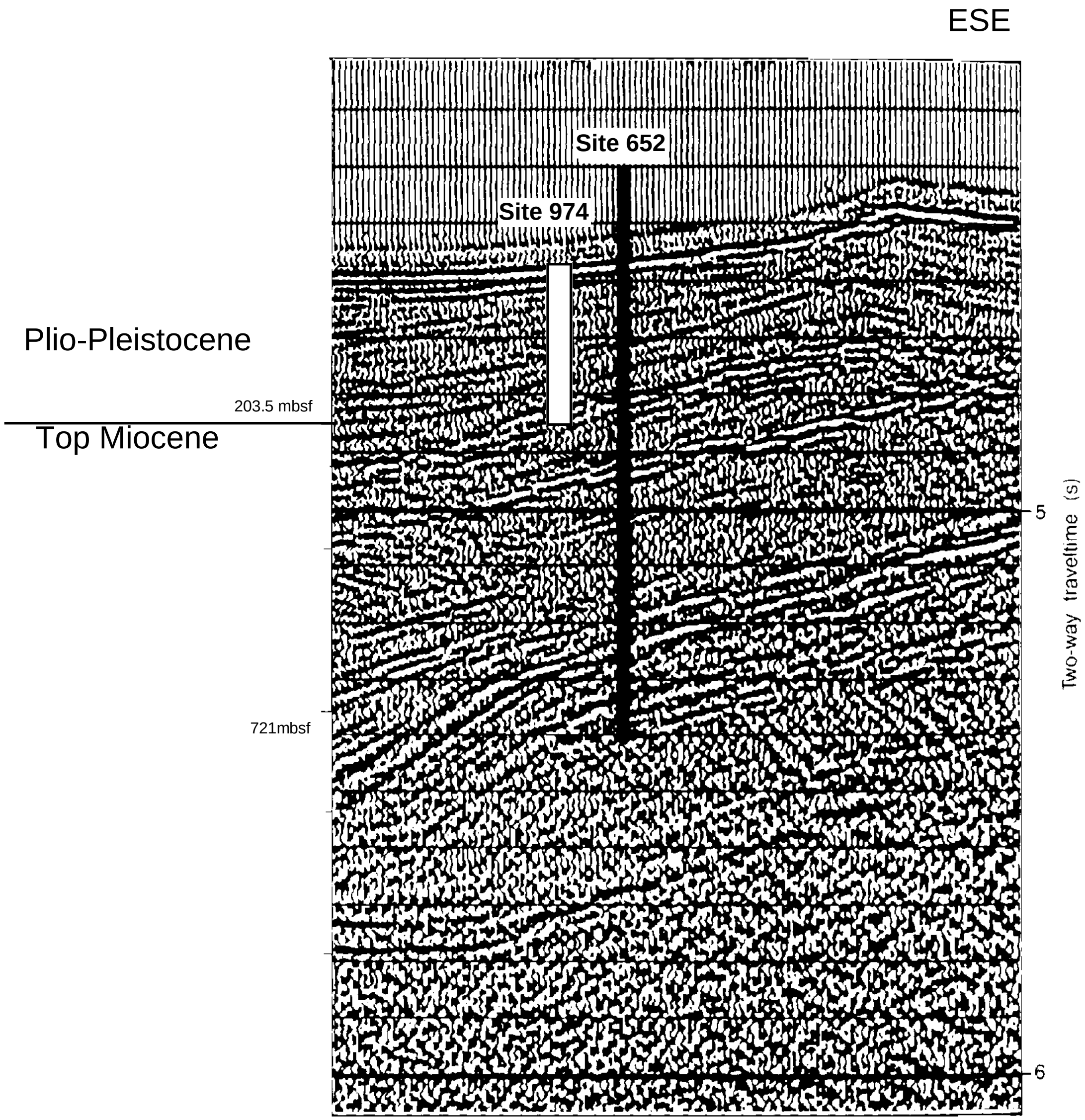


Fig. Prel. Rept-8

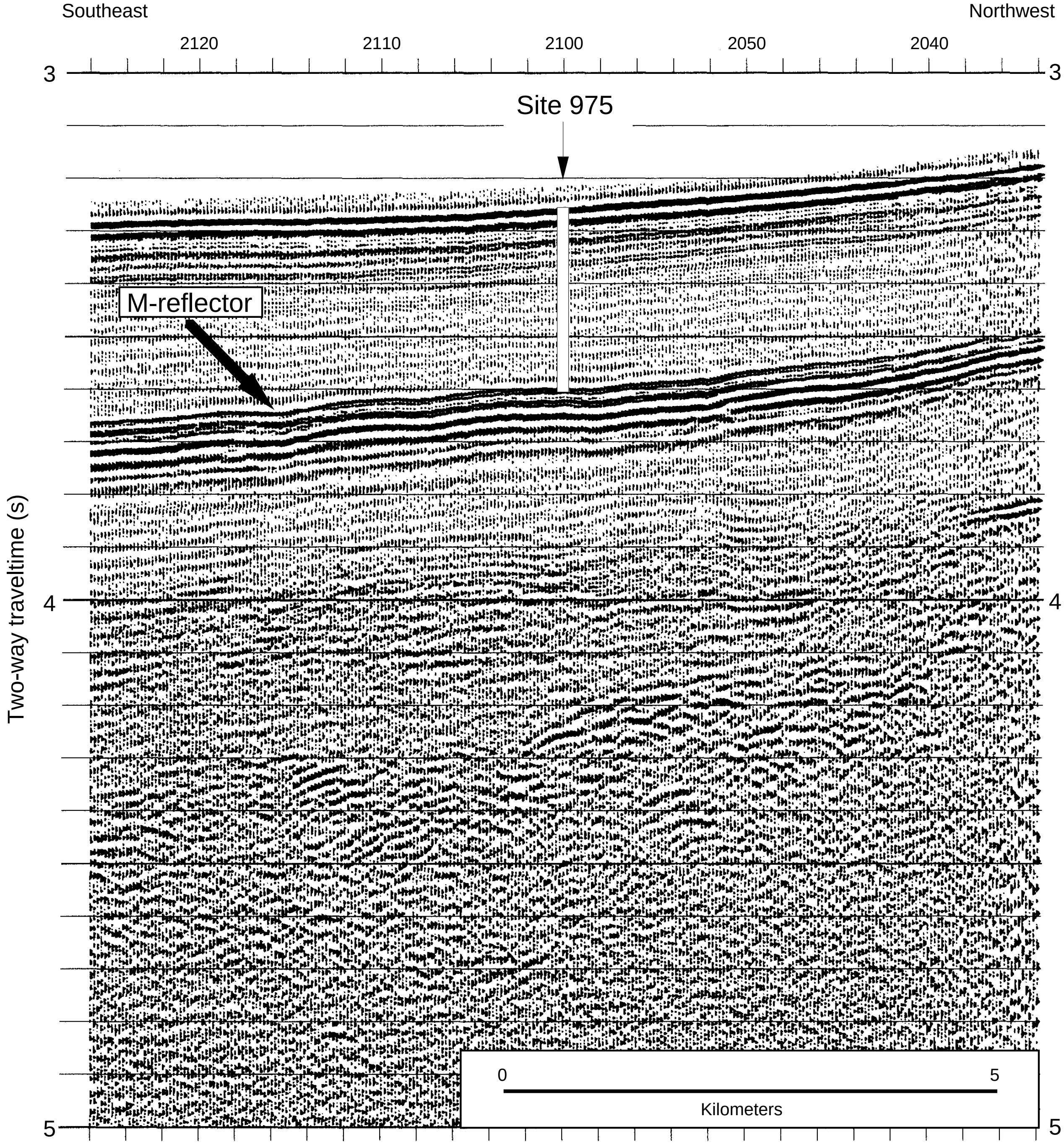


Fig. Prel. Rept-9

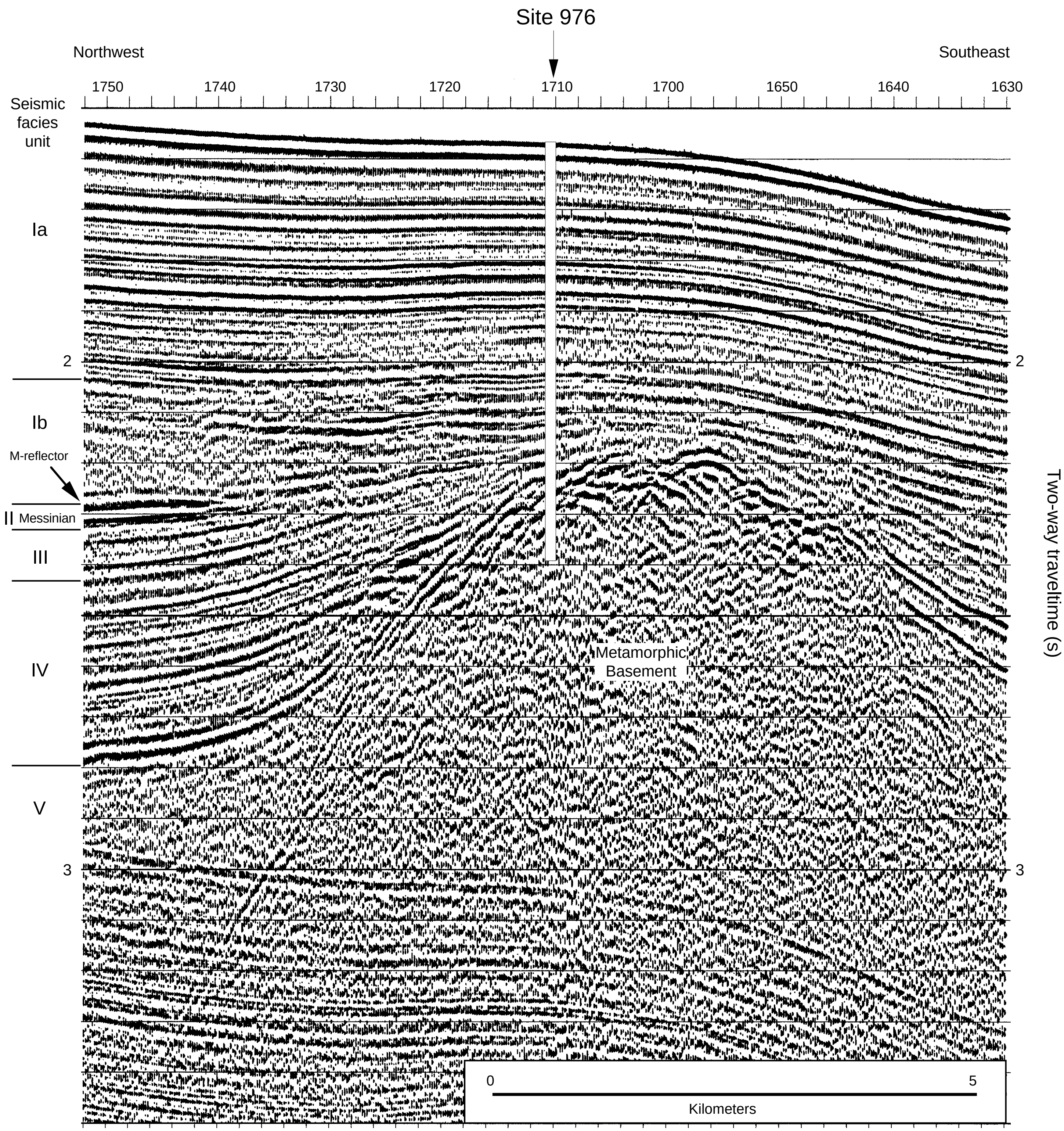


Fig. Prel. Rept-10

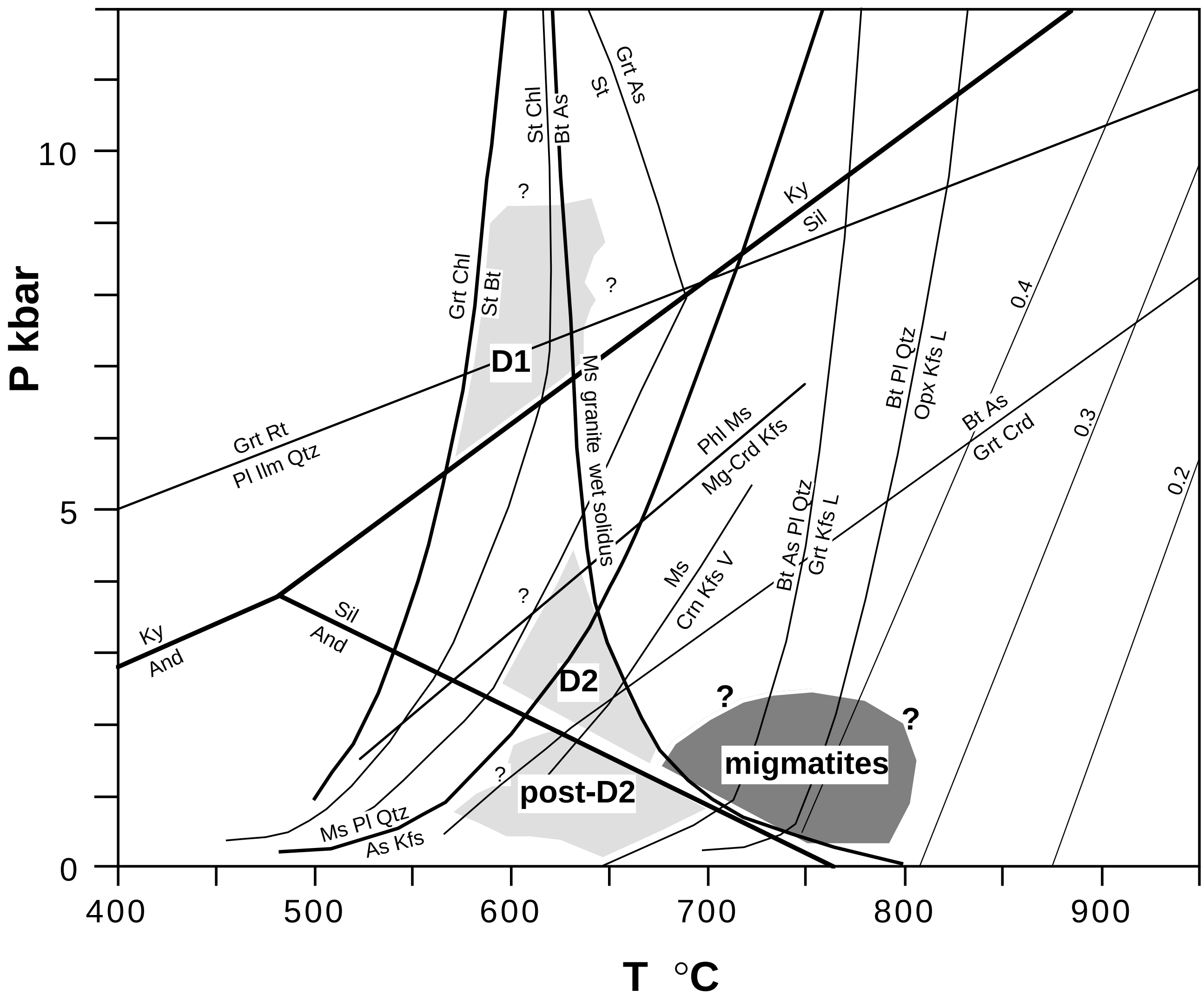


Fig. Prel. Rept-11

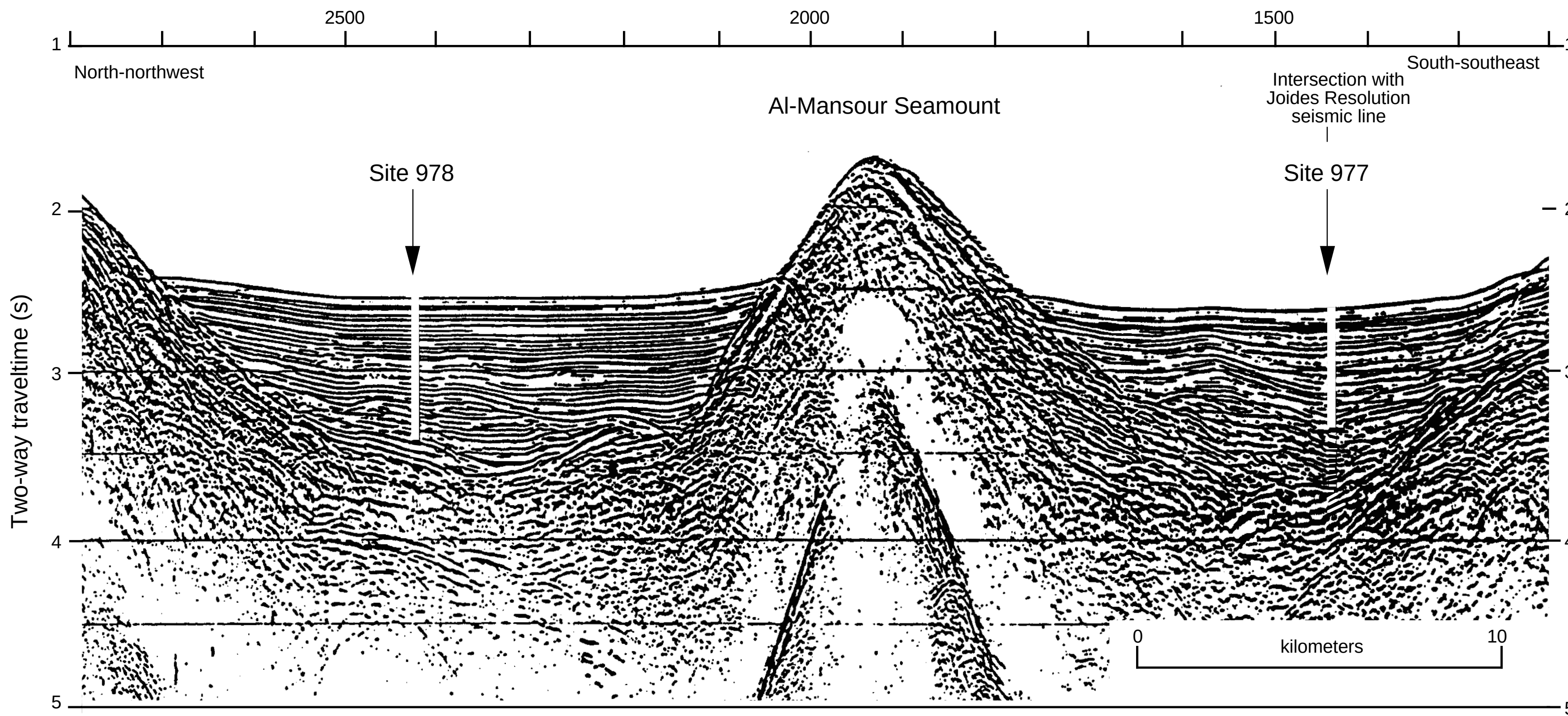


Fig. Prel. Rept- 12

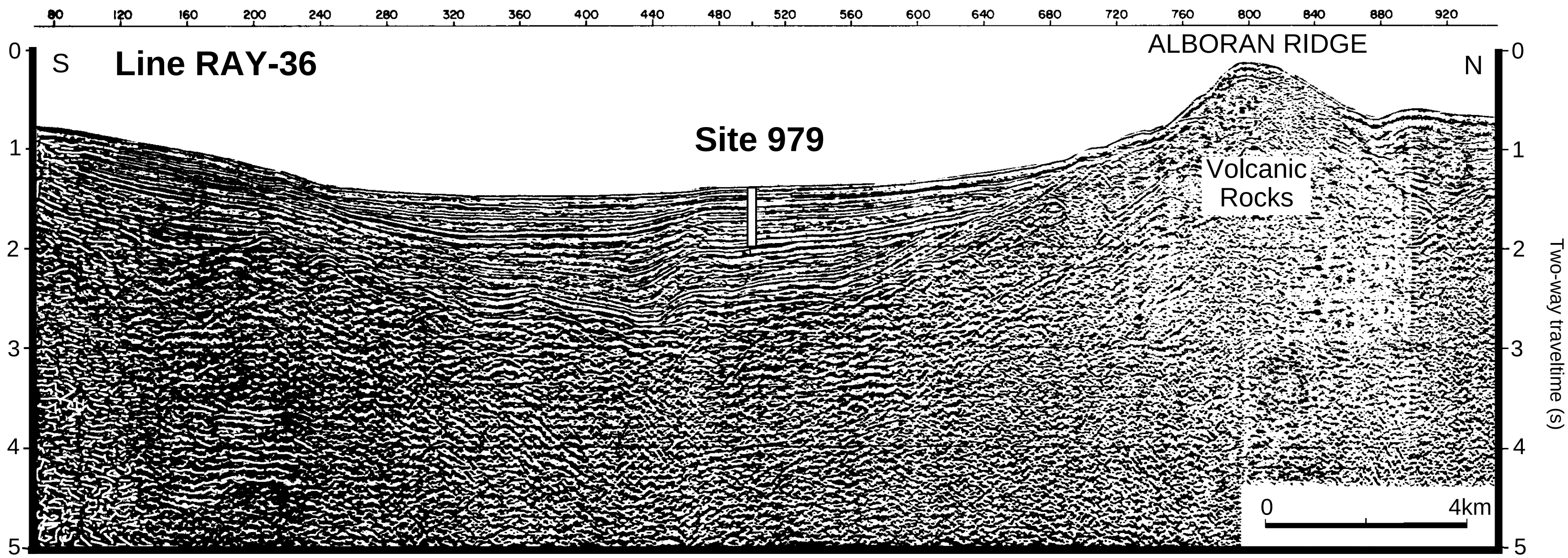


Fig. Prel. Rept-13

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 161 were:

Operations Manager:	G. Leon Holloway
Schlumberger Engineer:	Richard Sammy

TRANSIT FROM NAPOLI (NAPLES) TO SITE 974
(Proposed site MedSap-5)

The ship departed Napoli at 1815 hr, 6 May 1995 (all times in this report refer to ship time unless otherwise noted; ship time was UTC + 2 hr). The 105-nmi sea voyage to proposed site MedSap-5 required 9.75 hr at an average speed of 10.8 nmi/hr. During the transit, we collected navigation, 3.5 and 12 kHz reflection, and magnetic data.

SITE 974

We deployed a Datasonics 354M beacon at 40°21.3'N, 12°08.59'E on 0345 hr, 7 May. This is the location of Site 652, which was drilled during ODP Leg 107. We then deployed a second beacon about 175 m northwest of the first beacon. The first beacon was turned off and used as a backup. The ship was positioned over the second beacon, due to concerns of the scientific party that the borehole might be too close to the existing Site 652 tailings.

Unless otherwise noted, depths in the operations section within individual site reports refer to meters below rig floor (mbrf). This depth is calculated using drill pipe measurements (DPM) from the top of the dual elevator stool (DES) on the rig floor. The DES is approximately 10.9 m (10.86 m for Holes 974A, 974B, and 974C; 10.89 for Hole 974D) above sea level and varies over time depending on the ship’s draft. The seafloor depth, and therefore the depth below seafloor (mbsf) from which cores are recovered, are calculated using the recovery of the mud-line core at each hole, the DPM, and the elevation of the DES above sea level.

Hole 974A

Two APC/XCB holes to 200 mbsf and a third APC hole to refusal were planned for Site 974.
An APC/XCB bottom hole assembly (BHA) was assembled and used during the entire leg for the APC/XCB holes. It consisted of (1) an 11-$^{7}/_{16}$-in. Security roller cone bit (S/N 478458), (2) a bit sub (BS), (3) a seal bore drill collar (SBDC), (4) a landing saver sub (LSS), (5) a long top sub (LTS), (6) a head sub (HS), (7) a nonmagnetic drill collar (NMDC), (8) five 8-$^{1}/_{4}$-in. drill collars (DC), (9) a crossover sub (XO), (10) a 7-$^{1}/_{4}$-in. DC, (11) a crossover sub (XO), (12) five joints of 5-$^{1}/_{2}$-in. drill pipe (DP), and (13) a crossover sub (XO).
A “rabbit” was passed through all of the drill pipe to ensure that the core barrels would pass smoothly through the DP. Five stands of 5 in. drill pipe were not used because the “rabbit” would

not pass. The DP was then measured with a steel tape measure (SLM) as it was added to the drill string. Once assembled, a wiper “pig” was pumped through the pipe and onto the seafloor to clean the inside of the DP of rust and lubricant used on the pipe connections.

Hole 974A was spudded at 1630 hr, 7 May at 40°21.364'N, 12°08.506'E. The corrected precision depth recorder (PDR) indicated a water depth of 3474 mbrf. Core 161-974A-1H was taken with the bit at 3470.0 mbrf. Core 161-974A-1H, however, was full (9.81 m recovered; 103% recovery), indicating that we missed the mud line, and an exact seafloor measurement can only be assumed. Notes from the driller indicated that we may have lowered the bit into the seafloor by as much as 5 m before we shot Core 161-974A-1H. Since we missed the mud line, Hole 974A was terminated and the bit cleared the seafloor at 1700 hr, 7 May.

Hole 974B

We raised the drill string from 3469.7 to 3462.0 m, and spudded Hole 974B at 1730 hr, 7 May. Core 161-974B-1H recovered 6.78 m of sediment; therefore, the seafloor was defined to be at 3454 meters below sea level (mbsl). Cores 161-974B-1H to -18H were taken from 0 to 165 mbsf (3630 m) and recovered 172.73 m (105% recovery). We oriented Cores 161-974B-3H to -18H using the Tensor tool.

Coring was interrupted for about 3.5 hr when one of three strands of the sand line parted at the oilsaver while going in to retrieve Core 161-974B-11H. Approximately 1050 m of sand line was removed from the aft sand-line drum, and the forward sand line was used during the remainder of Site 974.

Overpull (up to 40,000 lb) started at Core 161-974B-16H, and partial bleed-off indicated that there may have been a partial stroke. A partial stroke of about 6.5 m was inferred for Core 161-974B-18H from the fact that both the pressure had to bleed off and that the driller raised the drill string 3 to 4 m before observing any resistance. Once retrieved on deck, we observed that the liner of Core 161-974B-18H was splintered for almost its entire length, most likely the result of a hard impact with the bottom of the borehole.

We started XCB-coring at 3630 m (165 mbsf) after drilling out the 6.5-m rat hole created by Core 161-974B-18H. XCB Cores 161-974B-19X to -22X were taken from 165 to 203.7 mbsf, with 38.7 m cored and 35.5 m recovered (92% recovery). The combined APC/XCB recovery for Hole 974B was 102%.

Having reached the depth objectives, we terminated Hole 974B, and the bit cleared the seafloor at 2345 hr, 8 May. Hole 974B was completed in a total of 30.75 hr.

Hole 974C

We offset the ship 50 m southeast and spudded Hole 974C at 0115 hr, 9 May, with the bit at 3459.0 m. Core 161-974C-1H recovered 4.36 m; therefore, the seafloor was defined to be at 3453 mbsl. Cores 161-974C-1H to -16H were taken to 146.8 mbsf (3611 m) and recovered 153.91 m (105% recovery). We stopped APC coring one core earlier than in Hole 974B in an attempt to prevent the liner from shattering and disturbing the core. ADARA temperature measurements were taken during Cores 161-974C-3H, -6H, -9H, -12H, and -15H. All ADARA measurements were successful. There was no indication of any significant frictional heating due to tool movement.

XCB Cores 161-974C-17X to -22X were taken from 156.4 to 204.5 mbsf (3611 to 3668.7 m), with 57.7 m cored and 45.94 m recovered (80% recovery). Flow ports in the XCB shoe continued to become clogged in the clay; however, except for Core 161-974C-17X, recovery was good.

The hole was conditioned for logging with a short wiper trip. No drag and only 6 m of sediment fill in the bottom of the hole indicated that conditions were good for logging. The hole was displaced with seawater. No KCl or bentonite mud was used. The bit was positioned at 63.36 mbsf (3527.56 m) to log. The bit was raised approximately 20 m (to ~43 mbsf) before the logging tools reentered the drill pipe to allow more of the upper borehole to be logged. The quad-combo tool was run first, then the FMS tool, and finally the GLT. The logs were run to 3662, 3625, and 3656 mbrf, respectively. No significant operational or hole stability problems were reported. The logs indicated that hole angle was about 1.5°, and the hole diameter ranged from 12 to at least 15 in. We finished logging at 2045 hr, 10 May, and the bit cleared the seafloor at 2100 hr, 10 May.

Hole 974D

We offset the ship 25 m to the northwest and spudded Hole 974D at 2245 hr, 10 May. The scientific party requested that the interval from 4 to 8 mbsf be recovered within a single core to fill in gaps from the previous holes. The bit was positioned at 3457.0 m, and Core 161-974D-1H recovered 1.64 m; therefore, the seafloor was defined to be at 3454.0 mbsl. Cores 161-974D-1H to -18H were taken to 163 mbsf (3628 m) and recovered 170.49 m (105% recovery). The beacons were released (1300 hr and 1510 hr, 11 May, respectively) and recovered (1420 hr and 1600 hr, 11 May, respectively). The BHA cleared the rig floor and was secured for transit at 1930 hr, 11 May, and the transit to proposed site MedSap-6A began at 1930 hr, 11 May.

SITE 975

(Proposed site MedSap-6A)

The 380-nmi sea voyage to Site 975 required 47 hr at an average speed of 8.1 nmi/hr. We conducted a pre-site seismic survey, lasting about 6 hr, over Site 975. We deployed a beacon at 38°15.612'N, 4°44.990'E, on 0100 hr, 14 May. We then deployed a second beacon at 0300 hr, 14 May. The elevation of the DES above sea level was 10.93 m for Holes 975A and 974B, 10.99 m for Hole 975C, and 11.02 m for Hole 975D.

Hole 975A

We spudded Hole 975A at 0700 hr, 14 May, at 38°53.795'N, 04°30.587'E. The bit was positioned at 2428.0 mbrf, and Core 161-975A-1H recovered 9.92 m (104.4% recovery). Since this core overshot the mud line, an exact seafloor depth could not be calculated and the hole was terminated. The bit cleared the seafloor at 0730 hr, 14 May.

Hole 975B

We raised the bit 7 m to 2421.0 mbrf and spudded Hole 975B at 0745 hr, 14 May. Core 161-975B-1H recovered 4.1 m of sediment; therefore, the seafloor was defined to be at 2416 mbsl. Cores 161-975B-1H to -16H were taken to 2573 m (146.6 mbsf) and recovered 151.68 m (103% recovery). Cores 161-975B-3H through -16H were oriented using the Tensor tool. While retrieving Core 161-975B-6H, the sand line broke before the core was brought onto the rig floor. The core barrel was dropped twice during attempts to fish the core barrel and sand line from inside the drill pipe. After the core was recovered and split, it was noted that the lower section of this core was disturbed. In addition, the next core (Core 161-975B-7H) also had some disturbance caused by Core 161-975B-6H having penetrated into the top of Core 161-975B-7H, as well as from the additional drill pipe motion during the 6 hr while Core 161-975B-6H was being retrieved.

Cores 161-975B-14H to -16H were partial strokes, even though the cores were full when recovered. After an overpull of 60,000 lb was recorded for Core 161-975B-16H, we switched to XCB-coring. XCB Cores 161-975B-17X to -34X were taken from 146.6 to 317.1 mbsf. We XCB-cored 170.5 m and recovered 147.3 m (86%). Several of the first few XCB cores

(Cores 161-975B-17X, -19X, and -20X) had lower recoveries. The total APC/XCB recovery in Hole 975B was 94%.

A hard layer was encountered at about 307.5 mbsf (2734 mbrf). This layer appears to correlate with a strong reflector in the seismic reflection data collected just prior to drilling at this location. Previous velocity analyses suggested that this reflector (M reflector) was at a depth of 350 mbsf. Hole 975B was terminated after advancing to 317.1 mbsf (about 9.6 m into the hard gypsum material) to abide by PPSP recommendations.

Hole 975C

We offset the ship 20 m to the north-northeast and spudded Hole 975C at 0230 hr, 16 May. Core 161-975C-1H recovered 2.43 m of sediment with the bit position at 2419.0 m; therefore, the seafloor was defined to be at 2415 mbsl. Cores 161-975C-1H to -16H were taken to 2571 m (144.9 mbsf) and recovered 152.54 m (104% recovery). ADARA temperature measurements were made while taking Cores 161-975C-3H, -6H, -9H, -12H, and -15H. Cores 161-975C-14H through -16H were recorded as partial cores with overpull exceeding 45,000 lb.

XCB Cores 161-975C-17X to -34X were cut from 144.9 to 313.7 mbsf and recovered 155.12 m (92% recovery). The hard gypsum “M” reflector was encountered at 2735.1 m (309 mbsf). Total APC/XCB recovery for Hole 975C was 307.66 m (98%).

We then conditioned the hole for logging with a short wiper trip. No drag was observed, and only 7 m of fill was encountered in the bottom of the hole, indicating good hole conditions for logging. The hole was displaced with seawater. The bit was positioned at 2497.53 m (71.43 mbsf) to log and was raised approximately 20 m more just before the logging tools reentered the drill pipe, allowing more of the upper portion of the borehole to be logged. Three tool strings were run in the following order: (1) quad-combo, (2) FMS, and (3) GLT. The logs were run to 2735, 2730, and 2723 mbrf, respectively. No significant operational or hole stability problems were reported by the logger. The log data indicated hole deviations $<2°$. There was a noticeable difference in hole diameters between the APC and XCB portions of the hole. The XCB portion exhibited a larger and more ragged diameter as compared to the APC section. Logging was finished at 1000 hr, 18 May, and the bit cleared the seafloor at 1015 hr, 18 May.

Hole 975D

We offset the ship 20 m north-northeast and spudded Hole 975D with the bit at 2424.0 mbrf at

1045 hr, 18 May. Core 161-975D-1H recovered 7.4 m of sediment; therefore, the seafloor was defined to be at 2415 mbsl. Cores 161-975D-1H to -16H were taken to 149.9 mbsf and recovered 157.13 m (105% recovery). Cores 161-975D-11H, -12H, and -16H were partial strokes with up to 50,000 lb overpull. The bit cleared the seafloor at 2245 hr, 18 May, and the BHA was secured for the transit to proposed site Alb-2 (Site 976) at 0330 hr, 19 May. The 11-$^{7}/_{16}$-in. Security bit (S/N 478458) had negligible tooth wear, and the bearings were still in good shape despite having been used for 37.7 hr.

SITE 976
(Proposed site Alb-2)

After a 439 nmi transit from Site 975 (36 hr; 12 nmi/hr), we conducted a seismic survey at Site 976 (52 nmi; 9.75 hr). We then positioned over the site and deployed two beacons (at 0100 and 0330 hr, 21 May, respectively). Both beacons were left on due to heavy seas and strong currents. The strong surface current flowing in from the Atlantic was mostly between 2.0 and 2.5 nmi/hr and varied from 250° to 280°. Site 976 was in the general shipping lane for all traffic entering and exiting the Mediterranean Sea. At times, more than 10 ships could be seen on the radar within a 12 nmi radius. This level of ship traffic continued throughout the time at Site 976. The elevation of the DES above sea level was 11.05 m for Holes 976A and 976B, 11.35 m for Hole 976C, and 11.38 m for Holes 976D and 976E.

Hole 976A

A reentry cone installation was planned at Site 976, so the first hole was used to establish the mud line and conduct a jet-in test. We spudded Hole 976A at 0615 hr, 21 May. Core 161-976A-1H was taken with the bit at 1115 mbrf and recovered 5.92 m; therefore, the seafloor was defined to be at 1107.5 mbsl. We then continued lowering the bit into the seafloor by circulating water only to determine the amount of 16-in. conductor casing that could be safely washed into the seafloor with the reentry cone. An XCB core barrel with a center bit was used during the jet-in test. The jet-in test took 1.5 hr and penetrated to 65 mbsf, using up to 45 strokes per min (spm).

Hole 976B

We offset the ship 15 m to the southeast (i.e., up-current to the deep Mediterranean outflow) and spudded Hole 976B at 1000 hr, 21 May. The hole was vertically offset 2 m from Hole 976A. Core 161-976B-1H was taken with the bit at 1113 mbrf and recovered 3.45 m of sediment;

therefore, the seafloor was defined to be at 1108 mbsl. Sea conditions at the time the mud-line core was taken may have contributed to the difference in the mud-line core recovery between Holes 976A and 976B. APC Cores 161-976B-1H through -14H were taken to 127 mbsf and recovered 128.04 m (101%). Cores 161-976B-3H to -14H were oriented with the Tensor tool. Temperature measurements were attempted during Cores 161-976B-3H and -6H, but good data were not recovered due to tool movement, caused by the sea conditions and the short, rigid drill string.

The failure of one of the flappers in the core catcher resulted in part of Core 161-976B-3H to be extruded onto the drill floor. The recovered cores experienced significant gas-induced expansion, causing parts of the cores to extrude from the liner. To reduce core disturbance and expansion, holes were drilled in the core liners prior to cutting them into sections to allow the gas to escape. In the APC cores, a C_1 maximum of 66,555 ppm was measured in a headspace sample from Core 161-976B-12H; however, no trends that might affect safety were observed.

XCB Cores 161-976B-15X to -74X were taken from 127.0 to 677.3 mbsf and recovered 358.34 m (65%). Three WSTP measurements were attempted prior to Cores 161-976B-18X, -20X, and -26X (1284.4, 1303.7, and 1351.7 mbrf, respectively). Gas was present in the

XCB cores, with the maximum C_1 being recorded as 14,662 ppm from headspace analyses. No significant trends were seen in either C_1 or C_1/C_2 ratios.

Fine sands(?) encountered from 367 to about 518 mbsf resulted in a very low core recovery. Less than 10 min was required to cut some of the cores in this interval. While coring through the sands, the borehole was completely circulated from the bottom up to the seafloor before recovering the core barrel each time. Despite the loose nature of the formation, no fill or significant hole problems were encountered while coring this interval. Firmer clays were then encountered below 518.3 mbsf (1637 mbrf). Additional sandy intervals were also seen from 621.6 mbsf down to about 670 mbsf, where basement was reached. Overall recovery for both the APC and XCB portion of the hole was 71.8%.

The hole was conditioned for logging with a wiper trip. Overpull of about 30,000 lb was observed in two zones while pulling the pipe up the hole. We had to use the top drive and rotate the drill pipe to get it to pass through numerous indurated layers throughout the sand interval (357.7 to 518.3 mbsf). After passing down through the sand, we found 36 m of fill in the bottom of the hole. We then reamed to the bottom of the hole and swept it with 30 bbl of high viscosity mud. We positioned the bit at 72 mbsf (1191 mbrf) to log. Since the first tool was unable to exit the bit, we dropped and retrieved an XCB core barrel. This cleared the LFV (lockable float valve) and allowed the tool to pass through the bit on the second attempt. The tool, however, only made it to 350 mbsf before encountering a bridge, and the hole was logged from 350 to 36 mbsf. The quad-combo caliper data indicated that most of the hole had washed out to larger than the caliper limit of 18.5 in. Therefore, we decided to terminate logging at 0930 hr, 26 May.

We then deployed a free-fall funnel (FFF) so that we could continue Hole 976B using RCB-coring. The BHA for the RCB was assembled with (1) a 9-$^7/_8$-in. RBI C-4 bit, (2) a mechanical bit release (MBR), (3) a head sub (HS), (4) an outer core barrel (OCB), (5) a top sub, (6) a head sub (HS), (8) eight 8-$^1/_4$-in. drill collars (DC), (9) jars, (10) two 8-$^1/_4$-in. drill collars (DC), (11) a crossover sub (XO), (12) a 7-$^1/_4$-in. DC, (13) a crossover sub (XO), (14) five joints of 5-$^1/_2$-in. drill pipe (DP), and (15) a crossover sub (XO).

We reentered the FFF at 2330 hr, 26 May. The drill string was run into the hole, and approximately 37 m of fill was found at the bottom of the hole. The hole was washed and reamed to the bottom. RCB coring began at 0830 hr, 27 May. RCB Cores 161-976B-75R to -106R were taken from 677.2 to 928.7 mbsf (1796.3 to 2047.7 mbrf) and recovered 49.12 m (19.5%). RCB drilling parameters were 15,000-23,000 lb WOB (weight on bit), 50-70 spm, and 40-70 rpm. Pump pressures with the core barrel in ranged from 350 to 700 psi.

Core jamming was noted in the first two cores. Short cores were attempted as a means to increase core recovery, but did not appear to make significant difference. The material being cored appeared to be a mixture of hard rocks and soft, unconsolidated, fine-grained fault gouge (only minimally recovered), resulting in a high rate of penetration (5 m/hr) but poor recovery. We believe that the fault gouge was being washed away and that only the rocks were recovered. In addition, we attempted taking cores both with, and without, a core liner. We thought that coring without a core liner might reduce the chances that a piece of core might jam off and prevent more core from entering the core barrel.

Prior to completing the hole, we made two wiper trips when the bit had reached a penetration of 1869.6 and 1961.1 mbrf (750 and 842 mbsf, respectively). These wiper trips were conducted to relieve an increase in pressure and as a preventive measure. During each wiper trip, the bit was pulled up to 659 mbsf (1778 mbrf). We terminated coring in Hole 976B after a final penetration to 928.7 mbsf.

In preparation for logging, we made a final wiper trip up to 535.9 mbsf (1655 mbrf) to condition the hole. We had some difficulty releasing the bit using the releasing tool to trigger the MBR. At first we thought that, since the MBR would not release, we might have to pull the string to the rig floor and then reenter the hole with a logging bit. Finally, after numerous attempts over a 2 hr period to jar off the overshot, the MBR sleeve shifted and released the bit. The releasing tool was rerun back down the pipe to confirm that the bit was released and to shift the sleeve into the logging position.

We used a conservative two-step approach to log, ensuring that we obtained good log data in the basement sections first. For the first log, we placed the bit just deeper than the top of basement at 698 mbsf. We were uncertain if, once we pulled above basement, we could get back into basement after dropping the bit. We ran the logging tools in the following order: quad-combo, FMS, BHTV, and GLT. The logs were run to 916.7, 914.7, 914.7, and 908.7 mbsf (2035, 2033, 2033, and 2027 mbrf, respectively). The drill pipe weight indicator during the first run suggested that material may have been starting to tighten around the drill pipe. The top drive was used between runs to circulate and make sure the pipe remained free. Logging was allowed to continue, since this weight increase did not appear to be a serious threat to the drill string or the BHA.

The logs indicated a >5° hole angle. This deviation is not surprising, based on the range of structural dips observed in the core and the variability in hardness of the formation. The hole diameter was relatively constant from 781 to 928 mbsf (1900 to 2047 mbrf, respectively). Hole diameters were considerably more variable above 1900 mbrf. The log data, however, were still considered to be very good. The basement logs were finished at 0600 hr, 1 June.

We then pulled the bit up to 536 mbsf (1655 mbrf) to attempt a second series of logs from 536 mbsf to the top of basement. Results from the quad-combo caliper data during the first run revealed that this portion of the hole was seriously washed out. We decided to terminate logging operations and attempt to log this interval in one of the next holes to be drilled at this site. Logging operations were completed at 1100 hr, 1 June. We displaced the hole with 80 bbl of 10.5 lb/gal barite mud before pulling out of the hole. The bottom of the drill pipe cleared the seafloor at 1245 hr, 1 June.

Hole 976C

The ship was offset 50 m east (upstream to the deep Mediterranean outflow) of Hole 976B, and Hole 976C was spudded at 2000 hr, 1 June. Core 161-976C-1H was taken with the bit at 1116.0 mbrf and recovered 5.98 m; therefore, the seafloor was defined to be at 1108.2 mbsl. APC Cores 161-976C-1H to -14H were taken to 129.5 mbsf and recovered 135.88 m (105%).

Cores were oriented beginning with Core 161-976C-3H. ADARA temperature measurements were taken during Cores 161-976C-3H, -6H, -9H, and -12H. The maximum gas detected was 32543 ppm C_1.

XCB Cores 161-976C-15X to -40X were taken from 129.5 to 379.7 mbsf (1249.0 to 1499.2 mbrf, respectively) and recovered 204.28 m (81.65%). Several cores with very low recovery occurred in similar depth intervals as at Hole 976B. Some sediment residue was observed on the inside of the liner, suggesting that sediment may have been inside the liners at one time. There were a couple of these low recovery cores (Cores 161-976C-20X and -25X) which had holes through the middle of the material that remained inside the cutting shoe. One possibility is that the sediment in the core barrel may have been forced out by gas expansion(?) as the cores were being withdrawn from the seafloor. Penetration rates of about 8-12 m/hr were achieved with circulation rates of 30-40 spm, 10,000 lb WOB, and 50-60 rpm. Overall APC/XCB recovery for Hole 976C was 89.58%. Prior to pulling the bit out of the hole, 100 bbl of 10.5 ppg heavy weight mud was displaced into the hole. The bit cleared the seafloor at 1145 hr, 3 June.

Hole 976D

Hole 976D was cored primarily to take high-resolution interstitial water samples in the upper 30 mbsf. The ship was offset 25 m northwest of Hole 976C (as we could not move farther to the east because of our distance from the beacon) and spudded Hole 976D at 1230 hr, 3 June. Core 161-976D-1H was taken with the bit at 1111.0 mbrf and recovered 1.54 m of sediment; therefore, the seafloor was defined to be at 1107.6 mbsl. APC Cores 161-976D-1H to -4H were taken from 0 to 30 mbsf (1119 to 1149 mbrf, respectively) and recovered 30.76 m (102.5%). After taking Core 161-976D-4H, the APC/XCB BHA was pulled out of the hole, clearing the seafloor at 1445 hr, and the rig floor at 1645 hr, 3 June.

Hole 976E

Hole 976E was drilled and cored so that additional samples could be taken across the sediment/basement contact and so this same interval could be logged. Therefore, an MBR was added to the RCB BHA. Hole 976E was spudded at 2130 hr, 3 June. We washed and drilled with a center bit to 543.81 mbsf (1662.81 mbrf), where we began RCB coring. RCB Cores 161-976E-1R to -28R were taken from 543.8 to 736.3 mbsf, coring 192.5 m and recovering 64.85 m (33.69%). We advanced only 5.0 or 4.6 m on 16 of these 28 cores. We did this to enhance our chances of good core recovery because we thought taking short cores might reduce the possibility of core pieces jamming. The other 12 cores advanced the standard 9.5 m.

Recovery in Hole 976E was better than in Hole 976B across, what was initially believed to be, the same transition zone of breccia, fault gouge, and metamorphic basement. The basement, however, was encountered approximately 10 m higher than in Hole 976B. A significant portion of the metamorphic basement exhibited a vertical foliation, which may have resulted in less core jamming and enhanced the core recovery.

We used a combination 8-finger with a 4-petal core catcher for the first four cores in the hard clay. The core catchers were then switched to a 10-finger placed in front of the 4-petal core catcher for the remainder of the sediment coring. Once basement was reached, we switched to two, rotatable 8-finger core catchers.

Drilling parameters while coring with the RCB were 35-45 spm, 15,000-25,000 lb WOB, and 50-70 rpm. Attempts to keep annular velocity low to reduce the hole erosion (to enhance chances for good logging conditions) resulted in slow penetration. The pump strokes were increased slightly to 45 spm on the sixth core, which helped the ROP and decreased the pressure (cleaned the hole of cuttings better).

We had hoped that the smaller diameter RCB hole would result in better hole conditions across the sediment/basement transition so that logs could be used to help fill in the gaps created by the poor recovery in this interval.

A short wiper trip was made to 570 mbsf (1689 mbrf). When we moved the bit back to the bottom, approximately 20 m of fill was encountered. We reamed the fill out of the hole, released the bit, and shifted the MBR sleeve back into the logging position. The pipe was raised to 570 mbsf (1689 mbrf), and logging operations were begun. The standard quad-combo log was run first. Some difficulty was encountered in getting the tool through the sediment/basement transition. Once logging was started, approximately 9000 lb of tension was experienced while pulling the log through basement section. This tension, combined with the severely washed-out borehole above 631 mbsf, caused us to terminate logging. The quad-combo tool was able to obtain logs from 713 to 570 mbsf.

Erratic signals with the two seafloor dynamic positioning beacons occurred almost daily. Signals from both beacons were temporarily lost around 1500 hr, 7 June. We deployed a backup beacon, but it failed to respond, so we deployed a second backup beacon. In the meantime, the signals from the first two beacons were reacquired.

The bottom of the drill pipe cleared the seafloor at 0545 hr, and the rig floor at 0800 hr, 8 June. Three of the four beacons deployed were recovered at the conclusion of operations at Hole 976E. We began the transit to Site 977 at 0830 hr, 8 June.

SITE 977

(Proposed site Alb-4A)

After the 99 nmi transit to Site 977 (~8 hr; ~12 nmi/hr), we conducted a seismic survey over the site. We then positioned over Site 977 and deployed a beacon at 2315 hr, 8 June, and a backup beacon at 0200 hr, 9 June. The elevation of the DES above sea level was 11.54 m for Hole 977A.

Hole 977A

We used the same APC/XCB BHA as had been run throughout the leg with a rerun security S87F bit. Since the site was in close proximity to a communication cable, the VIT was deployed as a precautionary measure while spudding Hole 977A. Hole 977A was spudded at 1100 hr, 9 June. Core 161-977A-1H was taken with the bit at 1990.0 mbrf and recovered 3.97 m; therefore, the seafloor was defined to be at 1984.0 mbsl. APC Cores 161-977A-1H to -17H were taken to 156.0 mbsf (2151.5 mbrf) and recovered 164.72 m (106%). Cores 161-977A-3H to -17H were oriented using the Tensor tool. ADARA temperature measurements were taken during Cores 161-977A-3H, -6H, -9H, and -12H. Some core expansion was observed beginning with Core 161-977A-12H. The maximum C_1 detected in the upper 156 mbsf was 35,695 ppm, with a poorly defined second high of 31,564 at about 310 mbsf. No trends in the gas analyses were significant enough for us to consider abandoning the hole.

XCB Cores 161-977A-18X to -63X were taken from 156.0 to 598.5 mbsf (2151.5 to 2594.5 mbrf, respectively), coring 442.5 m and recovering 380.77 m (86.05%). From 156.0 to 531.0 mbsf, XCB recovery was over 100% in stiff, hard clay. Starting at Core 161-977A-57X (531.0 mbsf), we encountered a conglomeratic interval (cobble, gravel, and sand), and recovery from 531.0 to 598.5 mbsf fell to less than 4%. Prior to allowing the whole BHA to penetrate into this interval, we made a short wiper trip back up to 482.58 mbsf. Immediately after cutting the next core (Core 161-977A-63X), the pipe became stuck before the connection could be made and the core barrel withdrawn. We worked the pipe for over 2 hr until it finally became free. This zone acted as if it was slightly overpressured. When the mud pumps were turned off, the pipe was able to be worked free. It appeared that the added flow from the bit was causing the hole to pack off.

At this point, we decided to log instead of trying to fight the hole conditions, since the bit had already accumulated over 86 hr and we had the weaker nonmagnetic drill collar in the BHA. Therefore, we made a wiper trip to 49.5 mbsf (2045 mbrf) and positioned the bit at this depth for logging. Fill was tagged at 578.5 mbsf (2574 mbrf), but we did not attempt to ream it out due to the BHA conditions, described above, and the amount of time that might be lost if the drill pipe became stuck again. We ran the quad-combo and then the FMS. We did not run the GLT, since we had some difficulty reentering the drill pipe with the FMS tool. Both logs were run to 564.5 mbsf (2560 m) and will help provide information about the extremely low recovery interval below 531 mbsf.

After logging, we deployed an FFF. The VIT was used to observe the BHA being withdrawn from the seafloor to ensure that the FFF was not dragged out of the hole. The bit cleared the FFF at 0700 hr, 14 June. The RCB BHA was assembled and run to the seafloor. The BHA consisted of the same components that were used at earlier sites, except that the jars were not included since it was damaged during Hole 976E operations. It took about 15 min to locate and reenter the funnel. The FFF was reentered at 1800 hr, 14 June. Several attempts at raising and lowering the BHA were needed until the BHA found the original hole and could be lowered without bowing the pipe.

The pipe was lowered into the hole and encountered fill at 533.21 mbsf (2523.21 mbrf). We then picked up the top drive and easily washed and reamed to 595.18 mbsf (2590.68 mbrf) in less than 2 hr. The last 3 m of fill, however, could not be penetrated without the drill pipe becoming stuck. Every time the bit was gently placed on top of the fill, the torque increased to 600-700 amps, rotation stopped, and pressure increased. We suspect that the hole was packing off, since the only way to free the pipe was by completely turning off the mud pumps. We spent over 8 hr attempting to ream out this last 3 m, without success. During the last attempt, the weight indicator began fluctuating as if the bit were bouncing on the bottom. Since we were unable to advance, we decided to terminate the hole.

Prior to abandoning the hole, we requested to offset from this hole. We thought that moving out of the subsurface channel axis might allow us to penetrate past this interval to the 1200 mbsf target depth. However, these offset locations were denied for safety reasons. Instead, we received approval for drilling close to proposed site Alb-4 (slightly modified to be able to avoid drilling close to a submarine telecommunications cable). The bit cleared the seafloor at 1030 hr, and cleared the rotary at 1430 hr, 15 June. The two beacons were recovered while the pipe was being retrieved. After the BHA was recovered, we observed that one cone had broken off the new bit and

that the welded collar around the location of the dogs on the MBR was heavily damaged. The rig floor was secured, and we began the transit to proposed site Alb-4B (Site 978) at 1430 hr, 15 June.

SITE 978

(Proposed site Alb-4B)

After the short 13 nmi (1.5 hr, 8.67 nmi/hr) transit to Site 978, we deployed two beacons at 1600 hr and 1840 hr, 15 June, respectively. No site survey was performed, since existing seismic data were sufficient for selecting the site and for correlation of coring results throughout this part of the east Alboran Basin. The elevation of the DES above sea level was 11.60 m for Hole 978A.

Hole 978A

We offset the ship 100 m northwest of the beacon to ensure that we were >0.5 nmi away from the known coordinates of a telecommunication cable. Hole 978 was drilled at 36°13.867'N, 2°03.424'W. The same RCB BHA was run as was used in Hole 977A, except that we added a new MBR and drill bit. To save time and reach the deep objectives as quickly as possible, the scientific party requested that the bit be lowered to the seafloor without using the VIT to determine the exact seafloor depth. The seafloor depth was determined to be at 1954 mbrf (1942.4 mbsl), based on the drill string weight indicator as the bit entered the seafloor. (N.B. The seafloor depth was later adjusted to 1941 mbrf or 1929.4 mbsl - see below.) Hole 978A was spudded at 2100 hr, 15 June.

The hole was drilled with a center bit in place to 110.3 mbsf (2064.3 mbrf), where the first RCB core was taken. The hole was then advanced (without coring) from 119.9 to 168.4 mbsf, where a second RCB core was attempted. Recovery in Cores 161-978A-1R and -2R was almost zero (0.2%). The hole was then drilled from 178.0 to 213.0 mbsf, where we started continuous RCB coring. At this depth, the formation was firm enough to be recovered without washing away. Core 161-978A-5R was advanced only 3.9 m for drilling convenience (so that the driller then could work with a full kelly).

RCB Cores 161-978A-3R to -53R were taken from 213 to 698.0 mbsf (2154 to 2629.4 mbrf, respectively). Recovery in the interval from 213.0 to 611.3 mbsf was 485.0 m (84%). Recovery was poor was in the interlayered sands and gravels. The total recovery for Hole 978A was 406.66 m (80.7%). Coring parameters were 4,000-25,000 lb WOB while rotating at 50-70 rpm with 100-200 amps torque, circulating seawater at 30-50 spm with pressures ranging from 150 to 400 psi with the core barrel installed.

A bit change was required to complete the hole, so we deployed an FFF at 0530 hr, 20 June. When pulling out of the seafloor, several attempts were required before the bit would clear the FFF without dragging the FFF up. The back-reaming buttons on the bit were apparently catching the lower lip of the FFF. We rotated the pipe about a fourth of a turn with chain tongs on the rig floor before we saw on the VIT that the FFF had dropped off. Then we withdrew the pipe from the FFF.

Upon clearing the FFF, it was noted that the drill pipe depth was significantly shallower (~17 m; 1937 mbrf) than first reported. After attaching a new bit, running back to the seafloor, and prior to reentering the FFF, we touched the seafloor with the bit while observing with the VIT. This accurate seafloor depth was 1929.4 mbsl (1941 mbrf). All previous depths were changed to reflect this correct depth.

The FFF was entered at 1530 hr, 20 June. The drill pipe was run into the hole to 33.27 mbsf (1974.27 mbrf), where it met resistance from the formation, suggesting that we probably did not reenter the previous borehole. Several attempts were made to raise and lower the drill pipe to find the same hole. We picked up the circulating head and attempted to wash down, but were met with the same amount of resistance. Finally, the top drive was picked up, and we unsuccessfully attempted to find the hole by rotating and washing to 150.21 mbsf (2090.21 mbrf). After 6.5 hr of unsuccessful attempts to reenter the same hole, we decided to terminate the hole and move on to the next site. A slug of heavy mud was placed in the hole prior to pulling out. The drill pipe cleared the seafloor at 2300 hr, 20 June. The beacons were released and recovered while the drill pipe was being pulled. The bit cleared the rotary table at 0230 hr, 21 June.

Hole 978A exhibited similar hydrocarbon patterns as Hole 977A. Core 161-978A-18R contained the maximum methane recorded for the hole of 20,710 ppm. This was accompanied by 10 ppm of C_2, 77 ppm of C_3, 9 ppm of IC_4, and 8 ppm of IC_5. Gas contents began to decrease below Core 161-978A-25. No gas trends were observed that were interpreted as consideration for abandonment.

SITE 979

(Proposed site Alb-3C)

The original proposed site Alb-3A site was situated <0.5 nmi from the reported location of a telecommunications cable, and drilling there was not permitted. Prior to arriving on site, we received permission to offset and drill about 0.75 nmi north of the cable at proposed site Alb-3C. After the 63 nmi transit to Site 979 (5.5 hr; 11.45 nmi/hr), we deployed two beacons at 0745 and 0945 hr, 21 June, respectively. Hole 979A was located at 35°43.427'N, 3°12.353'W. The elevation of the DES above sea level was 11.90 m for Hole 979A.

Hole 979A

We used the same APC/XCB BHA at this site as at all other APC/XCB sites during this leg. We spudded Hole 979A at 1730 hr, 21 June. Core 161-979A-1H was taken with the bit at 1066.0 mbrf and recovered 1.46 m; therefore, the seafloor was defined to be at 1062.1 mbsl. Cores 161-979A-1H to -15H were taken to 134.5 mbsf and recovered 140.42 m (104.42%). Cores were oriented from Core 161-979A-3H, and ADARA temperature measurements were taken during Cores 161-979A-3H, -6H, and -9H.

Cores 161-979A-11H, -14H, and -15H were partial strokes, and we terminated APC coring after Core 161-979A-15H. The cores contained significant amounts of gas, and small holes were drilled into the liners prior to cutting them into sections to minimize gas expansion. All of the cores expanded against the inside wall of the APC core barrel, making visible contact ring marks on the lower part of the liner once it was extruded. Cores 161-979A-11H, -14H, and -15H, which were partial strokes, become stuck in the inner core barrel and had to be pulled out with a winch.

XCB Cores 161-979A-16X to -62X were taken from 138.3 to 580.9 mbsf (1208.5 to 1654.9 mbrf, respectively) and recovered 442.69 m (99.17%). Despite the expansive nature of the sediment, XCB recovery was very good, although the cores were quite biscuited. Coring parameters were 10,000 to 25,000 lb WOB and 50 to 70 rpm with circulation rates of 30 to 45 spm at 200 to 500 psi. The hole was terminated because there was insufficient time remaining to penetrate to 600 mbsf and also log the hole. Overall APC/XCB recovery for Hole 979A was 100.4%.

The maximum methane gas detected in the APC cores was 29,757 ppm (Core 161-979A-7H), and high methane concentrations near the seafloor were due to biogenic processes and did not present any safety problems. The maximum concentration of hydrocarbons from the headspace analysis occurred in Core 161-979A-31X, where the following contents were reported in (ppm); C_1:37,130, C_2:17, and C_3: 13. C_1/C_2 ratios remained relatively constant with depth below Core 161-979A-26X, ranging from 700 to 1000.

We conditioned the hole for logging with a wiper trip to 79 mbsf (1153 mbrf). Three tight sections of hole were observed at 447, 494, and 528 mbsf (1516, 1568, and 1602 mbrf, respectively), and no fill was encountered in the bottom of the hole. The pipe was pulled back to 79 mbsf for logging. The quad-combo log was run into the hole, but met a bridge at 246 mbsf (1320 mbrf). We decided to log this part of the hole before moving the pipe down to attempt logging deeper in the hole. The caliper data in the APC and XCB portions of the hole were quite different, with the APC section being much more in gauge than the XCB section. This was also seen in Hole 977A.

After the upper portion of the hole was logged with the quad-combo, we removed the tool from the hole and lowered the pipe to 277 mbsf (1351 mbrf). When the tool was run back into the hole, it encountered numerous tight sections and had to be worked down the hole to 464 mbsf (1538 mbrf) until no further advance could be made. We then logged from 464 to 251 mbsf (1538 to 1325 mbrf, respectively). Caliper data indicated that the hole was moderately washed-out with few continuous sections of hole in gauge. After completing the quad-combo logs, there was not enough time remaining to attempt the FMS log or to move the pipe lower in an attempt to log the lowermost 100 m of hole. Logging was completed and the tools rigged down by 2400 hr, 24 June.

The pipe was raised to 79 mbsf (1153 mbrf) and 63 bbl (200 sacks) of cement was pumped into the hole prior to abandoning the hole. The bit cleared the seafloor at 0200 hr, 25 June. We circulated seawater through the pipe to clean any remaining cement residue before tripping back to the ship. While tripping out of the hole, the inner diameter of the pipe was coated with rust-inhibitor.

The bit cleared the rig floor at 0600 hr, 25 June. The backup beacon was recovered at 0230 hr, 25 June, while the drill string was being retrieved. The primary beacon would not release, despite the installation and testing of a new release mechanism immediately prior to deploying it at this site. The ship was secured for transit and departed at 0715 hr, 25 June, for a rendezvous with the *M/V RESE*, approximately 20 nmi off of Malaga, Spain. The transfer occurred at approximately 1400 hr, 25 June.

TRANSIT TO LEITH, SCOTLAND

After picking up two passengers and provisions off Malaga, the vessel headed toward the Strait of Gibraltar to begin the sea voyage to Leith. The 1831-nmi sea voyage from Site 979 through the straits to Leith required 179.25 hr at an average speed of 10.42 kt. At 2400 hr, 28 June, the clocks aboard *JOIDES Resolution* were retarded by 1 hr. Due to very favorable weather and sea conditions, the vessel made excellent time and arrived 24 hr ahead of schedule. The pilot was picked up at 1530 hr, 2 July, and *JOIDES Resolution* entered the harbor locks at 1700 hr. The ship docked at the Imperial Fuel Dock #5, with the first line ashore at 1730 hr, 2 July, ending Leg 161.

Total transit distance covered during Leg 161 was 2930 nmi, requiring 287 hr at an averaging speed of 10.21 kt. Surveying amounted to 130 nmi in 23.25 hr at an average speed of 5.6 kt.

ODP LEG 161

OPERATIONS SUMMARY

Total Days (3 May, 1995 - 2 July, 1995)	61.4
Total Days in Port	3.5
Total Days Underway	13.8
Total Days on Site	44.1

Stuck Pipe/Downhole Trouble	0.7
Tripping	5.0
Other	0.6
Drilling	1.7
Coring	28.1
Re-entry	0.8
Logging/Downhole Science	6.7
Fishing & Remedial	0.0
Repair Time (ODP)	0.4
Development Engineering	0.0
Repair Time (Contractor)	0.0
WOW	0.0
Casing & Cementing	0.1

Total Distance Traveled (nmi)	3060.0
Total Miles Transited (nmi)	2930.0
Average Speed Transit (kt)	10.2
Total Miles Surveyed (nmi)	130.0
Average Speed Survey (kt)	5.6
Number of Sites	6
Number of Holes	16
Total Interval Cored (m)	4591.3
Total Core Recovered (m)	3874.63
% Core Recovery	84.4
Total Interval Drilled (m)	737.6
Total Penetration (m)	5328.9
Maximum Penetration (m)	928.7
Maximum Water Depth (m from drilling datum)	3469.7
Minimum Water Depth (m from drilling datum)	1074.0

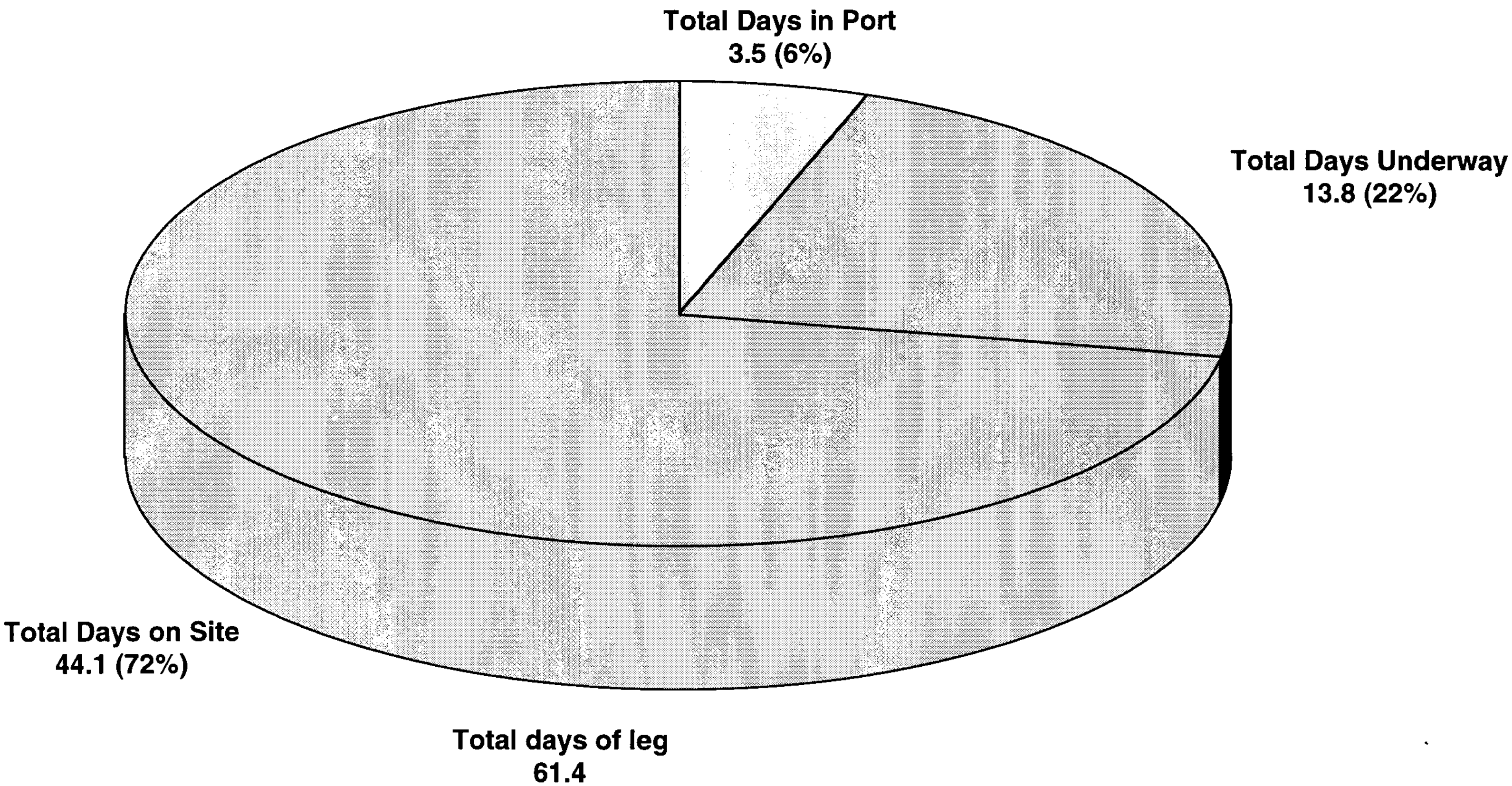
OCEAN DRILLING PROGRAM

SITE SUMMARY

LEG 161

HOLE	LATITUDE	LONGITUDE	WATER DEPTH (meters)	NUMBER OF CORES	INTERVAL CORED (meters)	CORE RECOVERED (meters)	PERCENT RECOVERED (percent)	DRILLED (meters)	TOTAL PENETRATION (meters)	TIME ON HOLE (hours)	TIME ON SITE (days)
974A	40 21.364 N	12 08.506 E	3469.7	1	9.5	9.81	103.3%	0.0	9.5	13.3	0.55
974B	40 21.362 N	12 08.515 E	3464.7	22	203.7	208.22	102.2%	0.0	203.7	30.8	1.28
974C	40 21.348N	12 08.534E	3464.1	22	204.5	199.85	97.7%	0.0	204.5	45.3	1.89
974D	40 21.357 N	12 08.520 E	3464.9	18	163.0	170.49	104.6%	0.0	163.0	20.5	0.85
	Site 974 Totals			**63**	**580.7**	**588.37**	**101.3%**	**0.0**	**580.7**	**109.75**	**4.57**
975A	38 53.795N	04 30.587E	2427.6	1	9.5	9.91	104.3%	0.0	9.5	6.50	0.27
975B	38 53.786N	04 30.596E	2426.4	34	317.1	298.97	94.3%	0.0	317.1	42.25	1.76
975C	38 53.795N	04 30.596E	2426.1	34	313.7	307.66	98.1%	0.0	313.7	56.50	2.35
975D	38 53.805N	04 30.605E	2426.1	16	149.9	157.17	104.8%	0.0	149.9	17.25	0.72
	Site 975 Totals			**85**	**790.2**	**773.71**	**97.9%**	**0.0**	**790.2**	**122.50**	**5.10**
976A	36 12.318N	04 18.800W	1118.6	1	5.9	5.92	100.3%	0.0	5.9	8.00	0.33
976B	36 12.313N	04 18.763W	1119.1	106	928.7	535.54	57.7%	0.0	928.7	267.75	11.16
976C	36 12.313N	04 18.735W	1119.5	40	379.7	340.16	89.6%	0.0	379.7	47.00	1.96
976D	36 12.330N	04 18.744W	1119.0	4	30.0	30.79	102.6%	0.0	30.0	5.00	0.21
976E	36 12.323N	04 18.744W	1119.0	28	192.5	64.85	33.7%	543.8	736.3	111.75	4.66
	Site 976 Totals			**179**	**1536.8**	**977.26**	**63.6%**	**543.8**	**2080.6**	**439.50**	**18.32**
977A	36 01.907N	01 57.319W	1995.5	63	598.5	545.49	91.1%	0.0	598.5	159.25	6.64
	Site 977 Totals			**63**	**598.5**	**545.49**	**91.1%**	**0.0**	**598.5**	**159.25**	**6.64**
978A	36 13.867N	02 03.424W	1941.0	53	504.2	406.66	80.7%	193.8	698.0	130.50	5.44
	Site 978 Totals			**53**	**504.2**	**406.66**	**80.7%**	**193.8**	**698.0**	**130.50**	**5.44**
979A	35 43.427N	03 12.353W	1074.0	62	580.9	583.14	100.4%	0.0	580.9	95.50	3.98
	Site 979 Totals			**62**	**580.9**	**583.14**	**100.4%**	**0.0**	**580.9**	**95.5**	**3.98**
	LEG 161 TOTALS:			**505**	**4591.3**	**3874.63**	**84.4%**	**737.6**	**5328.9**	**1057.00**	**44.05**

LEG 161
TOTAL TIME DISTRIBUTION



TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 161 were:

Laboratory Officer:	Burney Hamlin
Marine Laboratory Specialist (Photography):	Roy Davis
Marine Laboratory Specialist (Storekeeper):	John Dyke
Marine Computer Specialist:	John Eastlund
Marine Laboratory Specialist (Paleomagnetics):	Edwin Garrett
Assistant Laboratory Officer (U/W Laboratory):	Dennis Graham
Marine Laboratory Specialist (Thin Section):	“Gus” Gustafson
Marine Laboratory Specialist (Yeoperson):	Michiko Hitchcox
Marine Computer Specialist:	Rick Johnson
Marine Laboratory Specialist (Physical Properties):	Taku Kimura
Marine Electronics Specialist:	Eric Meissner
Marine Laboratory Specialist:	Andrew Mikitchook
Marine Electronics Specialist:	Dwight Mossman
Marine Laboratory Specialist (Chemistry):	Chieh Peng
Marine Laboratory Specialist (Chemistry):	Phil Rumford
Marine Laboratory Specialist (X-ray):	Don Sims
Marine Laboratory Specialist (Curatorial Representative):	Lorraine Southey

PORT CALL: NAPOLI (NAPLES)

The port call supporting Leg 161 was conducted at Naples, Italy from 3 May to 6 May, 1995. A bus took the technical staff and a few scientists from the hotel to the *JOIDES Resolution*, which was moored at the city's passenger terminal.

The movement of freight and cores was prompt and well coordinated. Moving the cores off the ship on 4 May took most of the working day. Chemistry laboratory training and curatorial preparation for the very close first site somewhat reduced the labor pool. The cores were shipped for archiving to the Bremen Core Repository, Federal Republic of Germany.

Keith Hall, a technical representative from GEOCAB NOR in the United Kingdom, conducted two days of training and service on the GEOFINA Hydrocarbon Meter (GHM), instructing the chemists on both crews.

VIP tours for 80 visitors were hosted by Dr. Jack Baldauf and Dr. Jamie Allan; general tours on Saturday for the public were guided by Italian scientists. Several hundred visitors were accommodated.

The ship sailed from Naples at 1815 hr, 6 May, for proposed site MedSap-5 (Site 974). The Spanish observer, J. M. Azanon, was unable to sail for medical reasons.

UNDERWAY

Navigation tapes were initiated as we left port, but watches were not formally begun, as Site 974 was only 8 hr out of port. The first beacon was dropped at 0345 hr, 7 May, at the GPS coordinate for the site; drilling activities commenced.

Regular underway watches began at 1930 hr, 12 May, initiating Line 2T. A strong weather front moved through the region as the ship passed south of Sardinia, resulting in some sharp rolls and uncomfortable motion. On 13 May, a 5.5-hr survey with one 80-in.^{3} water gun was made over proposed site MedSap-6A (Site 975), resulting in good seismic records.

On 19 May, Line 3T was made underway to proposed site Alb-2 (Site 976), beginning at 0330 hr.

At 1530 hr, the ship arrived at the survey point. Some remedial work was done en route on the starboard magnetometer sensor. Water guns were rigged to use a 200-in.^{3} gun for one segment of the seismic and an 80-in.^{3} gun for the other segment. This survey lasted 8.5 hr, and good records were obtained. Several brief bursts of 60 Hz noise were noted on the flatbed recorders and the digital record; the reason for this noise remains unknown. This site, in the middle of the shipping lane of the Strait of Gibraltar, resulted in a steady parade of ships passing, with 200 radar contacts logged during the first day.

Line 4T to proposed site Alb-4B (Site 978) was made on 8 June, and a seismic survey using a 200-in.^{3} water gun was conducted. A 5-hr single line crossing of the proposed site was conducted, and a position just off the track was selected.

Line 5T to proposed site Alb-2A, conducted on 15 June, was a depth-only line, and Line 6T to proposed site Alb-3A on 21 June was a depth and magnetics line, both to GPS positions on previous seismic lines.

Operations at the last site, proposed site Alb-3C (Site 979), were concluded on 25 June. Transit Line 7T to Leith, Scotland, was conducted via a rendezvous way point off Malaga, Spain. Magnetics records were terminated in shallow water upon leaving the Bay of Biscay, and formal underway watches ended at 1800 hr, 29 June, in the English Channel.

Backup procedures for the navigation system were tested and written to be included in the laboratory procedures manual. A multi-segment feature of the latest version of the WINFROG navigation system was successfully utilized, allowing the graphics display to move automatically from one line to another. It is now possible to keep track of total distances. Also, procedures to produce color plots of the surveys and ship tracks were written.

OPERATIONS

A rendezvous with the vessel *Christina* was effected on 23 May, allowing the two-person French film crew to depart and a replacement Spanish observer, Dr. Juan Soto, to join the scientific staff.

Captain Oonk observed that the *Christina* would not be suitable for the rendezvous proposed for 23 June, as there was no deck space on which to land the planned freight. Two DHL packages were received.

A second rendezvous was effected on 25 June, with the *M/V RESE* as a way point on the transit to Leith, Scotland. Two members of the ODP staff joined the ship with materials for office remodeling. A crate of special drilling tools for the ALVIN Project was offloaded.

CURATION

Leg 161 was a heavy-recovery leg and was complicated by several special sampling and handling programs for sapropels, gypsum, frozen WHO ephemeral organic samples, and hard rock (continental basement).

The first site was so close to port that no sampling classes could be scheduled, and around-the-clock “on the job” training was conducted.

Many of the cores were gassy, providing an opportunity for the assistant curator to review curatorial procedural guidelines for “closing up voids” and policies on “curating gas voids.”
A mud-line depth error at Site 978 resulted in record corrections for 53 cores.

CORE LABORATORY

Our resources became strained due to a preference for using plastic wrap on all cut cores measured with the color scanner. Warnings from the previous leg dictating the use of Saran wrap vs. Handiwrap (with no documentation) resulted in a shipboard test of the products that satisfied these users. The analysis supported the use of Saran wrap as a preferred product but vindicated the use of Handiwrap if it were needed. The results are included with this report.

The incandescent track lamps over all core laboratory work areas were replaced with halogen fixtures. Initial placements over the description and auxiliary tables proved to be too bright; one fixture from each track was removed, and the others were repositioned.

PALEOMAGNETICS LABORATORY

The cryogenic magnetometer was in use continuously during the entire leg, a situation that resulted in regular use of the troublesome MOLSPIN spinner magnetometer for discrete samples. Mechanical fixes kept both units functional, but problems with the interface boxes and control software mandated that they be used in manual mode only, a slow and tedious process. The problem was studied on the transit to Leith, and the results will be submitted to the laboratory working group.

Problems persist with weakly magnetized material being overprinted by drilling operations.

PHYSICAL PROPERTIES LABORATORY

Few problems were associated with the equipment in this laboratory. A replacement pycnometer proved trouble-free, although it was a little more complicated to operate. The MST was used heavily with no problems attributed to the drive mechanism, computers, or sensors. Maintenance of the other laboratory equipment was routine.

CHEMISTRY LABORATORY

Two of the days during port call focused on training and servicing of the GEOFINA hydrocarbon meter, leaving only 2 days to prepare the laboratory for the first site. The poor functioning of several instruments was attributed to work and repair inexperience.

The chemistry laboratory supported an aggressive high-resolution carbonate and interstitial-water sampling program associated with the sapropel recovery. Gas monitoring for safety and for science was also conducted.

X-RAY LABORATORY

XRD and XRF analyses were routine and trouble-free, although the workload was high. This was the first opportunity to use the NT-2100 XRF bead maker. For the most part, problems associated with learning the idiosyncracies of a new piece of equipment and of analyzing continental rock types were surmounted. Operational notes were added to the Japanese manual, and procedures were established for future specialists.

PALEONTOLOGY LABORATORY

While the laboratory was very busy, with four paleontologists and a heavy workload of samples, there were few notable problems. Replacement computers with video-capturing capabilities were installed. The FOSSILIST database functioned more successfully than during previous legs, and suggestions for improvements were documented.

COMPUTER SERVICES

A major hardware upgrade to the Macintosh component of the computing system was accomplished, replacing the Mac IIsi's and Iix's with nineteen Power Mac 7100's. Few software incompatibilities were observed; some potential problems were addressed by installation of updated software versions. A major effort was made to update the hardware and network databases to reflect the changes and accommodate the components that will remain on board. Also, two SUN workstations were installed, one in the Co-Chiefs' office and the other for use by the system managers.

NOVELL and cc:MAIL were installed during Leg 160, and testing and assessment of the systems continued during Leg 161. cc:MAIL files are transmitted one at a time and are mostly small, thus never allowing the modems and satellite links to achieve the faster data transfer rates that are possible. Archiving of the WORM data onto magneto-optical disks continued.

A new systems manager, Rick Johnson, was introduced to the computing environment on board *JOIDES Resolution*.

MICROSCOPES AND PHOTOGRAPHY LABORATORY

Besides configuring the microscopes to meet the needs of the scientists, two video imaging systems and capture boards were added to the laboratory computers. This system allows the scientists to reference photomicrographs for inclusion in the 4th Dimension FOSSILIST database. The two replacement Mac 7100's serviced this database. The original imaging system was retained.

Several items in need of repair were prepared for shipment, and several objectives were returned to ODP Science Operations for use ashore.

Operations and support in the Photography Laboratory were routine.

ELECTRONICS SUPPORT

Assistance and support were required for several laboratories. Chemistry equipment requiring electronics and mechanical repairs included the Rock-Eval, CNS, and one gas chromatograph. In the Paleomagnetics Laboratory, the MOLSPIN mini-spinner interface boxes were problematic, as were mechanical components in the unit. The GEOMETRICS magnetometer sensors were rebuilt when their signal became noisy. A device was built to enable the WINFROG navigation software to trigger the SUN seismic workstation, as well as the gun trigger box and the analog recorders, simplifying one gun operations. A means to let WINFROG access the magnetic values through the SUN workstation was also implemented.

The heat-flow objectives for the leg were met with ADARA tools in the APC cores and several WSTP runs in the deeper XCB portions of two holes. Temperature plots were provided.

Routine service and regular attention to the XEROX machines resulted in serviceable copies from both machines.

STOREKEEPING

The shipment of supplies to Naples was received, and offgoing cores and freight were shipped during the first 3 days of port call. An express shipment was closed and shipped on the last day in port.

There were some modifications made to MATMAN to reflect new items and changes in usage. Physical counts were made in two storage areas.

A large shipment of frozen samples was prepared for shipment to the Bremen Core Repository in the Federal Republic of Germany; this repository will also receive the Leg 161 core shipment.

SPECIAL PROJECTS

Refitting of the Co-Chief Scientists’ and Staff Representatives’ office was initiated during the transit to Scotland, displacing these personnel to the library.

Several long-standing requests for remedial work by SEDCO were accomplished during this leg, including catwalk maintenance, refrigeration manifold refurbishment, and carpet and plumbing replacements in a few of the living quarters. Components were replaced in the TRANE air handler. The port hose handler was relocated forward when the explosives locker frame was removed, and some vent and drain pipes were replaced on the lab stack.

SAFETY

While chemicals were being stored during port call, a 2.5-L bottle of methylene chloride was broken in the entrance to the refrigerated flammable liquids and solvents locker on the lower ’tween deck. The area was evacuated, then cleaned up by a team wearing respirators and protective clothing. Stored chemicals and the duck boards were removed from the locker and decontaminated. The spill was picked up with absorbent and then burned.

Manufacturers of these and other chemicals do not offer smaller packages, which makes them more difficult to ship and increases the chance of contamination for small-volume users and hazards during an accident.

There were two incidents involving the chemists working with the coulometer. In one instance, the individual became sensitive to the fumes associated with changing samples; the other was subjected to fumes while changing the solutions, making the individual sick. The unit was relocated into a fume hood as a precaution until procedures are reviewed. The unit has been in service in the chemistry laboratory for over 10 years.

Safety glasses were routinely used by the technical staff while working on the catwalk. There was routine ODP participation with the SEDCO fire team.

PROBLEMS

Some cases of dermatitis were treated during this leg. Typically, a few women become sensitive, but occasionally a man. Harsh soaps and cleaners, or incomplete rinsing, were singled out as the most likely cause of this problem. Bulk industrial soaps have been replaced by name brands, such as Tide, which was used during this leg. The problem persists with no direct cause and effect discovered. Requests for less soap or an extra rinse cycle when requestors’ clothes were washed were accommodated.

Refurbishing of the forward tanks was begun during this leg. As this cutting, welding, and fitting are close to many of the main deck cabins and the pipes pass through the quarters, sleep became disrupted. Air and welding leads were fed to the work area from the main deck entrance to the galley and then down the S deck ladder. The replacement of the emergency generator silencer progressed into deck repair and drain-line refurbishing, and allowed access to a decayed drain vent in the Paleontology Laboratory. This effort lasted a week and disrupted personnel working nearby.

Sandblasting was initiated on the bridge wings; associated mess and noise, again all telegraphing to the F and M decks, resulted in disturbance to the scientists and technicians.

LEG 161 LABORATORY STATISTICS

GENERAL

Sites:	6
Holes:	16
Meters Drilled:	738
Meters Cored:	4591
Meters Recovered:	3874
Time on Site (days):	44.04
Number of Cores :	505
Number of Samples:	19781
Number of Core Boxes:	574

DOWNHOLE TOOLS

ADARA HF:	20
WSTP HF:	2

ANALYSIS

Magnetics Laboratory	
Half section measurements:	2500
Discrete measurements:	250
Physical Properties Laboratory	
Index properties:	1285
Velocity:	2421
Thermal conductivity:	693
MST:	3101
Chemistry Laboratory	
Inorganic Carbonates ($CaCO_3$):	1441
Water Chemistry (pH, alkalinity, sulfate, calcium, magnesium, chlorinity, potassium, silica, lithium):	143
Head Space Gas Analysis:	383
Pyrolysis Evaluation (Rock-Eval):	136
X-Ray Laboratory	
XRD:	895
XRF:	12

THIN SECTIONS 94

UNDERWAY GEOPHYSICS (ESTIMATED)

Total Transit (nmi):	3060
Bathymetry (nmi):	1874
Magnetics (nmi):	1733
Seismic (nmi):	130
XBT's Used:	37