OCEAN DRILLING PROGRAM

LEG 173 PRELIMINARY REPORT

RETURN TO IBERIA

Dr. R.B. Whitmarsh
Co-Chief Scientist, Leg 173
Challenger Seafloor Processes Division
Southampton Oceanography Centre
European Way
Southampton SO14 3ZH
United Kingdom

Dr. Marie-Odile Beslier
Co-Chief Scientist, Leg 173
Géosciences Azur
Observatione Océanologique
B.P. 48
06235 Villefranche-sur-Mer Cedex
France

Dr. Paul Wallace
Staff Scientist, Leg 173
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.

Paul J. Fox
Director
of Science Operations
ODP/TAMU

Thomas A. Davies
Manager
Science Services
ODP/TAMU

Timothy J.G. Francis
Deputy Director
of Science Operations
ODP/TAMU

August 1997

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Preliminary Report No. 73

First Printing 1997

Distribution

Electronic copies of this publication may be obtained from the ODP Publications Home Page on the World Wide Web at http://www-odp.tamu.edu/publications.

D I S C L A I M E R

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

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

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

Technical Editor: Karen K. Graber

SCIENTIFIC REPORT

The following scientists were aboard *JOIDES Resolution* for Leg 173 of the Ocean Drilling Program:

Robert B. Whitmarsh, Co-Chief Scientist (Challenger Seafloor Processes Division, Southampton Oceanography Centre, European Way, Southampton SO14 3ZH, United Kingdom, Internet: bob.whitmarsh@soc.soton.ac.uk)

Marie-Odile Beslier, Co-Chief Scientist (Géosciences Azur, Observatoire Océanologique, B.P. 48, 06235 Villefranche-sur-Mer Cedex, France, Internet: beslier@ccrv.obs-vlfr.fr)

Paul J. Wallace, Staff Scientist (Ocean Drilling Program, 1000 Discovery Drive, College Station, Texas 77845, U.S.A., Internet: Paul_Wallace@odp.tamu.edu)

Natsue Abe, Petrologist (Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo, Japan, Internet: abenatsue@geo.titech.ac.jp)

Christophe Basile, JOIDES Logging Scientist (Institut Dolomieu, Laboratoire de Geodynamique des Chaines Alpines, Université Joseph Fourier, 15 rue Maurice Gignoux, 38031 Grenoble Cedex, France, Internet: cbasile@ujf-grenoble.fr)

James S. Beard, Petrologist (Department of Earth Sciences, Virginia Museum of Natural History, 1001 Douglas Avenue, Martinsville, Virginia 24112, U.S.A., Internet: jbeard@neocomm.net)

Véronique Gardien, Petrologist (Laboratoire de Pétrologie et Tectonique, Université Claude Bernard-Lyon I, UMR 5570, Bat 402, 43 Boulevard du 11 Novembre 1918, Villeurbanne 69622, France, Internet: vgardien@univ-lyon1.fr)

Nikolaus Froitzheim, Structural Geologist (Geologisch-Paläontologisches Institut, Basel University, Bernoullistrasse 32, 4056 Basel, Switzerland, Internet: froitzheim@ubaclu.unibas.ch)

Réjean Hébert, Petrologist (Département de Géologie et de Génie Géologique, Pav. Adrién-Pouliot, Université Laval, Ste-Foy, G1K 7P4, Quebec, Canada, Internet: hebert@ggl.ulaval.ca)

Laurence J. Hopkinson, Petrologist (Department of Geology, Southampton Oceanography Centre, University of Southampton, Empress Dock, European Way, Southampton SO14 3ZH, United Kingdom, Internet: L.Hopkinson@soc.soton.ac.uk)

Kristen E. Kudless, Sedimentologist (Department of Geological Sciences, Ohio State University, 125 South Oval Mall, Columbus, Ohio 43210, U.S.A., Internet: kristen@orton.mps.ohio-state.edu)

Véronique Louvel, LDEO Logging Scientist (Laboratoire de Mésures en Forage, IMT Technopole de Chateau Gombert, 13451 Marseille Cedex 20, France, Internet: louvel@imtmer1.imt-mrs.fr)

Gianreto Manatschal, Structural Geologist (Geologisches Institut, ETH-Zürich, CH-8092 Zürich, Switzerland, Internet: gian@erdw.ethz.ch)

Adrian C. Newton, LDEO Logging Trainee (Department of Geology, Leicester University, University Road, Leicester LE1 7RH, United Kingdom, Internet: acn7@le.ac.uk)

Michael J. Rubenach, Petrologist (Department of Earth Sciences, James Cook University, Townsville, 4811 Queensland, Australia, Internet: michael.rubenach@jcu.edu.au)

Alasdair D.L. Skelton, Petrologist (Grant Institute, Department of Geology and Geophysics, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, United Kingdom), Internet: askelton@glg.ed.ac.uk, Work: 44-131-650-5885, Fax: 44-131-668-3184

Susan E. Smith, Petrologist/Geochemist (Department of Geosciences, University of Houston, 4800 Calhoun, Houston, Texas 77204-5503, U.S.A., Internet: sesmith@uh.edu)

Hideo Takayama, Physical Properties Specialist (Geological Institute, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan, Internet: takayama@geol.s.u-tokyo.ac.jp)

Michael J. Tompkins, Physical Properties Specialist (Department of Earth and Atmospheric Sciences, Purdue University, 1397 Civil Engineering Building, West Lafayette, Indiana 47906, U.S.A., Internet: tompkins@geo.purdue.edu)

Brent D. Turrin, Paleomagnetist (Lamont-Doherty Earth Observatory, Route 9W, Palisades, NY 10964, U.S.A., Internet: brentt@ideo.columbia.edu)

Elspeth Urquhart, Paleontologist--Foraminifers (Department of Geological Sciences, University College London, Gower Street, London W4E 6BT, United Kingdom, Internet: e.urquhart@ucl.ac.uk)

Hans-Joachim Wallrabe-Adams, Sedimentologist (GEOMAR Research Center, Wischhofstrasse 1-3, D-24148 Kiel, Germany, Internet: hjwallrabe@geomar.de)

Roy H. Wilkens, Physical Properties Specialist (Hawaii Institute of Geophysics and Planetology, 2525 Correa Road, Honolulu, Hawaii 96822, U.S.A., Internet: wilkens@soest.hawaii.edu)

Richard C.L. Wilson, Sedimentologist (Department of Earth Sciences, The Open University, Milton Keynes MK7 6AA, United Kingdom, Internet: r.c.l.wilson@open.ac.uk)

Sherwood W. Wise, Jr., Paleontologist--Nannofossils (Department of Geology, Tallahassee, Florida 32306-3026, U.S.A., Internet: wise@gly.fsu.edu)

Xixi Zhao, Paleomagnetist (Department of Earth Sciences, Institute of Tectonics, University of California, Santa Cruz, Santa Cruz, California 95064, U.S.A., Internet: xzhao@earthsci.ucsc.edu)

ABSTRACT

During Leg 173, five sites (Sites 1065, 1067, 1068, 1069, and 1070) were drilled and cored along an east-west transect begun during Leg 149 across the ocean-continent transition (OCT) of the West Iberia continental margin. The main objective of Leg 173 was to investigate the mechanisms of thinning and breakup of the continental lithosphere and the early stages of oceanic crust formation. Subsidiary objectives were to better characterize the OCT, constrain the tectonometamorphic evolution of the continental and oceanic basement, determine the extent of synrift magmatism, examine the nature of the oldest oceanic crust, and investigate the early sedimentary history of the rifted margin. Basement rocks were cored under the sedimentary cover at the tops of structural highs. From east to west, Sites 1065, 1067, 1068, and 1069 lie within the OCT, and the westernmost Site 1070 is located over presumed early oceanic crust. Continental crust appears to underlie Sites 1065 and 1069; the latter site is probably an isolated continental fault block flanked to east and west by synrift melt products and/or exhumed mantle. The basement at Site 1067 consists of a 92-m-thick sequence of mafic rocks (amphibolite, tonalite gneiss, and meta-anorthosite), with enriched to normal mid-ocean ridge basalt tholeiitic affinities that probably represent differentiated products of synrift mantle melting. The meta-anorthosite and the tonalite gneiss are intrusive in the amphibolites. A ductile shear zone developed in the amphibolite at a level that is now at the top of the basement. Site 1068, located on the western flank of the same structural high, encountered breccias with clasts similar to the basement lithologies at Site 1067, and then, after drilling through a fault zone, serpentinized peridotite. The superposition of mafic rocks over ultramafics indicates that the strong seismic reflector that cross cuts the top of the basement on this structural high may be the crust/mantle boundary rather than a major synrift tectonic contact. Site 1070 was located in a region characterized by an oceanic crustal structure that is abnormally thin compared to typical oceanic crust and by seafloor-spreading magnetic anomalies. Basement at this site consists of serpentinized peridotite intruded by gabbroic veins, one of which is pegmatitic. The gabbroic veins may represent the early stages of seafloor spreading mantle melting, but no evidence of upper oceanic crust (lavas or sheeted dikes) was found.

INTRODUCTION

Rifted margins contain the principal record of the breakup that follows continental rifting and the onset of seafloor spreading, both of which are first-order plate tectonic processes. Such margins exhibit a wide spectrum of characteristics, probably in response to different combinations of asthenospheric temperature, lithospheric rheology, strain rate, stress and pre-existing heterogeneities. The rifting process, through the indirect effects of concurrent subaerial volcanism as well as greater sedimentation and heat flow, can also have important environmental and resource implications. Drilling commonly affords the only means of directly characterizing the nature, age, and emplacement conditions of igneous, metamorphic, and/or sedimentary rocks formed, deposited, or tectonically exposed during margin formation. Nonvolcanic margins in particular provide opportunities to investigate and understand the tectonic aspects of rifting for two reasons. First, normal faults and shear zones that penetrate deep into the crust and uppermost mantle are sometimes evident on seismic profiles and, as has been demonstrated on the west Iberia margin, allow rocks from deeper lithospheric levels to be exposed at the top of acoustic basement. Second, voluminous intrusives/extrusives, which can obscure crustal tectonics, are limited in volume and are commonly absent. Pairs of conjugate rifted margins often exhibit some asymmetry in structural style that may be related to the mode of lithospheric rifting (e.g., pure or simple shear).

The west Iberia margin (Fig. 1) is an excellent example of a nonvolcanic rifted margin. The Galicia Bank and Iberia Abyssal Plain segments of the margin were cored during Ocean Drilling Program (ODP) Legs 103 and 149, respectively, and have been sampled by submersible and studied extensively by geophysical methods. Iberia separated from the Newfoundland margin of the Grand Banks in the Early Cretaceous, after prolonged rifting that began in the Late Triassic (Wilson et al., 1989; Welsink et al., 1989). The subsequent plate tectonic and seafloor-spreading history of this part of the North Atlantic is mostly well constrained by seafloor-spreading magnetic anomalies and demonstrates that Iberia drifted away from North America and moved apart along roughly east-west fracture zones (e.g., Klitgord and Schouten, 1986). During the short-lived Late Cretaceous opening of the Bay of Biscay, a ridge-ridge-ridge triple-point existed off northwest Spain (Sibuet and Collette, 1991). However, throughout its post-rift history, the west Iberia margin has remained an essentially undisturbed rifted margin that has experienced only minor compression in the north during the Eocene (Pyrenean phase, short-lived subduction of Bay of Biscay crust under northern Spain) and in the south and center during the middle Miocene (Rif-Betic phase, gentle folding of abyssal plain sediments).

Offshore, the west Iberia continental margin has been studied extensively by geophysical techniques and, to a lesser extent, by geological sampling (e.g., Beslier et al., 1990, 1993; Boillot et al., 1987, 1988, 1995; Girardeau et al., 1988; Hoffman and Reston, 1992; Sawyer et al., 1994; Whitmarsh et al., 1990, 1993; Whitmarsh and Miles, 1995; Whitmarsh et al., 1996). It exhibits tilted continental fault blocks that often, but not always, seem to lack a wedge of synrift sediments (Reston, 1996; Wilson et al., 1996). There is an apparent lack of synrift volcanism offshore and significant synrift volcanism is equally absent onshore. Tilted fault blocks and a lack of volcanism are both characteristics of a nonvolcanic rifted margin. The first drilling of the OCT off the west Iberia margin was carried out by ODP Leg 103 in 1985 (Boillot, Winterer, Meyer, et al., 1988). During this leg, a short transect of holes was drilled west of Galicia Bank (Sites 637-641). In 1991, the recommendations of the North Atlantic Rifted Margin Detailed Planning Group were accepted by the JOIDES Planning Committee, which programmed two drilling legs in the North Atlantic during 1993. During one of these (Leg 149), a transect of holes was drilled into acoustic basement across the ocean-continent transition (OCT) in the southern Iberia Abyssal Plain (Sawyer, Whitmarsh, Klaus, et al., 1994).

In the Iberia Abyssal Plain, results of ODP Leg 149 defined landward and oceanward limits to the OCT where the transition zone is defined as the region between a margin-parallel peridotite ridge, marking the landward edge of oceanic crust, and the most seaward tilted fault block of continental crust (Fig. 2). However, only one hole penetrated basement in the 130-km-wide region between these limits. The main objectives of Leg 173 were as follows:

1. Sample acoustic basement, principally within the OCT, to characterize the tectonic and magmatic processes that dominate the transition from continental to oceanic crust in space and time.
2. Determine the role of detachment tectonics in the evolution of the margin by drilling through a seismic reflector which has been interpreted as a major tectonic contact or detachment on the east side of the basement high where Site 900 has already been drilled.
3. Determine the role and extent of synrift magmatism in the OCT basement, which is inferred to

exist from the new magnetic anomaly chart and other data.

4. Sample acoustic basement beneath Site 901 or Site Iberia-8A/8B to confirm the predicted existence of continental crust there and to determine from which approximate original crustal level it came, thereby setting an unequivocal landward limit to the OCT and defining geometrical relationships between deep and shallow lithospheric levels.
5. Sample the early formed oceanic crust to complete the whole transect from continental to oceanic crust.
6. Investigate the early sedimentary history of the rifted margin.

SUMMARY OF DRILLING RESULTS

During Leg 173, five sites were drilled and cored in the southern Iberia Abyssal Plain (Sites 1065, 1067, 1068, 1069 and 1070; see Figs. 1 and 2). Site 1066 was the location of a jet-in test for setting a reentry cone that was never used.

Site 1065

Site 1065 lies in a water depth of 4770 m near the northern edge of the Iberia Abyssal Plain. The site is crossed by a single east-west time-migrated seismic reflection profile that shows a large basement high with relief of 1.7 s two way traveltime (TWT; ~2000 m) on its west side, conformably overlain by 0.2-0.35 s TWT of seismically transparent sediment on its landward side. This basement high is the largest of a series of highs on the seismic profile that reduce in relief westward. On time sections, these highs are bounded on their oceanward (west) sides by strong curved reflectors. These reflectors are probably normal faults that were involved in the rifting process, and their presence suggests that the high is a fault block. The basement high and the transparent sediments are overlain by subhorizontally layered post-rift sediments. The principal objective for this site was to identify the nature of the basement rocks and, if continental, to determine the approximate crustal level from which the rocks originated and their petrostructural evolution, to better constrain the modes of crustal thinning and breakup during a rifting episode. Ancillary objectives were to date the overlying pre-rift or synrift sediments and to determine the early subsidence history of the fault block.

Site 1065 was chosen to reach igneous or metamorphic rocks under a tilted fault block with the principal objective of demonstrating that the rocks were continental. While the shallow-water lithologies encountered in the pre-rift/synrift (Middle-Late Jurassic) sediments strongly indicated the presence of underlying continental crust, igneous or metamorphic basement was not reached; the acoustic basement reflection appears to be caused by lithification of Jurassic clays. No clear seismic reflection from the top of the crystalline crust could be discerned beneath the lithified clays.

The lithostratigraphic units used during Leg 173 were numbered so as to be consistent with the unit designations that were defined in this region during Leg 149. The sedimentary section in Hole 1065A (Fig. 3) consists of two lithostratigraphic units: slumped early Miocene nannofossil chalks (Unit II, >58 m thick) overlying Middle to Upper Jurassic clays, claystones, and dolomitic claystones (Unit V, >322 m). The light greenish gray to dark gray thinly bedded and laminated nannofossil chalks and claystones of Unit II were largely deposited from suspension as pelagites and hemipelagites. Pebbles of continental basement lithologies (slate and meta-arenite) and shallow-water limestones occur, and probably originated from the seamounts located ~30 km to the north of Site 1065. The limestones are very similar to Tithonian rocks recovered during Leg 103 from the Galicia Bank margin. Unit V is subdivided into two subunits. Dark greenish gray to medium dark gray soft clay dominates Subunit VA (192.7 m); these clays were remarkably plastic and very slow to drill. Subunit VB (>129.9 m) consists of claystone, some of which is dolomitic.

The structures observed in the cores almost exclusively indicate soft-sediment deformation. Unit II exhibits pervasive slump folds, closely-spaced microfault arrays with both extensional and contractional orientations, and low-angle clay-rich shear zones. Overprinting relations indicate a prolonged history of soft-sediment deformation. Bedding dips measured in the cores are highly variable because of the slumping. Lithostratigraphic Unit V is much less deformed than Unit II. After its deposition, Unit V was tilted into its present, moderately dipping orientation. Bedding dips measured in this unit range between 0˚ and 65˚ relative to the core reference frame. The mean dip is 18˚ with a standard deviation of 10˚.

Calcareous nannofossils are moderately to well preserved and abundant in the lower Miocene chalks of lithostratigraphic Unit II, but they are virtually absent in some intercalated siliceous claystones. Relatively undisturbed chalks at the top of Unit II cap the underlying slump complex, providing a minimum date of 16.4 Ma for slump emplacement, based on the absence of middle Miocene planktonic foraminiferal index taxa in the chalk. Small numbers of moderately to well-preserved nannofossils provide a Tithonian age for the upper portion of the pre-rift/synrift sediments (Cores 173-1065A-8R to 13R), but only long-ranging taxa are present down to Core 20. A 132-m barren interval separates this core from the lower 33 m of the hole, which contains dissolution-resistant nannofossils that may have been introduced with turbidites. These nannofossils constrain the age of the bottom of the section to Middle to Late Jurassic. Calcareous benthic foraminifers are very rare and occasionally pyritized within these older clastic sediments, which also contain rare, sporadic occurrences of poorly preserved, indeterminate agglutinated foraminifers.

Shipboard magnetostratigraphy within the early Miocene interval is not well defined because of the low core recovery, although there are distinct polarity changes in portions of the cores. The construction of a magnetostratigraphy over this interval is not possible because of the absence of adequate age control, poor recovery, and the disturbance caused by slumps. The Tithonian cores all have normal polarity except for a short reversed interval from 569.7 to 569.9 mbsf. A preliminary calculation of paleolatitude using the inclination data suggests that the drilling site was located about 29˚N during the Tithonian, indicating that 11˚ northward displacement of the region has occurred since the Late Jurassic.

Methane concentrations in headspace gases were very low, varying from 2 to 6 ppm, and concentrations of other hydrocarbons and CO, CO_2, and H_2S were generally below detection levels. Carbonate contents are relatively high in the chalks of lithostratigraphic Unit II (avg. 68%) and variable in the sediments of Unit V, ranging from values <1% in clay and claystone to around 60% in chalk and dolomitic claystone. Unit II sediments contain only trace amounts of organic carbon, but in Unit V organic carbon contents are quite variable, ranging from 0.1% to 0.85% (avg. 0.4%). The organic matter generally appears to have a marine origin. However, organic C/N values as great as 20 indicate a component of terrestrial material, consistent with the presence of microscopic plant fragments (charcoal) in some sediments.

Between 251.0 and 631.4 mbsf, wet bulk densities range from 1.7 to 2.8 g/cm^3, porosities vary between 2 and 60%, and acoustic velocity ranges from 1.7 to 5.7 km/s. Grain densities for all but two samples are almost constant around 2.75 g/cm^3. Although bulk densities increase and porosities decrease downward in general, there are two layers associated with lithologic (and most likely seismic) unit boundaries that have particularly low porosities, high bulk densities, and high velocities. One of these layers appears near 330 mbsf, which is just below the interface between lithostratigraphic Unit II and Subunit VA, and the other exists near 500 mbsf, near the boundary between Subunits VA and VB. These layers consist of limestone in which the maximum acoustic velocity is more than two times the velocity in the adjacent sediments.

Logging data correlated well with the lithologic units identified from core observations. A sharp increase of natural gamma ray, a clay-indicator, was observed between Units II and V (300–302 mbsf), as well as a pronounced decrease in the photoelectric effect, an indicator of atomic weight and hence indirectly of sediment type. Neutron porosity was generally high in Unit V, and may be attributed to the high-clay content of the formation and/or to the enlarged borehole. Resistivity increased smoothly with depth. The variable resistivity observed in Subunit VB is probably caused by bands of well-lithified claystone. The calipers revealed that the hole was washed out above 510 mbsf. The hole deviated slightly (1˚–2˚) in a northwest (350 mbsf) to northeast (600 mbsf) direction. Good-quality Formation MicroScanner (FMS) images were recorded in the lowest part of the hole. Preliminary analysis identified sedimentary layers dipping about 20˚ toward the east to northeast.

Site 1067

Site 1067 lies in a water depth of 5021 m near the northern edge of the Iberia Abyssal Plain. The primary objective at this site was to drill and core down through acoustic basement (supposedly early post-rift or synrift sediment or crystalline basement) to a strong extensive intrabasement reflector believed to represent a major synrift tectonic contact. This objective could not be met directly for technical and logistical reasons but was partly achieved by drilling at an offset location (Site 1068).

The principal result of this site was identifying a 92-m-thick sequence of mafic rocks (amphibolite, tonalite gneiss, and meta-anorthosite) that probably represents differentiated products of mantle melting with mid-ocean ridge basalt (MORB) tholeiitic affinities. They could represent former gabbro retrometamorphosed under amphibolite facies conditions. The meta-anorthosite and the tonalite gneiss are intrusive in the amphibolites. The intensity of the ductile deformation decreases from the top toward the bottom of the cored section. This observation suggests that a ductile shear zone developed in the amphibolite at a level which is now at the top of the basement.

Coring commenced at 648 mbsf in Hole 1067A, and 118.2 m of sediment was drilled before basement rocks were encountered at 763.8 mbsf (Fig. 4). The sediments are middle Eocene to late Paleocene in age, and consist of claystones, calcareous claystones, calcareous silty claystones, and calcareous siltstones/sandy siltstones/sandstones. The cored interval is very similar to sediments of the same age recovered 800 m to the west at Site 900. Therefore, the sediments drilled at Site 1067 are assigned to the lower part of Subunit IIB as defined at Site 900. Upward-darkening units between 3 and 25 cm thick dominate the succession. They show a basal siltstone/sandstone overlain by calcareous claystone and capped by claystone, and are interpreted as being deposited close to the carbonate compensation depth (CCD) by turbidites, with evidence of some reworking by contour currents. A two-cm-thick conglomerate horizon encountered in Paleocene sediments near the base of lithostratigraphic Subunit IIB contains 1–5 mm granules/pebbles of pale shallow-water limestones and dark gray pelite clasts that are similar in composition to clasts recovered in the Upper Jurassic and Miocene sediments drilled at Site 1065. Their presence suggests that metamorphic basement and Mesozoic shallow limestones were exposed in nearby uplifted areas, probably about 15 km to the north.

Calcareous benthic foraminifers are commonly present throughout the section, whereas agglutinated foraminifers occur only sporadically. Planktonic foraminifers in the core-catcher samples vary in abundance and preservation; this is thought to be facies controlled. A few horizons of fossiliferous foraminiferal chalk were identified. The interval between 658.4 nd 763.8 mbsf is assigned a Paleogene age based on planktonic foraminiferal recovery. All Okada and Bukry calcareous nannofossil zones are accounted for from Subzone CP13c (Zone NP15 of Martini) in Core 1067A-1R to Subzone CP8 (NP9) in Core 13R (representing early middle Eocene to late Paleocene).

Basement was first recovered at a depth of 763.8 mbsf. The basement consists largely of strongly to weakly foliated amphibolite. Tonalite gneiss and weakly to moderately deformed meta-anorthosite occur as veins or patches distributed throughout the recovered sections. Matrix-supported to grain-supported amphibolite breccia is also present. The basement has been divided into three units reflecting the dominant structural features (Fig. 4). Basement Unit 1 consists of strongly foliated amphibolite (locally brecciated) with regions of tonalite gneiss and minor epidosite. Unit 2 consists of matrix-supported amphibolite breccia with minor amphibolite, tonalite gneiss, moderately deformed meta-anorthosite, and cataclasite. Unit 3 consists of foliated to weakly foliated amphibolite with disseminated meta-anorthositic veins and patches. Within the Unit 3 amphibolite, relict igneous textures (metagabbro) are locally preserved. The Y and Zr contents of amphibolite and tonalite gneiss from Site 1067 are shown in Figure 5.

Foliation in the basement rocks is defined by elongate amphibole crystals, plagioclase lenses, and quartz ribbons, depending on the mineralogy and the intensity of the deformation. Dynamic recrystallization during shear deformation is extensive in quartz ribbons and locally observed in plagioclase lenses. Deformation intensity appears to decrease downward. The foliation is steeply dipping in the upper part of the cored section and less steep farther down (never less than 35°). Tonalite gneiss and meta-anorthosite occur as layers parallel or oblique to the foliation. Various types of folds occur throughout the section. Later fracturing, which is extensively but unevenly developed in the rocks, resulted in veins filled mainly with epidote, chlorite, and calcite and evolved locally into brecciation, particularly in Unit 2. In places they appear to be randomly oriented, but elsewhere epidote and chlorite veins tend to be shallow and are crosscut by steep calcite veins. Small-scale normal faults with steeply plunging slickensides occur throughout the section.

The physical properties of the claystones and sandstones fall into two distinct populations. Sandstone porosities are generally less than 20% and bulk densities greater than 2.4 g/cm^3, whereas claystone porosities are greater than 20% and bulk densities less than 2.4 g/cm^3. Compressional wave velocities in the claystones are relatively constant (about 2400 m/s). Sandstone velocities appear to increase with depth from less than 4000 m/s at 650 mbsf to 5700 m/s at 714 mbsf. Bulk densities of basement rocks vary from ~2.1 to 2.9 g/cm^3. Grain densities are uniformly high and relatively constant about a mean of 3.0 g/cm^3. Porosity is generally 10% or less. Velocities appear to be lithology dependent; breccias are less than 5000 m/s and amphibolites range from around 5000 m/s to over 6000 m/s, depending, most likely, on the amount of fracturing and alteration.

Pass-through measurements of the sediments yielded dominantly positive inclinations (normal polarity) indicating weak natural remanent magnetiziation (NRM) intensities. Progressive alternating field (AF) and thermal demagnetization failed to substantiate any polarity changes. The data suggest the presence of multiple overprints that may be related to phases of magnetite reduction and iron sulfide generation. Thus, it was not possible to construct a reliable magnetostratigraphy. Medium-grained metamorphosed mafic rocks from below 763.8 mbsf showed some resistance to AF demagnetization. Preliminary results for discrete samples show both normal and reversed magnetic polarity. The thermal demagnetization data, however, indicate the magnetization is complex and renders any polarity evaluation suspect. The unblocking temperatures and coercivities indicate that the dominant magnetic mineral in these samples is magnetite.

Site 1068

The primary objective at Site 1068 was to sample the crystalline basement just to the west of where a strong east-dipping seismic reflector, interpreted as a major synrift tectonic contact, intersects the top of the acoustic basement (i.e., to sample the lower plate to this contact). The site, located on the west flank of the same north-south trending basement high as Sites 900 and 1067 (600 m and 1400 m to the east, respectively), was chosen after technical problems rendered it impossible to reach the reflector and underlying terrane at Site 1067.

The principal result at this site was identifying ultramafic rocks that lie beneath a shallow east-dipping strong intrabasement reflector overlain by metagabbros, tonalite gneisses, amphibolites, and meta-anorthosites sampled at Sites 1067 and 900. Because serpentinized peridotites were also cored directly under the sediments at Site 897, located 80 km farther west, this result indicates that mantle rocks occur, at least as isolated outcrops in basement, over a broad region in the OCT.

Two subunits are recognized in the 139-m-thick sedimentary succession cored in Hole 1068A (Fig. 6). Lithostratigraphic Subunit IIB consists of upward-darkening sequences, 3 to 15 cm thick. These consist of a lower turbiditic calcareous sandy siltstone and calcareous claystone capped by a hemipelagic claystone. In Subunit IIC, the upward-darkening sequences are up to 45 cm thick and are largely dominated by nannofossil claystones and nannofossil chalks. Occasional laminated calcareous sandstones up to 15 cm thick occur within otherwise continuous claystone intervals, and are interpreted as lag deposits because of winnowing by contour currents. The bedding is shallowly dipping (~5˚).

Biostratigraphically, the calcareous claystone section of lithostratigraphic Unit II is essentially continuous and its age ranges from middle Eocene to Maastrichtian. Calcareous microfossils are common and generally well preserved at the tops of both the Eocene and Paleocene sections, but become less so toward the bottoms of those intervals, parts of which were deposited as microfossiliferous turbidites emplaced below the CCD. Planktonic foraminifers are variable in preservation and abundance. They indicate early Eocene (Zone P9) to late Paleocene (Zone P4). All Cenozoic Okada and Bukry calcareous nannofossil zones are present from Subzone CP12a (Zone NP14 of Martini) to CP1a (NP1a). An intact K/T boundary was not recovered as it has apparently been completely eroded away and/or thoroughly mixed within the bioturbated turbidites. *Micula prinsii* and *M. murus* in Section 14R-1 help to delineate the Cretaceous/Tertiary transition there.

The 42-m-thick sedimentary breccias drilled at Site 1068 are assigned to lithostratigraphic Unit IV to conform with the lithostratigraphic scheme devised during Leg 149. Subunit IVA (<14 m) consists of matrix-supported breccias, in which a few Tithonian-Lower Cretaceous limestone clasts occur, and in which the matrix consists of carbonate mudstone yielding Early Cretaceous nannofossils. It is interpreted to have been deposited by at least three separate debris flows. Subunit IVB (18.8 m) consists entirely of clast-supported breccias. Subunit IVC (8.9 m) consists of clasts showing jigsaw brecciation set in a cataclasite matrix that also contains sand- and silt-sized grains of clast material. These weakly to undeformed sedimentary breccias were probably deposited as talus deposits or rock falls at the foot of a fault scarp. The breccias of Unit IV consist of angular fragments of weakly to strongly foliated amphibolites, meta-anorthosites, and meta-gabbros in a calcite-rich matrix. These clasts record a retrograde metamorphic evolution and an intense deformation under conditions ranging from upper amphibolite facies to greenschist facies comparable to those of the Site 1067 amphibolites and Site 900 (Leg 149) metagabbros. Preliminary geochemical data reveal a tholeiitic compositional range that is intermediate between these two types of rocks (Fig. 5). Toward the base of Unit IV, the matrix is more chloritic and the breccias are increasingly overprinted by brittle deformation, cataclasis, and hydrothermal alteration, and rest along a tectonized contact. There is strong circumstantial evidence to suggest the hole penetrated a seaward-dipping normal fault at this depth.

Pervasively serpentinized upper mantle peridotites (60 m recovered) constitute basement Unit 1, the deepest acoustic basement unit (Fig. 6). The pervasive serpentinization of the rocks has left behind only relicts of spinels rimmed by chlorite probably derived from plagioclase, and locally from clinopyroxene, which suggests that these rocks are derived from plagioclase-bearing lherzolites comparable to those cored at Site 897 during Leg 149 (Fig. 7). Headspace gas samples from the serpentinite and serpentinite breccia contain as much as 6000 ppm methane and 1.2 ppm ethane, with no other detectable hydrocarbons. Such anomalously high methane values are probably a result of the process of serpentinization. The uppermost part of the serpentinized peridotite is a fault breccia (Subunit 1A), whereas in the lower part (Subunit 1B), a high-temperature foliation is marked by elongated spinels that dip 25˚ to 40˚ toward the west-southwest according to the paleomagnetic reorientation of one interval in the cored section. This foliation is overprinted by fractures filled with serpentine and chlorite.

The physical properties of the sediments vary on a small scale according to lithology within the repetitive sequence of calcareous sandstone, calcareous claystone, and claystone. The sandstones are the most dense, least porous, and have the highest velocities. Claystones are at the opposite end of the spectrum. In general, sandstone is not as abundant as the other two lithologies and the entire sedimentary section most probably has characteristics close to that of the calcareous claystone component (velocity ~2600-2800 m/s, density ~2.3 g/cm^3). Breccias in Unit IV have velocities almost double those of the overlying sediments (over 5000 m/s) and densities 10% to 20% greater (averaging around 2.6 g/cm^3). Below the breccia layer there is a velocity and density decrease at the contact with the underlying serpentinite of Subunit 1A. The serpentinite has a lower density (2.3 g/cm^3) by virtue both of lower grain density and higher porosity, while velocity is almost as low as in the claystones (2700 m/s).

Shipboard paleomagnetic results indicate a number of magnetic reversals between 711.3 and 855.9 mbsf. The combined biostratigraphic and paleomagnetic data indicate that these polarity zones span Chrons C29r to C21n. Wholecore magnetic susceptibility and intensity measurements and discrete samples reveal sharp peaks in brown claystone from 778.9 to 788.5 mbsf. This characteristic brown bed and the associated peaks in NRM intensity and volume susceptibility were also observed at nearby Sites 1067 and 900 and appear to provide a stratigraphic marker within the sediments of the Iberia Abyssal Plain. The bed may represent an abrupt change in the rate of supply of terrigenous material in the early Eocene. The NRM intensity and volume susceptibility of the serpentinite unit have average values consistently above 0.15 A/m and 0.002 SI units, respectively, suggesting that serpentinites could contribute significantly to magnetic anomalies observed over the OCT of the Iberia Abyssal Plain.

Because of bridges, the hole was logged in two separate runs by the Triple Combination toolstring

(507–114 mbsf and 768–614 mbsf). Although only the deepest 40 m of the logged interval was cored in Hole 1068A, the interval corresponds in depth to the sedimentary section cored and partially logged at Site 900 (Leg 149), located 600 m to the east.

Site 1069

This site is situated in a water depth of 5150 m. It lies on a north-south seismic line over the crest of a relatively flat-topped north-south basement ridge overlain by a wedge of sediments on its east flank. Seismic data suggest that the basement ridge is a possible fault block tilted toward the continent. The site lies in a location where a variety of structural and geophysical models for the development of the OCT can be tested.

The principal conclusion at this site is that the balance of evidence indicates that the north-south elongated fault block on which it was drilled is composed of continental crust. Biostratigraphic data from Site 1069 indicate that this site was at shelf depths in the earliest Cretaceous and then subsided and had reached abyssal depths by the late Campanian. This evidence, together with very low-grade metasediments (probably occurring as clasts in a friable mixture) encountered in acoustic basement at the bottom of the hole, lead us to the tentative conclusion that the site was drilled on a continental fault block. There is no sign of the mafic or ultramafic rocks encountered at Sites 897, 899, 900, 1067, or 1068.

The middle Eocene to upper Campanian 147-m-thick sedimentary succession cored at Hole 1069A (Fig. 8) is dominated by upward-darkening sequences (2- to 55-cm thick) of calcareous siltstone or sandstone, overlain by calcareous claystone or nannofossil chalk, and capped by dark hemipelagic claystone. Two subunits are recognized in this interval based on an increase in the frequency, proportion, and thickness (up to 50 cm) of sandstone lithologies at the base of individual turbiditic sequences from lithostratigraphic Subunit IIB to Subunit IIC. These sequences are interpreted as being deposited by turbidites near or below the CCD. A 2.4-m-thick upper Berriasian to lower Valanginian yellow nannofossil chalk is defined as Unit IV. The chalk is interpreted to have been deposited as a thin pelagic drape over the underlying basement ridge above the CCD. The chalk in turn is separated from an underlying Tithonian black silt by an erosional unconformity. A 9-cm interval of Upper Jurassic (Tithonian?) hemipelagic/pelagic gray clay occurs above eight curated pieces of limestone conglomerate containing granules of pelites and meta-basic arenite. The limestone clasts consist of grainstones and algal boundstones. The thin clay and limestone pieces are defined as Subunit VA. The lithology of the limestone clasts is similar to the Upper Jurassic limestones drilled on the Galicia margin and to clasts occurring within the conglomerates in Unit V at Site 1065. The limestone clasts were probably transported and resedimented from a carbonate shelf situated to the north, probably above the present day Vasco da Gama Seamount and associated basement highs.

The calcareous nannofossil sequence at Site 1069 began in the middle Eocene (CP12b) and then passed downhole through a more-or-less continuous succession of zones and subzones to a barren interval within the Paleocene in which zones CP5 to CP4 are not represented. Interbedded hemipelagites are barren of coccoliths. The Cretaceous/Tertiary transition lies within a bioturbated turbidite sequence in Core 12R where the boundary has been obliterated. The lithologic succession then continues from the uppermost Maastrichtian to the uppermost Campanian. It is interrupted in Section 1069A-16R-2 by an unconformity, below which lies the yellowish chalk described above (Unit IV). The upper portion of the chalk is dominated by nannoconids.

Paleogene planktonic foraminifers are common and moderately well preserved in the upper part of Subunit IIB (718.8–757.4 mbsf), but, with one exception, are rare to absent and generally poorly preserved in the lower section (757.4–873.3 mbsf). Calcareous benthic foraminifers and agglutinated foraminifers are present in most core-catcher samples above Core 14R. Within the latter group, the persistent occurrence of species such as *Ammodiscus* spp., *Bathysiphon* spp., and *Glomospira* spp. suggests that these Paleogene sediments were deposited in a fully marine environment, probably at abyssal depths.

Pieces of very hard rock were first encountered in Core 17R (beneath the Tithonian clay and limestone clasts) and continued to the bottom of the hole (Core 25R; see Fig. 8). These rocks (Subunit VB) consist of meta-arkosic wacke, metasiltstone, and dolomitic meta-arkose. Some of the pieces are moderately rounded and lack drilling percussion marks, which suggests that they are clasts whose original surfaces are preserved. The rocks are weakly deformed, with a metamorphic foliation defined by aligned sericite and chlorite. Relict sedimentary textures such as detrital grains and bedding/lamination are also preserved. In the siltstones, many quartz fragments are elongate parallel to foliation. Pyrite-quartz vugs are common and, in some pyrite-rich samples, thin pyritic veins and elongate pyrite-quartz vugs also parallel foliation. Core recovery in Subunit VB was extremely low, yet the rate of penetration was relatively fast (35–80 minutes per core). The only material recovered from Subunit VB (85.6 m thick) that could have been the original intraclast matrix was small amounts of dark sandy clayey silt in Cores 21R and 24R. Headspace gas from the Core 21R silt contained 101.7 ppm methane and 1.6 ppm ethane.

Metasedimentary rocks in Subunit VB contain abundant detrital quartz and plagioclase and a metamorphic mineral assemblage that includes sericite, chlorite, and in some cases dolomite. Unusually large ilmenite and leucoxene pseudomorphs (after ilmenite) appear to be metamorphic porphyroblasts, although a detrital origin in some rocks cannot be ruled out, especially for fine-grained ilmenite and leucoxene. Dolomite forms subhedral porphyroblasts in one sample and may be part of the diagenetic assemblage in the second. The stable coexistence of dolomite+chlorite and dolomite+muscovite indicates very low-grade metamorphism, probably subgreenschist. Similar rocks of Paleozoic age have been reported from Galicia Bank, where they also underlie Tithonian sediment.

Overall, the bedding in lithostratigraphic Subunits IIB and C is shallowly inclined. Within Subunit IIB, a marked change occurs at 760 mbsf. Above, the true dip is ~12°, below, only ~4°. At the base of Unit II and in Unit IV the bedding is again more steeply inclined (~14°). Whereas Unit II is essentially undeformed (only some minor normal faults), Unit IV was pervasively affected by pre-Unit II soft-sediment folding and normal faulting. The deformation of the basement rocks (Subunit VB) was dominated by pressure solution. The dip of the bedding is variable in the few basement pieces that could not have rolled over in the core liner. The foliation is often subhorizontal.

The magnetic intensities of sediments in Subunits IIB and IIC are generally weak. Characteristic peaks in NRM intensity and volume susceptibility associated with an early Eocene brown bed, which was observed at four other Iberia Abyssal Plain sites, were detected in Core 7R at ~777 mbsf. Cryogenic magnetometer measurements on whole cores and on discrete samples indicate that several polarity reversals are recorded in Cores 3R through 14R (738.1-854.0 mbsf). In the lower part of Subunit IIC, below 854.0 mbsf, the sediments are entirely normally magnetized, which is consistent with the Late Cretaceous long normal superchron and the late Campanian age of the sediments.

Claystones have bulk densities from 1.94 to 2.21 g/cm^3 and porosities from 31% to 44%, and calcareous claystones have bulk densities from 2.18 to 2.36 g/cm^3 and porosities from 22% to 38%. Whereas sandstones have bulk densities from 2.16 to 2.34 g/cm^3 and porosities from 21% to 32% in Subunit IIB, the values of bulk density and porosity are more variable in Subunit IIC (bulk density ~2.2-2.63 g/cm^3, porosity ~5-30%). Compressional wave velocities have a reasonable correlation with porosity and bulk density. Metasediment samples of Subunit VB have high densities from 2.70 to 2.73 g/cm^3, and high velocities from 4521 to 5639 m/s and very low porosities (<3%). Consequently, acoustic basement at this site is identified at the top of Subunit VB.

The Triple Combination tool was run successfully between 102 and 764 mbsf. The logs overlap the cored interval between 719 to 764 mbsf (Cores 1R to 5R), which represents part of Subunit IIB, a calcareous claystone. Preliminary analysis of the logs shows a good correlation with Site 1068 between 100 and 380 mbsf and 600 and 764 mbsf. Variations of inferred sedimentation rates between sites suggest a greater rate during the Miocene at Site 1069 and a slightly lesser rate during the Eocene, relative to Site 1068. A water overpressure encountered at 650 mbsf during the final pipe trip to the rig floor may be tentatively related to a 20-m-thick interval (670-690 mbsf) where high porosity and low resistivity were recorded.

Site 1070

Site 1070 lies over an elongated basement ridge about 15 km east of the crest of the J magnetic anomaly and 20 km west of the peridotite ridge. Both ridges lie parallel to the continental margin. The main objective at this site was to sample oceanic basement to characterize the chemistry and melting of the early formed oceanic crust.

The principal result from Hole 1070A is that the basement consists of pegmatitic gabbro overlying serpentinized peridotite intruded by gabbroic veinlets that have been highly altered to low-grade or very low-grade assemblages. Contrary to expectations, no rocks from the upper oceanic crust (basaltic lavas or sheeted dikes) were encountered. Protolith assemblages suggest that the peridotites were lherzolites, harzburgites, and dunites.

A 59.34-m-thick, lower Oligocene to Aptian sedimentary succession was cored at Site 1070 (Fig. 9). It is divided into three lithostratigraphic units. Coring commenced in the 20-m-thick Subunit IIC which consists of upward-darkening sequences of calcareous to nannofossil claystone overlain by claystone that were deposited as calcareous turbidites and noncarbonate hemipelagites, probably near or below the CCD. The 39 m of brown claystones in Unit III are interpreted to be the product of slow accumulation of clay in an oxygenated environment on the abyssal plain below the CCD. The manganese content in the claystones and the micronodules also indicate a low rate of deposition. Thin beds of sand near the base may have been deposited as turbidites (one is normally graded) and may be distal equivalents of the high-density turbidites present in Subunit IIIB at Site 897.

The boundary between Units III and IV occurs at the change from brown claystone to nannofossil claystone in Section 7R-2 (17 cm). Matrix-supported sedimentary breccias are interbedded with a 0.4-m-thick nannofossil chalk in Unit IV. The breccias are 3–4 cm thick and normally graded. They were probably deposited as small debris flows or turbidites that transported locally derived material relatively short distances. The chalk is pelagic in origin and was deposited above the CCD. The petrographic features of the calcareous chalks interbedded with the breccias strongly suggest that their constituent calcite grains are largely detrital. The likely source of the calcite clasts is the underlying calcitized basement material.

This site was located in deeper water, farther from turbidite sources, and over a higher basement high than the other sites drilled in this area. Consequently the cores recovered more hemipelagic sediments and less carbonate than in equivalent sections at the other sites, and calcareous fossils were recovered only near the top (Paleogene) and bottom (Lower Cretaceous) portions of the cored sequence. In between, most of lithostratigraphic Unit III is barren. Calcareous benthic foraminifers occur sporadically only between Samples 1070A-1R-1, 43-48 cm and 3R-CC. Agglutinated benthic foraminifers and ichthyoliths occur consistently throughout the cored section from Sample 1070A-1R-1, 43-48 cm through Sample 7R-CC with the exception of Sample 5R-CC, which is barren of foraminifers. The recovery of agglutinated foraminiferal assemblages characteristic of deep water habitats, and the paucity of sediment input of grain size larger than 63 microns suggests that the environment of deposition was probably at bathyal depths during the Aptian.

The basement at Site 1070 is divided into two units, reflecting the dominant petrological features of each (Fig. 9). Basement Unit 1 is found in Cores 7R through 8R and consists of matrix-supported serpentinized peridotite breccias. The clasts consist mainly of serpentinized peridotite with variable amounts of pyroxenes and, in a few cases, of weakly deformed, coarse-grained gabbro. The matrix consists of several generations of calcite, including spherical aggregates (botryoidal calcite). Serpentinization preceded calcite precipitation (serpentinite mesh structures are cut by calcite veins). Abundant "jigsaw" clasts and the transition downward into an incohesive fault gouge suggest a tectonic origin for these breccias. Pervasive calcitization of the matrix and calcite veining indicate that deformation was assisted by fluid flow. The occurrence of tectonosedimentary breccias and gouge on top of serpentinized peridotite, commonly observed during Legs 149 (Site 897) and 173 (Sites 1068 and 1070), is related to a late stage of emplacement of the ultramafic rocks on the seafloor. However, to what extent the breccias are formed by sedimentary processes and/or result from brecciation along fault planes is not yet clear.

The contact between basement Units 1 and 2 consists of a short interval of highly sheared serpentinite over pegmatitic gabbro (i.e., between Cores 1070A-8R-5 and 9R-1). Unit 2, made of igneous (mafic and ultramafic) rocks, starts at 676.2 mbsf in Core 9R and continues through the bottom of Core 14R at 718.8 mbsf. Unit 2 is divided into two subunits: Subunit 2A consists of pegmatitic gabbro and Subunit 2B consists of serpentinized peridotite. Subunit 2A was encountered in Core 9R at a depth of 676 to 686 mbsf. The gabbro shows a clear intrusive contact with the underlying serpentinized peridotites (visible in Core 9R). In the gabbro of Subunit 2A, a weak foliation is observed locally in the core. In thin section, incipient crystal plastic deformation (recrystallization) of plagioclase and amphibole indicates weak heterogeneous ductile deformation. Within Subunit 2B, the serpentinized peridotite is intruded at several locations by 1- to 4-cm-thick, strongly altered, coarse-grained gabbroic dikes. The peridotite displays variable amounts of pyroxene, from pyroxenitic layers in Core 10R (up to 80% pyroxene) to a more dunitic layer in Core 14R (less than 10% pyroxene; see Fig. 7). In general, the peridotites are strongly serpentinized; relict clinopyroxene and spinel are common and small but abundant relicts of olivine are present in the deeper part of the cored section. A high-temperature foliation is only locally marked by the alignment of spinels and pseudomorphs after pyroxenes; it is generally weak and shallowly to moderately inclined (between 9˚ and 45˚). Evidence for possible high-temperature shear deformation is observed in Cores 13R and 14R. These observations suggest that the peridotites were only weakly deformed at high temperatures. The presence of gabbroic veins demonstrates that a later stage of brittle deformation occurred in the mantle rocks during the emplacement of the intrusives.

Results from the pass-through cryogenic magnetometer measurements and discrete sample demagnetization experiments indicate that two or three magnetic polarity reversals may be recorded in the cores. Unfortunately, biostratigraphic data are not available for these cores, except to suggest that these reversals fall in a period between early Oligocene and Late Cretaceous. The most interesting result generated from the preliminary shipboard study is the identification of what appears to be a reversely magnetized zone in the serpentinized peridotites (Subunit 2B). A similar feature found in the serpentinized peridotites recovered from nearby Sites 897 and 899 during Leg 149 suggests that the Iberian peridotites preserved a Cretaceous magnetic record. Further analyses of this magnetic polarity zone, integrated with shore-based geochronologic and isotopic studies, may provide a unique opportunity for dating the tectonic processes that accompanied continental breakup and opening of the North Atlantic.

The poorly consolidated clays, which dominate the sedimentary section, have the lowest bulk densities (1.8 to 2.0 g/cm^3) and highest porosities (44% to 54%) measured during Leg 173. The velocities of all sediment samples from above 635 mbsf are less than 2000 m/s, and only two sediment samples in the lower part of lithostratigraphic Unit III have higher velocities of approximately 2200 m/s. The magnetic susceptibility values in Subunit IIC are less than 100 SI units and those in Unit III are between 100 and 400 SI units. There is a 1000 SI units peak of magnetic susceptibility around 649 mbsf in Unit III. Gamma-ray activity is generally between 70 and 80 c/s in Subunit IIC and has a peak of over 110 c/s at 612 mbsf. Gamma-ray activity decreases to between 60 and 70 c/s in Unit III and a peak of over 80 c/s lies at 649 mbsf. All basement samples except one have velocities over 4000 m/s and the maximum value is greater than 7000 m/s. Breccia and serpentinite samples from acoustic basement have bulk densities from 2.3 to 2.5 g/cm^3 and porosities from 7% to 17%. Basement rocks have a much higher magnetic susceptibility from a few hundreds of SI units to over 4000 SI units. Gamma-ray values of basement rocks are less than half of those of sediments.

CONCLUSIONS

ODP Leg 173 was devoted to investigating the nature and evolution of the basement within the ocean-continent transition (OCT) zone of the west Iberia continental margin to understand modes of lithospheric extension and to test models of the tectonic and igneous processes that accompanied this extension. Five relatively deep holes (terminating between 630 and 960 mbsf) were drilled into basement highs along an east-west transect begun during Leg 149. The degree to which the six major scientific objectives of this leg were met is briefly outlined below.

Objective 1. *To sample acoustic basement, principally within the OCT, to characterize the tectonic and magmatic processes that dominate the transition from continental rifting to oceanic crustal formation in space and time.*

Acoustic basement was sampled at all five sites drilled during the leg; however, at only three of these sites (Sites 1067, 1068, and 1070) were igneous/metamorphic basement rocks reached. Nevertheless, the acoustic basement samples from all the sites contribute in some way to the characterization of those tectonic and magmatic processes that dominate the transition from continental to oceanic crust in space and time (see below). For example, samples of igneous basement from Sites 1067, 1068, and 1070 will provide important geochronologic, geochemical, petrologic, and structural constraints about the age, origin, and tectonometamorphic evolution of the OCT. Fault gouge and breccias encountered at Sites 1068 and 1070 will help to characterize details of the synrift tectonic activity. Mineralogical and structural variations in the serpentinized peridotites (Sites 1068, 1070) will be used to document the nature and evolution (e.g., partial melting, mode of extension) of the mantle during the transition from continental rifting to incipient oceanic crustal formation. Moreover, the occurrence of mantle rocks at this latitude of the OCT demonstrates that the mantle is exposed, at least sporadically, over a width of more than 100 km.

Objective 2. *To constrain models of continental thinning and breakup by drilling (1) through a major synrift tectonic contact (detachment) on the east side of the basement high on which Site 900 has already been drilled (Iberia-9) and (2) a basement high 14 km further west bounded by westward-dipping normal faults (Iberia-7A).*

The results from Sites 1067, 1068 (both Iberia-9), and 1069 (Iberia-7A) will have implications for tectonic activity on a broad scale, particularly regarding hypotheses that involve simple shear as a stretching mechanism of the lithosphere. The intense ductile shear deformation in the upper part of the cored sections of the amphibolite (Site 1067) suggests the existence of a major shear zone in rocks that are now at the top of the basement. The hypothesis that the upper H reflector is a major low-angle fault is not enhanced by the results from Sites 1067 and 1068; the reflector may in fact represent the crust/mantle boundary. It proved impossible for logistic and technical reasons to reach the H reflector under Site 1067; hence, Site 1068 was drilled in an offset location to sample the rocks (serpentinized peridotite) beneath the reflector. The presence of upper continental crust under Site 1069 was established fairly conclusively. Thus, any tectonic hypothesis for development of the OCT must also now take into account, in addition to the presence of mantle rocks at Site 1068, the likelihood that Site 1069 lies over an isolated fault block of continental crust.

Objective 3. *To determine the role and extent of synrift magmatism in the OCT.*
Evidence of possible synrift melting within the OCT was acquired at Sites 1067 and 1068. At Site 1067, amphibolites had been intruded by tonalite gneiss and meta-anorthosite and appear to be part of a ~550-m-thick sequence overlying the upper H reflector, which may represent the crust/mantle boundary. Clasts of similar material, together with metagabbro, were cored at Site 1068 overlying serpentinized peridotite. These rocks display a heterogeneous and locally intense ductile deformation that suggests they may have played an important role in localizing deformation during the formation of the margin.

Objective 4. *To sample acoustic basement beneath Site 901, or at a site 20 km farther west (Iberia-8B), to confirm the existence of continental crust and to determine the approximate crustal level from which it came.*
Site 1065 (Iberia-8B) attempted to sample continental crust on a major tilted fault block. Unfortunately acoustic basement was discovered to consist of lithified claystones that could be cored only very slowly and no clear crystalline basement reflector could be discerned beneath them. Nevertheless the earliest sediments indicate shallow-water deposition in the Middle-Late Jurassic, which is a strong argument for there being continental crust beneath the site.

Objective 5. *To sample early-formed oceanic crust, 20 km west of the peridotite ridge that marks the landward limit of oceanic crust.*
Site 1070 (Iberia-10A) sampled serpentinized peridotite intruded by several thin (1 to 4 cm wide) gabbroic veins and a 4-m-thick intrusion of pegmatitic gabbro. These cores may represent early formed oceanic seafloor. However, no evidence of upper oceanic crust, either lavas or sheeted dikes, was found. It may be that the thermal state of the lithosphere at this time was too cold to supply enough partial melting to generate typical upper oceanic crust. The oldest microfossils above basement indicate a late Aptian (115 Ma) age somewhat younger than the age (125 Ma) predicted by modeling seafloor-spreading anomalies.

Objective 6. *To investigate the early sedimentary history of the rifted margin.*
Mesozoic sediments were cored in three out of the four holes drilled within the OCT zone (Sites 1065, 1068, and 1069). These sediments provide glimpses of the early history of the west Iberia margin. For example, at Site 1065 Middle-Late Jurassic basal sediments are pre-rift while the Early to Late Cretaceous sediments of Sites 1068 and 1069 record events on the margin during or immediately after breakup. Many basement highs are capped by breccias that directly or indirectly reflect the tectonic events that accompanied the late stages of rifting.

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FIGURE CAPTIONS

Figure 1. Bathymetric chart of the west Iberia margin (contours at 200, 500, 1000, 1500 m etc.). Sites drilled during Leg 173 and Leg 149 are shown by solid triangles and open circles, respectively. Previous DSDP/ODP sites are shown by solid circles. Submersible dives that sampled rock and dredge sites are shown by solid squares and crosses, respectively. VdG = Vasco da Gama seamount; VS = Vigo seamount; PS = Porto seamount; ES = Estremadura Spur. Inset shows locations of Leg 149 and Leg 173 drillsites with respect to relevant seismic profiles.

Figure 2. Composite east-west cross-section through the Leg 149 and Leg 173 drill sites. Sites in parentheses are offset a short distance from the profile. The profile is made from three separate segments of seismic reflection profile.

Figure 3. Summary lithologic column for Hole 1065A.

Figure 4. Summary lithologic column for Hole 1067A.

Figure 5. Zr vs. Y variation diagrams for the Site 1067 amphibolites and tonalite gneiss. The Site 1067 samples are shown in relation to the Site 899 metamicrogabbros, Site 900 metagabbros, and Site 1068 clasts of metagabbro, amphibolite, and meta-anorthosite. The fields of oceanic gabbro compositions from the Southwest Indian Ridge (Leg 118) and Mid-Atlantic Ridge (Leg 153) are displayed. Also shown are the approximate paths for apatite and zircon accumulation.

Figure 6. Summary lithologic column for Hole 1068A.

Figure 7. CaO (wt%) vs. Al_2O_3 (wt%) variation diagrams for the Holes 1068A and 1070A serpentinized peridotites. Also shown are the serpentinized peridotites from Holes 897C, 897D, and 1068A from the Iberia Abyssal Plain and Leg 153 serpentinized harzburgites from the Kane Transform region, Mid-Atlantic Ridge. Mineral compositional fields based on Leg 149 results are displayed.

Figure 8. Summary lithologic column for Hole 1069A.

Figure 9. Summary lithologic column for Hole 1070A.

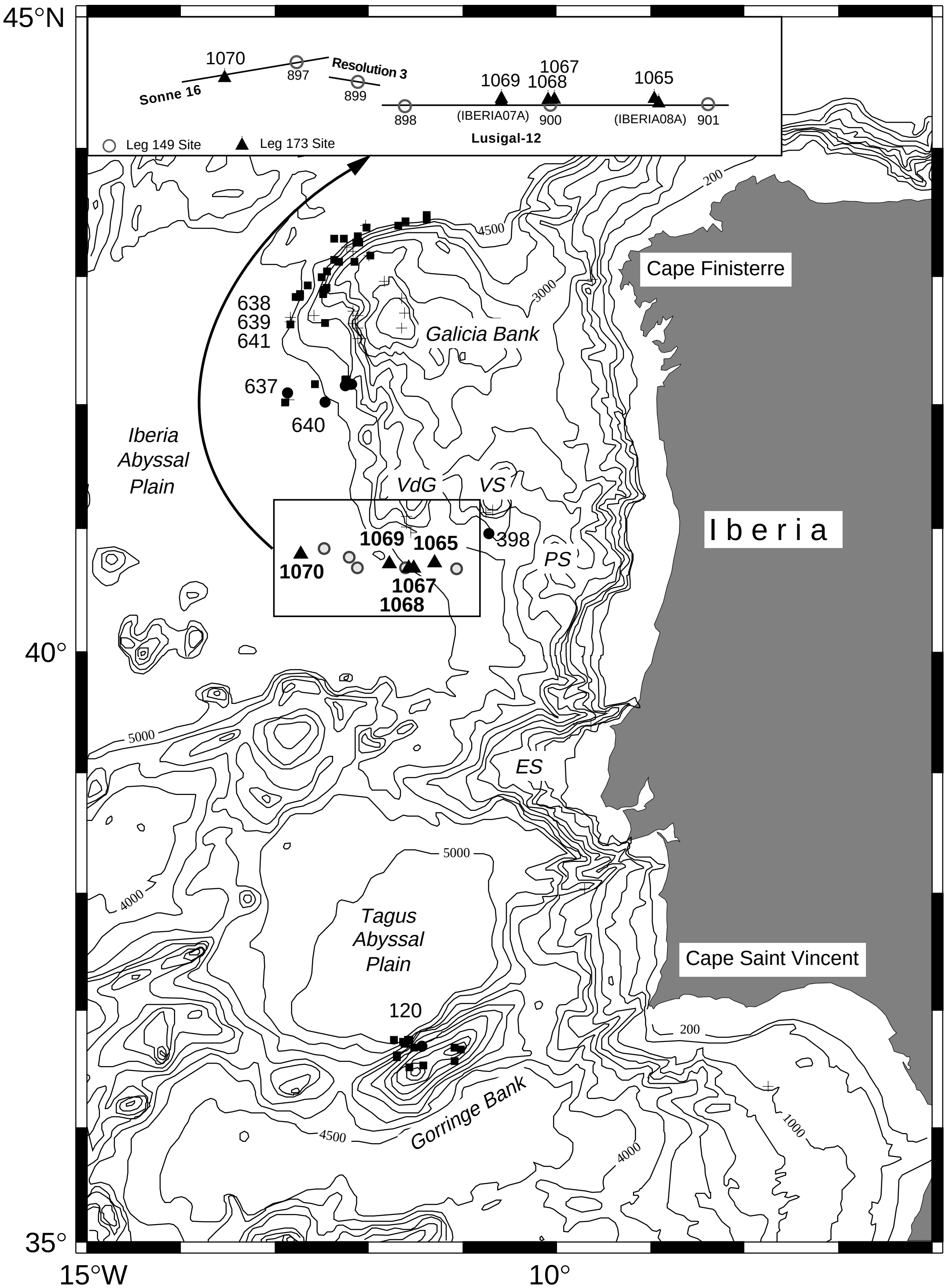

45°N
40°
35°
15°W
10°
1070
897
Resolution 3
Sonne 16
899
1069
1067
1068
1065
898
(IBERIA07A)
900
(IBERIA08A)
901
Lusigal-12
Leg 149 Site
Leg 173 Site
Cape Finisterre
Galicia Bank
638
639
641
637
640
Iberia
Abyssal
Plain
VdG
VS
398
PS
1069
1065
1070
1067
1068
Iberia
ES
Tagus
Abyssal
Plain
Cape Saint Vincent
120
Gorringe Bank
200
4500
3000
5000
4000
1000

Figure 1

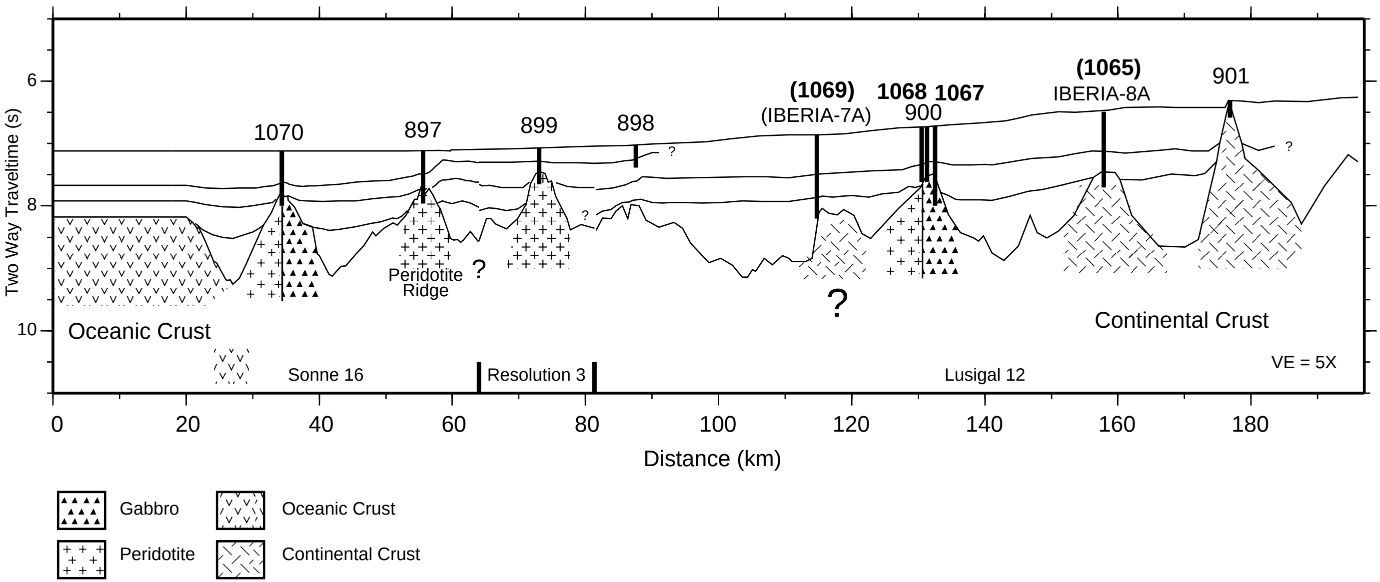

1070
897
899
898
(1069)
(IBERIA-7A)
1068
1067
900
(1065)
IBERIA-8A
901
Two Way Traveltime (s)
6
8
10
Peridotite Ridge
Oceanic Crust
Continental Crust
Sonne 16
Resolution 3
Lusigal 12
VE = 5X
0
20
40
60
80
100
120
140
160
180
Distance (km)
Gabbro
Peridotite
Oceanic Crust
Continental Crust

Figure 2

Leg 173 Hole 1065A

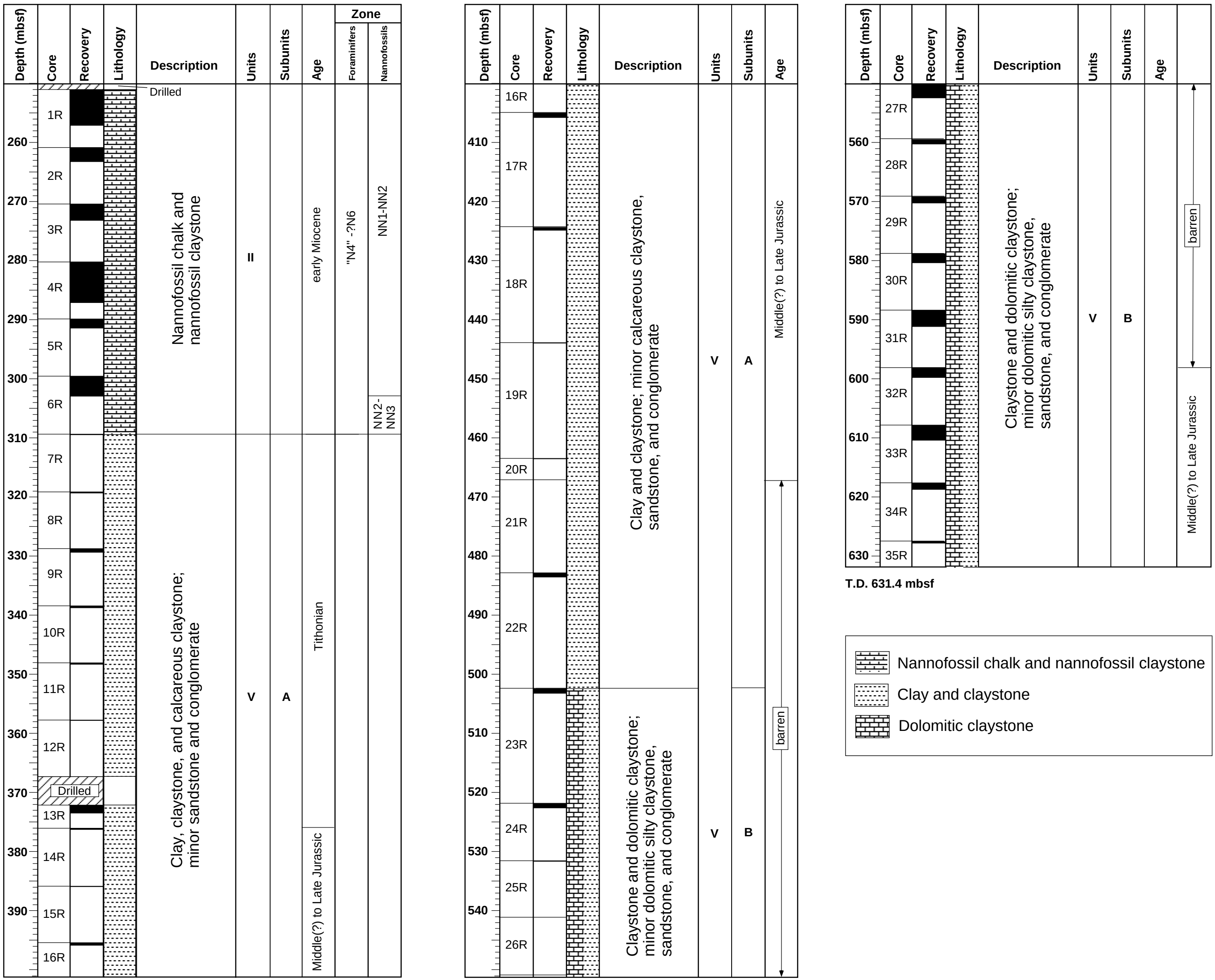


Figure 3

Leg 173 Hole 1067A

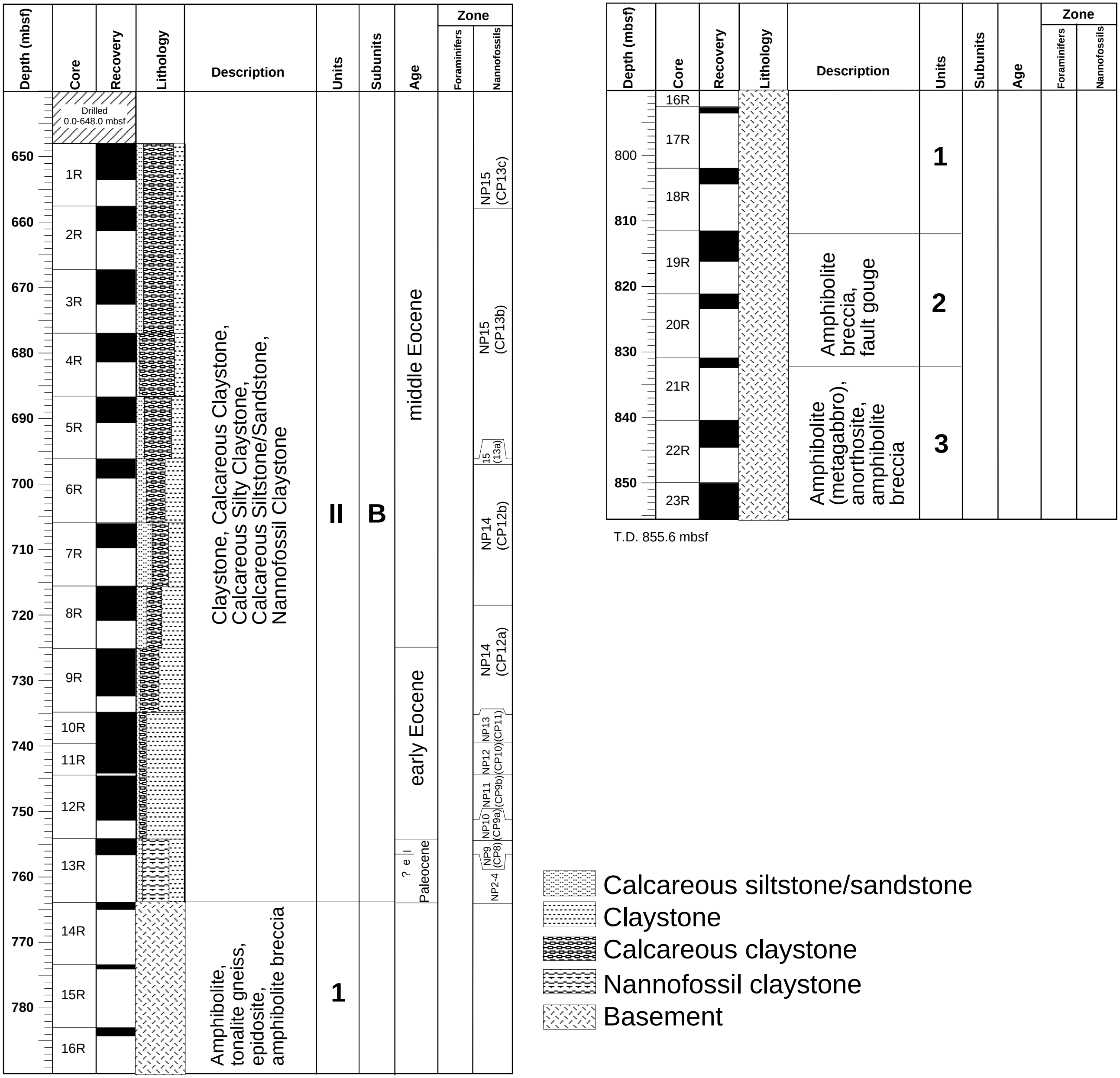


Figure 4

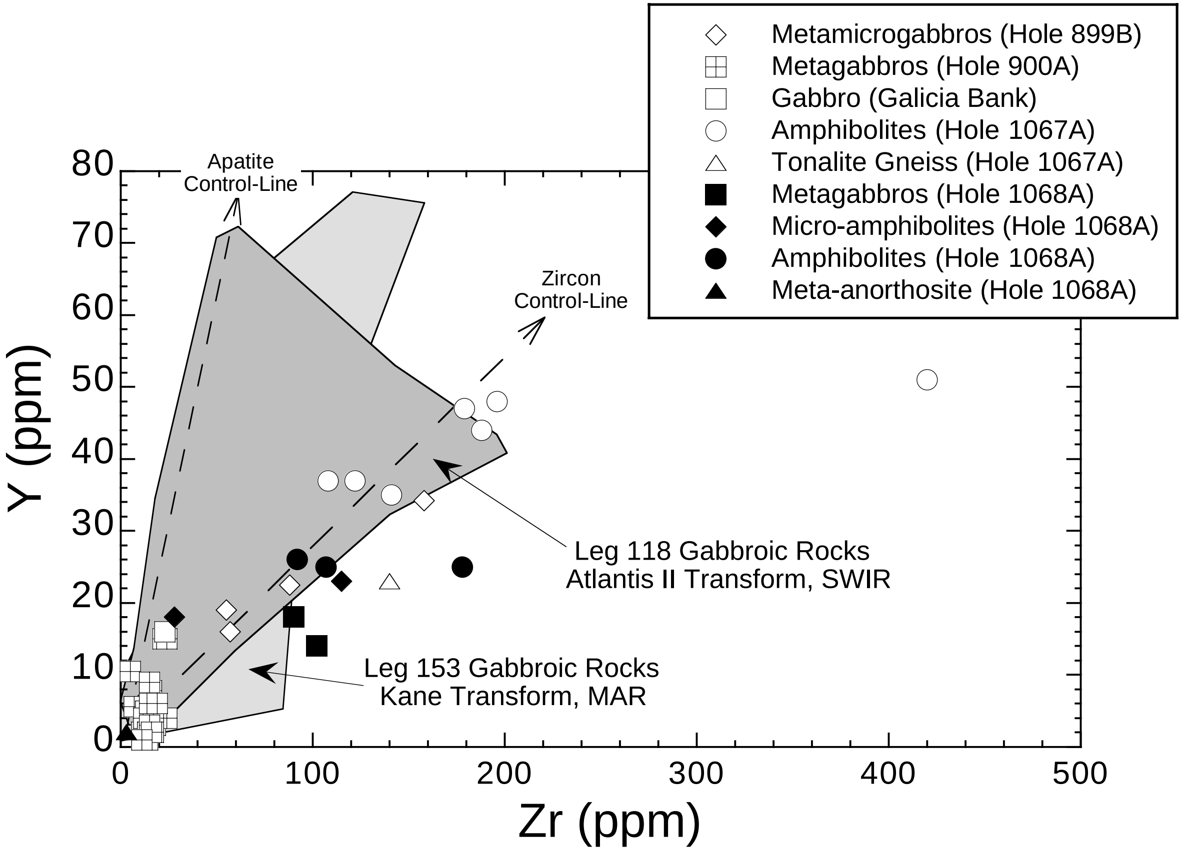

Metamicrogabbros (Hole 899B)
Metagabbros (Hole 900A)
Gabbro (Galicia Bank)
Amphibolites (Hole 1067A)
Tonalite Gneiss (Hole 1067A)
Metagabbros (Hole 1068A)
Micro-amphibolites (Hole 1068A)
Amphibolites (Hole 1068A)
Meta-anorthosite (Hole 1068A)
Apatite Control-Line
Zircon Control-Line
Leg 118 Gabbroic Rocks Atlantis II Transform, SWIR
Leg 153 Gabbroic Rocks Kane Transform, MAR
Y (ppm)
Zr (ppm)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500

Figure 5

Leg 173 Hole 1068A

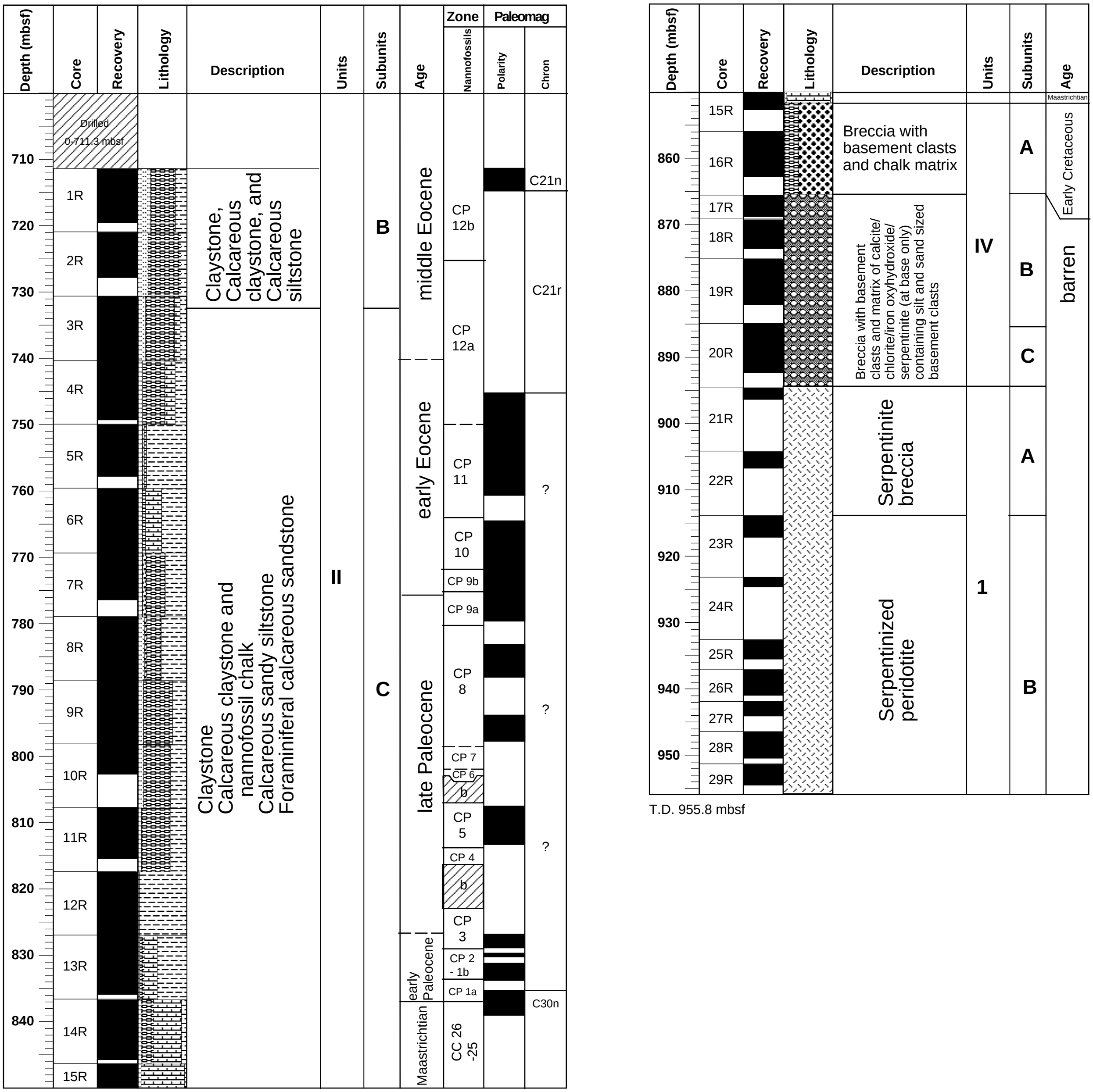
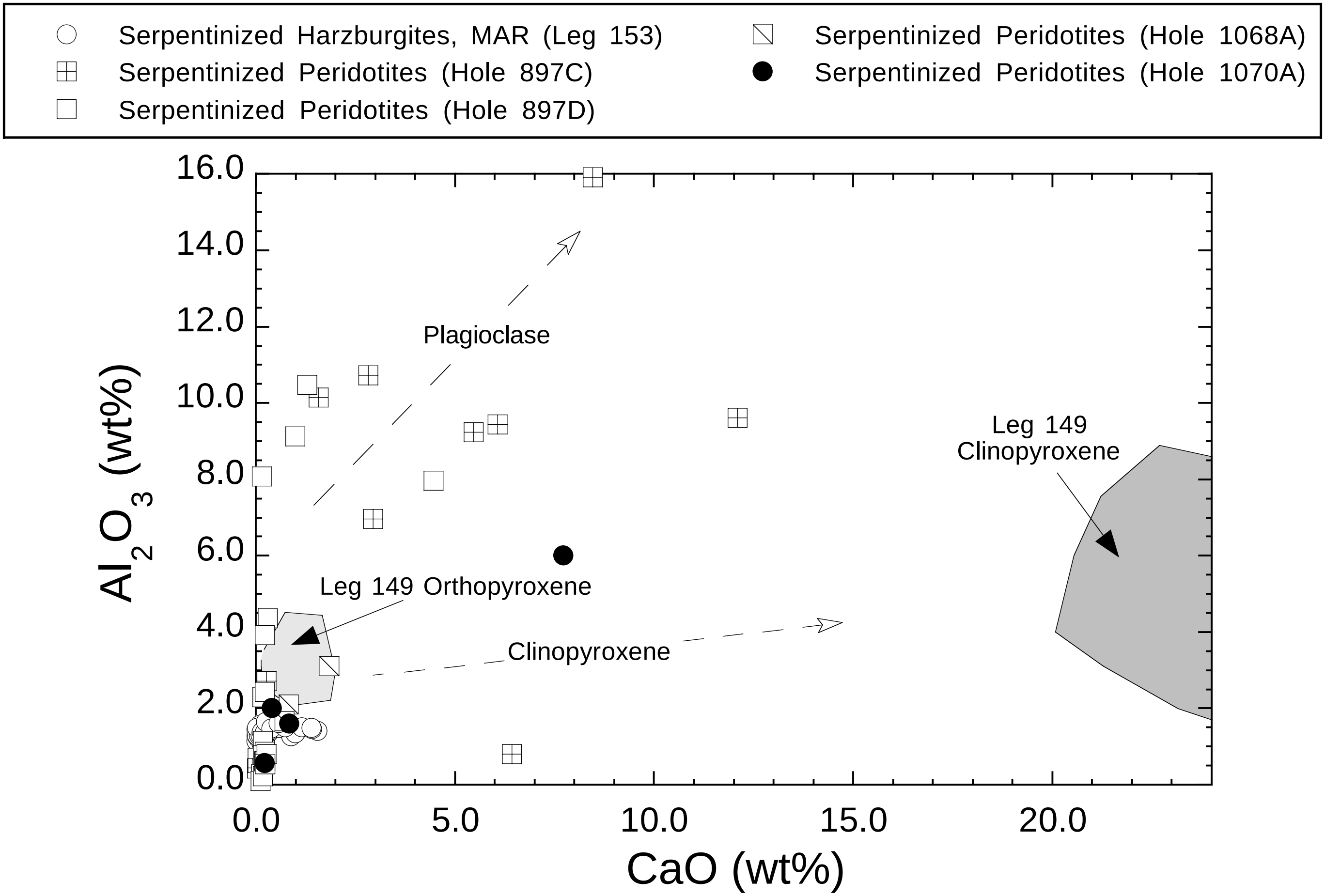


Figure 6



Serpentinized Harzburgites, MAR (Leg 153)
Serpentinized Peridotites (Hole 897C)
Serpentinized Peridotites (Hole 897D)
Serpentinized Peridotites (Hole 1068A)
Serpentinized Peridotites (Hole 1070A)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Al_2O_3 (wt%)
Plagioclase
Leg 149 Clinopyroxene
Leg 149 Orthopyroxene
Clinopyroxene
0.0
5.0
10.0
15.0
20.0
CaO (wt%)

Figure 7

Leg 173 Hole 1069A

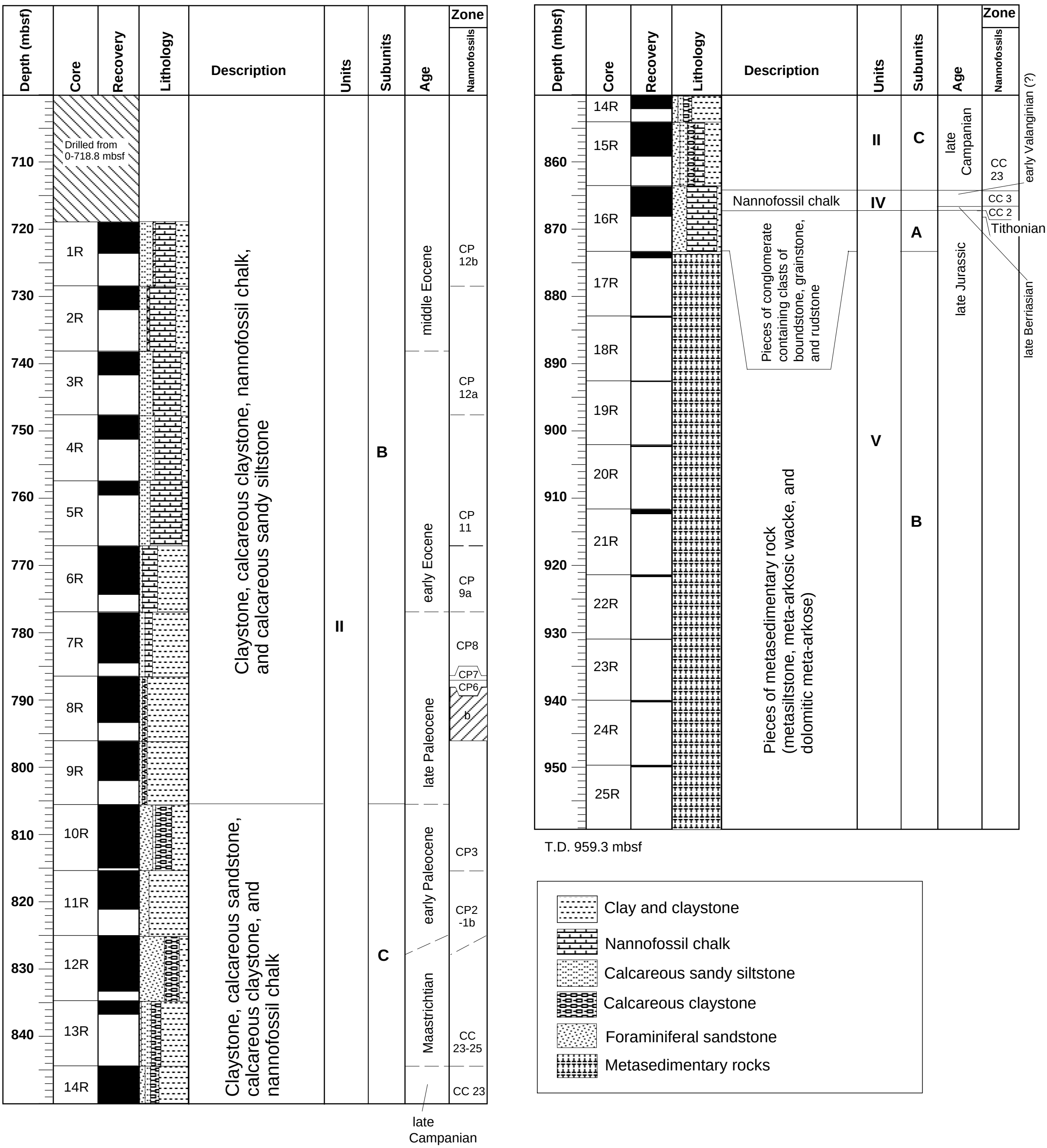


Figure 8

Leg 173 Hole 1070A

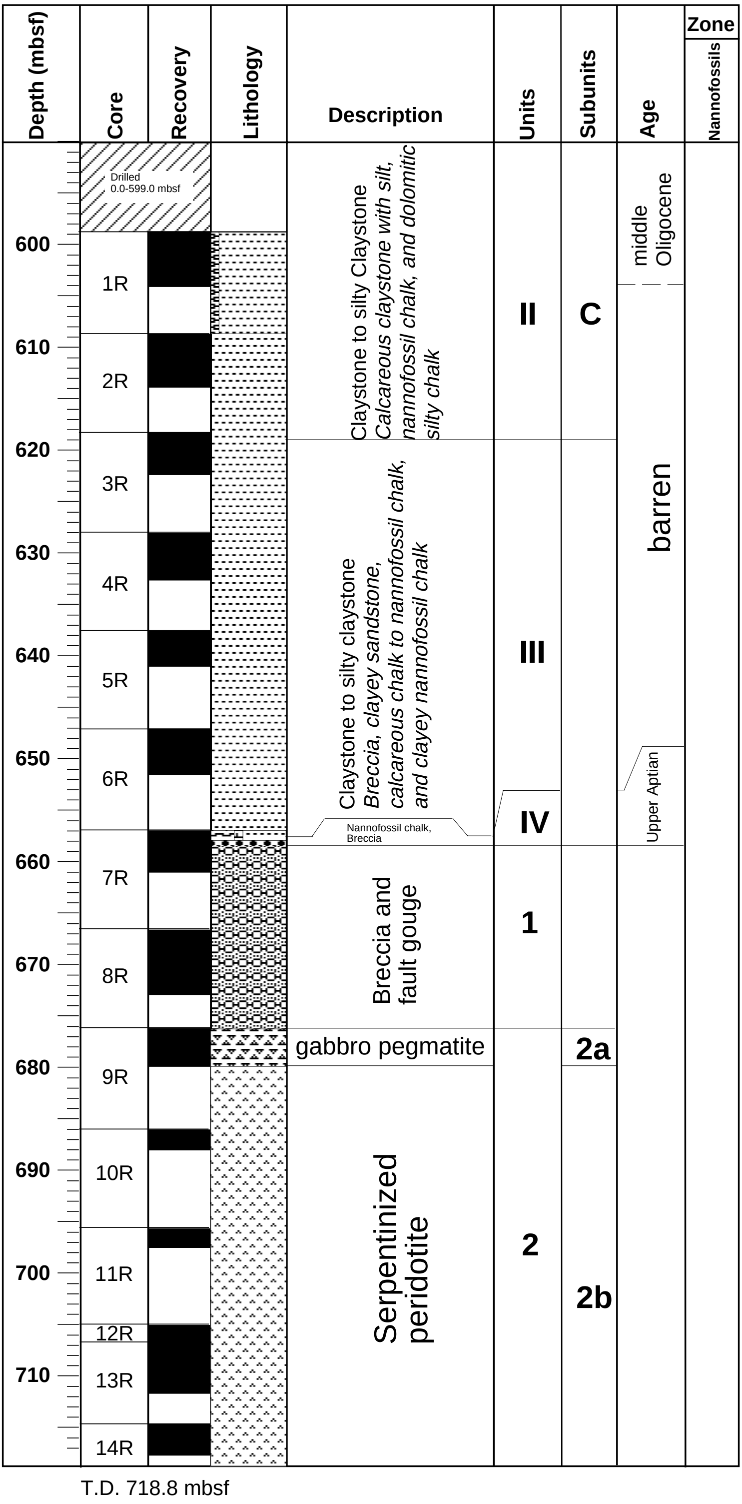


Figure 9

SITE SUMMARY DATA

SITE 1065
Hole 1065A (40˚ 43.447'N, 11˚ 17.724'W)
Water Depth: 4770.1 mbsl
Penetration: 631.40 mbsf
Coring totals:
Type: RCB; Number: 35; Cored: 375.8 m; Recovered: 46.6 m; Average Recovery: 12.4%
Sedimentary sequence:
Unit II: 251.0-308.8 mbsf; early Miocene; Nannofossil chalk and nannofossil claystone
Unit V: 308.8-631.4 mbsf; Middle to Late Jurassic; Clay, claystone, and dolomitic claystone

SITE 1067
Hole 1067A (40˚ 40.950'N, 11˚ 35.750'W)
Water Depth: 5020.9 mbsl
Penetration: 855.6 mbsf
Coring totals:
Type: RCB; Number: 23; Cored: 207.6 m; Recovered: 77.67 m; Average Recovery: 37.4%
Sedimentary sequence:
Subunit IIB: 648.0-763.8 mbsf; middle Eocene to early Paleocene; Claystone, calcareous claystone, calcareous siltstone to sandstone
Basement:
Unit 1: 763.8-802.3 mbsf; strongly foliated amphibolite, tonalite gneiss
Unit 2: 802.3-822.6 mbsf; matrix-supported amphibolite breccia
Unit 3: 822.6-855.6 mbsf; foliated to weakly foliated amphibolite, meta-anorthosite

SITE 1068
Hole 1068A (40˚ 40.955'N, 11˚ 36.720'W)
Water Depth: 5043.9 mbsl
Penetration: 955.8 mbsf
Coring totals:
Type: RCB; Number: 29; Cored: 244.5 m; Recovered: 180.59 m; Average Recovery: 73.9%
Sedimentary sequence:
Subunit IIB: 711.3-733.55 mbsf; middle to early Eocene; Calcareous claystone, claystone, and calcareous siltstone
Subunit IIC: 733.55-853.0 mbsf; early Eocene to Maastrichtian; Claystone, calcareous claystone, nannofossil chalk, and calcareous sandy siltstone
Acoustic basement:
Subunit IVA: 853.0-865.6 mbsf; Early Cretaceous nannofossils in calcareous matrix
Matrix-supported breccia with calcareous matrix; clasts of weakly to strongly foliated amphibolite, meta-anorthosites, and meta-gabbro
Subunit IVB: 865.6-884.9 mbsf; matrix is barren of nannofossils
Clast-supported breccia with matrix of sand and silt-sized grains of clast material encased in calcite and Fe-oxyhydroxide; clasts are dominantly amphibolite
Subunit IVC: 884.9-892.8 mbsf; matrix is barren of nannofossils
Cataclastic breccia with matrix of calcite, chlorite, albite, and Fe-oxyhydroxide; clasts of meta-anorthosite and metagabbro
Crystalline basement:

Unit 1: 892.8-955.8 mbsf; serpentinite and serpentinized plagioclase peridotite

SITE 1069
Hole 1069A (40° 43.612'N, 11° 46.632'W)
Water Depth: 5074.8 mbsl
Penetration: 959.3 mbsf
Coring totals:
Type: RCB; Number: 25; Cored: 240.5 m; Recovered: 96.3 m; Average Recovery: 40.0%
Type: G; Number: 1; Cored: 0 m; Recovered 0.4 m; Average Recovery: N/A
Sedimentary sequence:
Subunit IIB: 718.8-805.8 mbsf; middle Eocene to early Paleocene; Claystone, calcareous claystone, nannofossil chalk, and calcareous sandy siltstone
Subunit IIC: 805.8-865.5 mbsf; early Paleocene to late Campanian; Claystone, calcareous sandstone, calcareous claystone, and nannofossil chalk
Unit IV: 865.5-867.8 mbsf; Early Cretaceous (late Berriasian to early Valanginian); Nannofossil chalk
Subunit VA: 867.8-873.7 mbsf; Late Jurassic (Tithonian?); Conglomerate containing clasts of grainstone, boundstone, rudstone; minor clay
Subunit VB: 873.7-959.3 mbsf; barren; meta-siltstone, meta-arkosic wacke, and dolomitic meta-arkose

SITE 1070
Hole 1070A (40˚ 47.779'N, 12˚ 43.430'W)
Water Depth: 5321.8 mbsl
Penetration: 718.8 mbsf
Coring totals: Type: RCB; Number: 14; Cored: 119.8 m; Recovered: 51.77 m; Recovery: 43.2%
Sedimentary sequence:
Subunit IIC: 599.0-619.0 mbsf; late Eocene; claystone and silty claystone
Unit III: 619.0-658.0 mbsf; barren; claystone and silty claystone
Unit IV: 658.0-658.4 mbsf; late Aptian; nannofossil chalk, calcareous chalk, and breccia
Basement:
Unit 1: 658.4-676.2 mbsf; poorly sorted breccia with serpentinite clasts in a calcite matrix
Subunit 2A: 676.2-685.7 mbsf; very coarse-grained (pegmatitic) gabbro
Subunit 2B: 685.7-718.8 mbsf; serpentinized peridotite

OPERATIONS SYNOPSIS

The drilling and engineering personnel aboard *JOIDES Resolution* for Leg 173 were:

Operations Manager:	Mike Storms
Schlumberger Engineer:	Jonathan Kreb

PORTUGUESE DRILLING CLEARANCE

Before ODP Leg 173 sailed, clearance had been obtained from the Portuguese government to operate in the Portuguese Exclusive Economic Zone (EEZ). However, while the *JOIDES Resolution* was in port in Lisbon, we learned that a Portuguese telecommunications company, Marconi Portugal, filed a written protest with the Portuguese Ministry of Foreign Affairs asking that Leg 173 drilling clearance be withdrawn. They were concerned about possible damage to seafloor telecommunication cables (TAGIDE 1, TAGIDE 2, Eurafrica, TAT-9, and FLAG) located in the Iberia Abyssal Plain operating area. A meeting was held with Marconi on 17 April 1997 in an attempt to alleviate their concerns. It was explained to Marconi that the drill ship could locate itself very accurately using a very sophisticated Global Positioning System (GPS), that it was a dynamically positioned drill ship that did not require the setting or recovery of anchors, and that the seafloor could be visually surveyed using a subsea television system before to spudding any drill hole. It was further indicated that all of the Leg 173 drill sites were at least 2.0 nmi away from the cables in question. Marconi was not appeased and reiterated its position that all drill sites should be moved outside a 15 nmi corridor extending to either side of each cable. The Foreign Ministry subsequently put the Leg 173 drilling clearance verbally on hold until the problem could be resolved.

During further negotiations, ODP/TAMU agreed in writing to assume full fiscal liability for cable damage and in addition agreed to drop Site Iberia-8A from the drilling prospectus. Thus, the closest drill site to the Iberia pennisula was Site Iberia-8B, which was located 3.6 nmi away from TAGIDE 1. Marconi continued to resist removing their official protest, and the Ministry of Foreign Affairs was reluctant to reinstate the drilling clearance while the protest remained in effect. The issue was finally resolved when ODP/TAMU further agreed to assume all financial liability for lost revenue should a cable become damaged as a result of the drilling operation. It should be noted that the vessel would have officially sailed from Lisbon at 0745 hr 20 April had it not been for the drilling clearance problem. This incident cost the leg nearly 1.5 days (34.25 hr) of operating time, excluding ~6 hr spent waiting for clearance at the first site.

TRANSIT TO SITE 1065

At 1800 hr on Monday, 21 April 1997, the last line was passed ashore and the vessel headed down the river Tagus to the entrance of Lisbon harbor. At 1830 hr the harbor pilot disembarked, and the vessel got under way at full speed toward the first site of Leg 173. Clocks were set back 1 hr to GMT during the night. The 170-nmi transit to Site 1065 was accomplished at an average speed of 7.2 kt. During the transit a reduced speed was maintained because official drilling clearance had yet to be received. The vessel arrived on location at 1630 hr 22 April 97. Thrusters and hydrophones were lowered and the vessel began "drifting" on-location while in dynamic positioning (DP) mode. At 1700 hr, word was received that a beacon could be deployed, drill pipe tripped to the seafloor, and a subsea television (TV) survey conducted while awaiting clearance. Permission to spud the hole remained withheld.

SITE 1065
(Proposed Site Iberia-8B)

Hole 1065A

At 1800 hr on 22 April, a Datasonics beacon was dropped on the GPS coordinates for Site 1065 officially initiating Hole 1065A. The beacon subsequently failed within 2.25 hrs and a second beacon was deployed at 2015 hr. The precision depth recorder (PDR) indicated a seafloor depth adjusted to the rig floor of 4780.4 m. The pipe was tripped to the seafloor and the subsea camera was deployed. While waiting on clearance to spud the hole, a visual TV survey was done for 1000 m to the west and 880 m to the east of the site. The GPS coordinates placed this site ~5 nmi west of the TAGIDE 1 cable and ~10 nmi to the east of the TAGIDE 2 cable. There was no visual indication that the site location was at or near any subsea cables.

At 1715 hr 23 April 97, word was received that the hold on drilling clearance for the Portuguese EEZ had been removed by the Ministry of Foreign Affairs, and we were now free to continue with Leg 173 scientific drilling and coring operations. Within fifteen minutes, at 1730 hr, Hole 1065 was spudded at a seafloor depth of 4781.0 m. The bit was washed ahead to 40 mbsf without rotation while the subsea TV was retrieved. Once the TV was recovered, drilling operations commenced using the rotary core barrel (RCB) coring system with a center bit installed. The hole was drilled to a depth of 251.0 mbsf in ~12.5 hr, including the wireline time for one center bit inspection at a depth of 135.8 mbsf and final recovery of the center bit before initiating coring operations.

Continuous wireline coring proceeded initially with an acceptable 40.9% recovery from 251.0 to 308.8 mbsf (nannofossil chalk and claystone). Recovery became very poor (<5%) below 308.8 mbsf (soft clay, siltstone, sandstone, and conglomerate). Acoustic basement was reached at a depth of ~501.5 mbsf. At this point the rate of penetration (ROP) continued to be slow at 3.8 m/hr; however, recovery did improve slightly, averaging 13.2% over the interval from 501.5 to 631.4 mbsf. Because of the poor drilling conditions and the lack of crystalline basement beneath the reflector defining the acoustic basement, coring was halted at a depth of 631.4 mbsf at 1830 hr 29 April, and preparations were begun for wireline logging.

The hole was swept with 30 bbl of sepiolite drilling mud after Core 1065A-34R and then swept again with 30 additional bbl that was timed to reach the bit at the conclusion of the last core (1065A-35R). A wiper trip was made to a depth of 100 mbsf and back. Pipe overpull of 50k was noted at 331.0 mbsf during the trip out, and a bridge was encountered at 585.0 mbsf on the return. A minimal amount of fill (~1.0 m) was found on bottom. The bit was released, the sleeve shifted, the hole was displaced with 200 bbl of sepiolite mud, and the pipe was placed at a logging depth of 108 mbsf. Wireline logging proceeded with the first suite of logging tools, the Triple Combination, consisting of NGS (Natural Gamma-ray Sonde), DIT (Dual Induction Tool), HLDT (Hostile Litho-Density Tool), APS (Accelerator Porosity Sonde) and the Lamont temperature tool. The first run had trouble passing a tight spot in the hole at 321.0 mbsf, but the tools were eventually worked through and reached within 5 m of the bottom. On the return trip the tools would not pass the same tight spot. After 1.5 hours the tools were eventually worked through the suspected keyseat and recovered aboard ship. The pipe was then lowered across the bad zone placing the open ended pipe at a depth of 5128.0 m (347.0 mbsf). The second logging run consisted of the NGT (Natural Gamma-ray Tool), SDT (Sonic Digital Tool), and FMS. These tools reached to within 17.4 m of bottom and yielded some good logs in areas where the hole was not vastly over gauge. Upon concluding wireline logging operations, the pipe was pulled clear of the seafloor and the primary positioning beacon was released and recovered.

TRANSIT TO SITE 1066

While the pipe trip continued, the vessel was moved in DP mode at ~0.5 kt to a way point located halfway between Sites 1066 and 1067. The end of the bottom hole assembly (BHA) reached the rig floor at 0830 hr 1 May 1997, officially ending Hole 1065A and beginning Hole 1066A. A new C-4 RCB bit and bit release were made up and the pipe was started back to bottom. Once the way point was reached (~375 m from each of the two sites) a primary positioning beacon was deployed at 1345 hr 1 May 97. The vessel then continued on to the GPS coordinates for Site 1066.

SITE 1066
(Proposed Site Iberia-9B)

After completing Site 1065, the vessel moved to a point halfway between Sites 1066 and 1067 where a beacon was deployed at 1345 hr on 1 May 1997. A jet-in test was done at Site 1066 to avoid an additional round trip of the drill string if a reentry cone had to be deployed at this site later. A subsea TV survey was conducted in the vicinity of the site coordinates prior to initiating the jet-in test. No evidence of subsea cables was observed. Hole 1066A was spudded at 2100 hr on 1 May 1997. The seafloor was determined to be 5032.0 m (drill-pipe measurement [DPM]) and the jet-in test proceeded to a depth of 5093.0 m or 61.0 mbsf. The drill string was pulled clear of the seafloor at 2245 hr that same day ending Hole 1066A. The drill string was secured with knobbies through the guide horn and the vessel proceeded to move in DP mode the ~750 m to Site 1067.

SITE 1067
(Proposed Site Iberia-9A)

The vibration-isolated television (VIT) camera was left deployed while the ship was moved from Site 1066 to Site 1067. No subsea cables were visible on the seafloor. Hole 1067A was spudded at 0100 hr 2 May 1997. It was at this time that the core tech noticed a spooling problem with the coax winch. While the ship was offset to the southwest in search of deeper water, an additional 30 m of line was let out and the problem was corrected. After about 2.5 hr, the ship was back on location and ready to re-spud the hole.

Hole 1067A was "officially" spudded at 0330 hr 2 May 1997. TheVIT was retrieved during a jet-in test to a depth of 5092.8 mbrf or 60.8 mbsf. Drilling with an RCB/center bit commenced at 0600 hrs; however, 2.5 hr later, at a depth of 109.0 mbsf, the WKM valve developed a severe leak causing the drilling operation to be halted for less than 2 hr. Drilling continued to a depth of 5680.0 mbrf averaging 14.5 m/hr. Drilling weight on bit was limited to 15,000 lb to prevent over loading/torquing the core barrel latch and latch sleeve. A total of 44.75 hr were required to drill the hole down to 648.0 mbsf, including time to recover and inspect the center bit four times.

Continuous RCB coring began at this depth and, after encountering basement at approximately 764.0 mbsf, coring continued to 855.6 mbsf. Between Cores 17R and 18R, a short trip of the drill string was required to replace 10 stands of drill pipe fitted with aluminum pipe protectors with standard 5-1/2-in pipe. Given the length of pipe that was removed, this short trip raised the bit to level above that of the sediment-basement contact. A wash barrel was used while running the pipe back to the bottom of the hole, and Core 18R was taken using this same core barrel. Thus the numerous claystone and siltstone pebbles at the top of Core 18R are almost certainly derived from sediments overlying the sediment-basement contact.

When coring had proceeded to 855.6 mbsf, the original C-4 core bit had 101.6 rotating hours and the rate of penetration for Core 23R was down to 0.9 m/hr. A sepiolite mud pill was circulated and the drill string was pulled to a depth of 185.0 mbsf. During the trip an overpull of 50,000 lb was seen at a depth of 744.0 mbsf; however, this was the only tight spot in the hole. After rigging and dropping a free fall funnel (FFF), theVIT was deployed. On the first attempt at pulling clear of the seafloor the C-4 core bit snagged the 13-3/8 in. casing joint on the FFF. The bit was immediately lowered back down hole ~9 m and another attempt was made. This time the bit came clear of the FFF without incident and at 0600 hr 9 May 1997 the bit cleared the seafloor. The VIT was retrieved as the pipe trip continued to the surface and the bit was on deck at 1400 hr.

A new C-7 bit, and a rebuilt mechanical bit release (MBR), were being made up to the outer core barrel when a vertical crack ~2 in long was found that ran downward from the shoulder of the MBR box connection. The cracked MBR top connector, used previously in Hole 1065A, was replaced and the drill string was tripped to the seafloor. With the VIT deployed, the vessel maneuvered for 3.5 hr before reaching a position over the FFF. Reentry was made at 0415 hr on 10 May 1997. At the time of reentry, vessel heave was causing the weight indicator to fluctuate

20,000-40,000 lb. Once inside the hole, the drill string was lowered slowly until 0430 hr, when the bit reached a depth of 80.0 mbsf. At this point 20,000-25,000 lb weight on bit was taken.

The drill string could not be rotated or run in at normal speeds until the VIT was retrieved. Use of the heave compensator or rapid downward movement of the drill string could have jeopardized the safe recovery of the VIT system because the cable can wrap around the drill pipe. While retrieving the VIT (~45 min), the string was worked up and down slowly three times with 20,000-25,000 lb weight in an attempt to pass the obstruction and place the BHA in a less vulnerable position. When the drill string was picked up the second time, an ~20,000-lb loss in string weight was noted, and the drill string was pulled back to 5102 mbrf where the circulating head was made up and circulation started. The drill string was not moved again until the camera frame was recovered.

After recovering the VIT frame, a rotary core barrel was run in on the wireline. If the BHA had been intact, the core barrel should have landed at 5108 mbrf. Instead, the barrel repeatedly landed at 5032 mbrf or 76 m above the landing point. The core barrel was pulled back ~20 m and landed two more times at the same point. This indicated that there had indeed been a failure in the BHA, most likely in a drill collar connection. The wireline was retrieved, the top drive set back, and the drill string was pulled back to the surface. While pulling the pipe, the beacon was released and subsequently recovered at 1745 hr on 10 May 1997. The BHA cleared the rotary table at 1815 hr that same day officially ending Hole 1067A.

A BHA failure was confirmed in the connection between 8-1/4-in drill collars #7 and #8. While the vessel was moved in DP mode to Site 1068 (Iberia-9C), the two remaining 8-1/4-in. drill collars and the tapered drill collar were inspected using magnetic particle techniques with no positive indications of any cracks. As a result of the BHA failure, Hole 1067A was abandoned short of the primary depth objective.

SITE 1068

After finishing at Site 1067, the ship was moved in DP mode to alternate Site 1068 (Iberia-9C; not in original prospectus) located ~1600 m to the west of Hole 1067A. Once on location, the VIT camera system was deployed to greater than 5000 m water depth to detorque the coaxial cable.

During this time, the new drill collars for the BHA were picked up and the RCB core barrels were spaced out. A beacon was deployed at 1845 hr on 10 May 1997; however, the beacon signal became erratic. At 2100 hr that same day, a second beacon was deployed.

Because of spooling problems with the coax winch,the TV system was near the seafloor for about 9 hr while we tried to correct gaps in the spooling of the cable on the winch. No indication was observed of subsea cables during the survey.

The drill string was tripped to bottom and Hole 1068A was spudded at 1430 hr 11 May 1997. A rig-floor corrected seafloor depth of 5055.0 m was established. Drilling ahead with the RCB center bit assembly continued while checking the center bit approximately every 100 m, beginning at 300 mbsf. Use of the 5-1/2-in. drill pipe with the aluminum wear knots was begun at a depth of ~600 mbsf. Drilling proceeded until 1630 hr on 14 May 1997, when a depth of 711.3 mbsf was reached. Originally the plan had been to drill to a depth of 780.0 mbsf before initiating coring; however, because of the limit to how much weight can be placed on the bit while drilling with a center bit, the increasingly slow penetration rate (2.8 m/hr) meant that coring would take equal or less time than drilling. Therefore, the center bit was recovered, and a core barrel was deployed. Coring with the RCB continued at an average ROP of 3.6 m/hr until basement was reached in Core 15R at an approximate depth of 852.0 mbsf. Coring continued into the basement rocks including a several-meter-thick band of dark bluish black serpentinite breccia that was extremely difficult to core. This material packed very easily, jamming the core catcher, and slowing the ROP to 1.0-2.0 m/hr. With depth, the formation graded into massive serpentinized peridotite. Coring was eventually suspended after Core 29R at a depth of 955.8 mbsf because of time constraints and the uncertainty about how much deeper the hole would have to progress before unaltered basement rock (peridotite) could be reached.

During the wiper trip in preparation for wireline logging, the driller noted constant 25,000 lb drag until reaching a depth of 781.0 mbsf. During the trip, the top drive had to be picked up at a depth of 775.0 mbsf. In general, high torque was noted from 899.0 mbsf to 915.0 mbsf, and there were three exceptionally tight spots that required heavy reaming and high torque at depths of 775.0 mbsf, 899.0 mbsf, and 908.0 mbsf. There was 6.0 m of fill on bottom. In preparation for logging, the hole was flushed with 30 bbl of sepiolite mud, the bit was released, the sleeve shifted, and the hole was displaced with another 265 bbl of sepiolite mud. The drill pipe was pulled to a logging depth of 114.0 mbsf and at 0415 hr on 21 May 1997, the crew began rigging up for logging. Because the hole was in poor condition, particularly in the basement rocks, and because of the heavy reaming required during the wiper trip, the side entry sub was not used.

Wireline logging proceeded with the first suite of logging tools, the triple combo, consisting of NGS/DIT/HLDT/APS and the Lamont temperature tool. The first run had trouble passing a tight spot in the hole at 520.0 mbsf. After unsuccessfully expending some effort to pass this point, the hole was logged back up to the open ended pipe (114.0 mbsf). After recovering the first suite of tools, the pipe was lowered across the bridge placing the open ended pipe at a depth of 614.0 mbsf. This was the deepest the pipe that could be placed without severely jeopardizing the pipe string. The triple combo logging suite was again run in the hole, this time reaching a depth of 770.0 mbsf before again reaching an obstruction. The hole was logged up from that point, the tools recovered, and further wire line logging efforts were abandoned. Upon concluding wireline logging operations, the pipe was pulled clear of the seafloor at 2200 hr on 21 May 1997. A pipe overpull of 25,000 lb was noted on the first two stands of drill pipe. After pulling clear of the seafloor, the first beacon was commanded to release but did not surface. Once the second beacon was released and recovered aboard at 2400 hr, the vessel began to slowly DP move to alternate Site 1069. The pipe trip continued during the DP move. The mechanical bit release reached the rig floor at 0530 hr on 22 May 1997, officially ending Hole 1068A.

SITE 1069
(New Site Iberia-7B)

Once the location for Site 1069 (Iberia-7B; near Prospectus Site Iberia-7A) was reached, a positioning beacon was deployed at 0845 hr on 22 May 1997. A brief TV survey was conducted, although the closest subsea cable was estimated to be at least 11.5 nmi away. Hole 1069A was spudded at 1715 hr on 22 May 1997 at 5086.0 mbrf with the RCB center bit assembly. The center bit was recovered for inspection at ~350 mbsf and again at ~700 mbsf. Drilling proceeded until 0830 hr on 25 May when a depth of 5804.9 m (718.9 mbsf) was reached. Originally the plan had been to drill to a depth of 810.0 mbsf before initiating coring; however, the steadily decreasing penetration rate (3.4 m/hr) made coring a more attractive option at that point.

Continuous RCB coring was begun after the center bit was recovered and a core barrel was deployed. Metasedimentary basement rocks were encountered in Core 17R. Penetration proceeded with extremely poor recovery (0%–10%) at an average ROP of 9.7 m/hr. The ROP was too slow for coring through loose sand and too fast for basement material. To explain the erratic torque ranging from 200-350 amps, lack of fill between connections, and coring times ranging from 35-80 minutes (16.5 to 7.2 m/hr ROP), we speculated that the unrecovered formation consisted of loosely cemented sands interlayered with harder, more indurated rock. Coring ended at 959.3 mbsf. Because of the importance of logging the basement section of the hole, extra time was spent making wiper trips and hole conditioning. The first wiper trip (902-593 mbsf) was an abbreviated trip made during the coring operation to short trip 10 stands of wear knotted 5-1/2-in pipe. While running the pipe back to bottom, the top drive had to be picked up and a center bit dropped at a depth of 795 mbsf. High torque during reaming was noted from 887 to the bottom of the hole at 902 mbsf.

After coring operations were completed at a TD of 959 mbsf a second complete wiper trip was made to ~100 mbsf. Then the pipe was run back to 773.0 mbsf where the top drive was picked up and a center bit deployed. It took 4.0 hours to ream back to bottom. A third wiper trip was made up to a depth of 767.0 mbsf. On the return trip an obstruction was encountered at 800 mbsf. The hole was reamed to bottom from this point using the top drive and a center bit. Elevated pump pressure was experienced during the last 15 m. As on the previous wiper trip, 30 bbl of sepiolite mud were circulated once TD was reached. In total, 23 hr was spent in making the 3 wiper trips, including the mud sweeps. Upon recovering the center bit after the last wiper trip, 0.41 m of silty sand and a gray clay ball were found inside the core barrel that had been extruded through the 1 cm diameter center bit jet. This material was curated as Core 26G, a "ghost" core, and came from an interval extending from 767 to 959 mbsf.

Circulation was immediately lost when the bit was released, and the pipe became plugged with back-flow material. The pipe was pulled back to a depth of 862 mbsf, which was the originally intended pipe placement for logging. While attempting to set back the top drive, the pipe was taking 20,000-lb weight forcing the driller to pull additional pipe back to 800 mbsf. The pipe was then pulled farther up to 776 mbsf to enable logging of the deepest sedimentary section.

Wireline logging proceeded with the triple combo, consisting of NGS/DIT/HLDT/APS and the

Lamont temperature tool. This tool string was unable to pass a point only 1-2 m beyond the open ended pipe. After working the tools for a while without success, the effort was abandoned and the tools were recovered. The top drive was then picked up and the drill string was advanced 11 m to a depth of 788 mbsf without seeing any indication of an obstruction in the hole. The top drive was set back and the pipe was then pulled to a depth of 102 mbsf. While pulling pipe to this position, back flow was observed coming from the drill pipe at a depth of ~651 mbsf. A total of 30 bbl of 10.2 ppg barite weighted gel mud was spotted in the pipe at a depth of ~564 mbsf and this solved the back-flow problem. The hole was displaced with sepiolite mud and rig up for logging began.The triple combo logging suite was again run, this time reaching a depth of 764 mbsf. Logging was conducted up from that point. The hole was in good shape, and the caliper logs showed a hole only slightly out of gauge (12-14 in). The second logging run consisted of the NGT, SDT, and FMS. These tools were able to reach to the same depth (780 mbsf), however, a tool fault made the FMS inoperable and the tools had to be pulled out of the hole. At 0600 hr 31 May, rig down was completed and wireline logging operations for the hole were concluded. The pipe was pulled clear of the seafloor at 0615 hr and the positioning beacon was released and recovered aboard at 0845 hr. The pipe trip was completed, and the ship was secured for transit to Site 1070. Departure from the site began at 1445 hr 31 May 1997.

SITE 1070
(Proposed Site Iberia-10A)

The 44-nmi distance from Site 1069 to Site 1070 was covered in 4.25 hr at an average speed of 10.4 kt. At 1900 hr on 31 May 1997, a positioning beacon was deployed, thrusters and hydrophones were lowered, and by 1930 hr the vessel was stabilized over the drilling location. A new C-7 core bit and mechanical bit release were made up, and the drill string was tripped to the seafloor. At 2045 hr on 31 May, a backup positioning beacon was deployed. Hole 1070A was spudded with the RCB center bit assembly at 0445 hr on 1 June at a seafloor depth of 5333.0 mbrf. At 20 mbsf, the driller noted higher than normal pump pressure, which continued sporadically throughout the drilling operations at this site. Intermittent plugging of the bit jets was suspected as the cause. The center bit was recovered for inspection at ~100 mbsf, ~200 mbsf, and again at ~400 mbsf. At a depth of ~500 mbsf, the center bit was recovered and a core barrel, without a check ball installed, was deployed to see if the rate of advancement would improve.

Drilling ahead continued at exactly the same rate (19.2 m/hr) as with the center bit. Drilling proceeded until 2230 hr on 2 June at 599.0 mbsf. The wash barrel was then recovered and a core barrel was deployed. Continuous RCB coring continued to a total depth of 718.8 mbsf. Crystalline basement, made up of serpentinized peridotite, was identified beginning with Core 9R at ~676.0 mbsf. The last two cores (13R and 14R) achieved an ROP of only 1.1 m/hr, but recovery was an impressive 55% and 71%, respectively.

At 0945 hr on 5 June, coring operations were ended and a pre-logging wiper trip was begun. While pulling the first stand of drill pipe off the bottom, a 20,000-lb overpull was noted. During the remaining pipe trip to 100 mbsf there were no indications of hole problems. The trip back to bottom was equally uneventful until a hard obstruction was encountered at 673.0 mbsf, or about 46 m above the bottom. Once the top drive was in place, the pipe was able to be rotated and circulated but could only be worked between the depths of 666.0 to 655.0 mbsf. A 20-bbl sepiolite mud pill was circulated but did nothing to improve the situation. The ability to rotate the pipe was lost on several occasions and then regained, although high and erratic torque was present throughout the exercise. After working the pipe for nearly 3 hr without any measurable success, it was decided that logs in the lower part of the hole were unlikely to be obtained even if the pipe could be freed. The shifting tool was deployed in the hope that the pipe was stuck at the bit and would come free once the bit was released. At 1630 hr, the bit was released but the drill string remained stuck. Another 2 hr were spent circulating sepiolite mud and working the pipe with overpulls of up to 150,000 lb over the 630-kip hanging weight.

At 1930 hr on 5 June, while continuing to work the stuck drill string, an unusual noise was heard from the drawworks when the low drum clutch was engaged. Further investigation revealed that the hub had spun on the motor shaft of the forward traction motor, separating the drive sprocket from the armature shaft. At the time of the incident, no overpull was being applied and only a static string weight of 630,000 lb was being supported. As a result of the failure, the drawworks were electrically isolated and the input chain was removed from the motor and chain case. No progress had been made up to that point in freeing the drill string and a single drawworks motor did not provide enough hoisting capacity to continue the attempt. Therefore, at 2000 hr on 5 June, drill string severing operations were initiated. The Schlumberger logging line was rigged up and an explosive charge was assembled to sever the stuck drill string in the 5-1/2-in transition pipe above the BHA. The first charge was detonated at 0215 hr on 6 June at a depth of 536.0 mbsf.

Approximately 30,000 lb overpull and 4,000 ft-lb of torque were applied to the drill string at the time. There was no indication that the charge had fired, and the drill string remained stuck. From all indications, the hole had collapsed above the point of detonation. A second charge was detonated at 0900 hr on 6 June 97 at 30 mbsf. This time the drill string came free. The severing tool was retrieved and Schlumberger logging line and sheaves were rigged down.

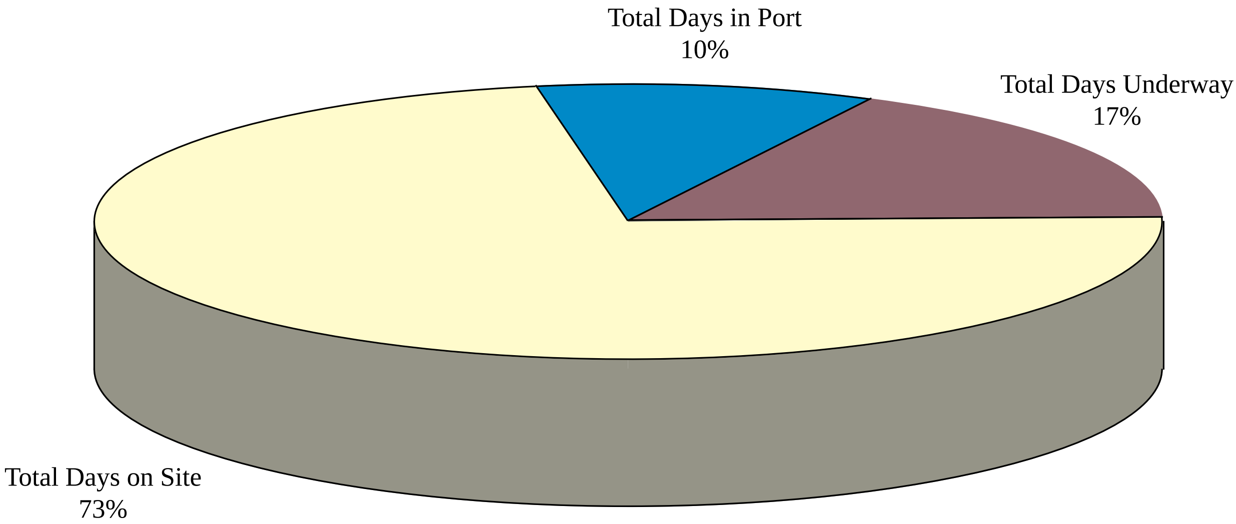
The drill string trip commenced at 1130 hr on 6 June using the single remaining (aft) drawworks motor. Once repairs were completed, 1.5 hr were taken to reinstall the forward drawworks motor. At 0130 hr on 7 June, with 1982 m of pipe remaining to be recovered, the trip resumed. The pipe trip was completed at 0415 hr and the rig was secured for transit. Aside from losing a complete BHA, including 10 each 8-1/4-in. drill collars, a tapered drill collar, and 2 stands of 5-1/2-in. transition pipe, an additional 16 stands of 5-in. drill pipe were left in the hole plus a single severed joint. As a result of the stuck pipe and the resultant severing, no wireline logging was accomplished.

Weather conditions during the last 2 days of operations at this site were the worst experienced during the leg. Force 9-10 conditions continued for the last 24-36 hrs eventually moderating to force 8. Sustained winds averaged 33 kt with gusts to 42 kt. Seas and swells averaged 25 ft, and 18 ft respectively. The vessel began the voyage to Halifax, Nova Scotia at 0415 hr on 7 June, departing the last drill site 7.25 hr behind schedule in force 8 weather conditions.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 173

Total Days (15 April 97 to 16 June 97)		60.5
Total Days in Port		6.2
Total Days Underway		10.2
Total Days on Site		44.0
	days	
Stuck Pipe/Downhole Trouble	1.2	
Tripping	6.1	
Other	1.3	
Drilling	10.9	
Coring	21.8	
ODP Breakdown	0.0	
Logging/Downhole Science	2.5	
Fishing & Remedial	0.0	
Development Engineering	0.0	
Repair Time (Contractor)	0.2	
Reentry	0.1	
W.O.W.	0.0	
Casing and Cementing	0.0	
Total Distance Traveled (nautical miles)		2465.0
Average Speed Transit (knots):		10.2
Number of Sites		6
Number of Holes		6
Number of Reentries		1
Number of Cores Attempted		126.0
Total Interval Cored (m)		1188.2
Total Core Recovery (m)		452.9
% Core Recovery		38.1%
Total Interval Drilled (m)		2993.7
Total Penetration		4062.1
Maximum Penetration (m)		959.3
Minimum Penetration		61.0
Maximum Water Depth (m from drilling datum)		5333.0
Minimum Water Depth (m from drilling datum)		4781.0
Average Water Depth		5053.2

LEG 173
TOTAL TIME DISTRIBUTION



TOTAL DAYS = 60.5

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 173

HOLE	LATITUDE	LONGITUDE	SEA FLOOR (mbrf)	NUMBER OF CORES	INTERVAL CORED (meters)	CORE RECOVERED (meters)	PERCENT RECOVERED (percent)	DRILLED (meters)	TOTAL PENETRATION	TIME ON HOLE (hours)	TIME ON HOLE (days)
1065A	40°43.4469N	11°17.7236W	4781.0	35	375.8	46.56	12.4%	255.6	631.4	206.50	8.60
	SITE 1065 (IB-8B)		**TOTALS:**	**35**	**375.8**	**46.56**	**12.4%**	**255.6**	**631.4**	**206.50**	**8.60**
1066A	40°40.9504N	11°35.2257W	5032.0	0	0.0	0.00	0.0%	61.0	61.0	14.25	0.59
	SITE 1066 (IB-9B)		**TOTALS:**	**0**	**0.0**	**0.00**	**0.0%**	**61.0**	**61.0**	**14.25**	**0.59**
1067A	40°40.9502N	11°35.7500W	5032.0	23	207.6	77.67	37.4%	648.0	855.6	211.50	8.81
	SITE 1067 (IB-9A)		**TOTALS:**	**23**	**207.6**	**77.67**	**37.4%**	**648.0**	**855.6**	**211.50**	**8.81**
1068A	40°40.9550N	11°36.7196W	5055.0	29	244.5	180.59	73.9%	711.3	955.8	275.25	11.47
	SITE 1068 (IB-9C)		**TOTALS:**	**29**	**244.5**	**180.59**	**73.9%**	**711.3**	**955.8**	**275.25**	**11.47**
1069A	40°43.6126N	11°46.6325W	5086.0	25	240.5	96.30	40.0%	718.8	959.3	225.25	9.39
	SITE 1069 (IB-7B)		**TOTALS:**	**25**	**240.5**	**96.30**	**40.0%**	**718.8**	**959.3**	**225.25**	**9.39**
1070A	40°47.7788N	12°43.4302W	5333.0	14	119.8	51.77	43.2%	599.0	718.8		0.00
	SITE 1070 (IB-10A)		**TOTALS:**	**14**	**119.8**	**51.77**	**43.2%**	**599.0**	**718.8**	**153.25**	**6.39**
		LEG 173	**TOTALS:**	**126**	**1188.2**	**452.89**	**38.1%**	**2993.7**	**4062.1**	**1086.0**	**45.3**

TECHNICAL REPORT

The ODP technical personnel aboard *JOIDES Resolution* for Leg 173 were:

John Dyke	Marine Lab Specialist (Storekeeper/Shipping)
John Eastlund	Marine Computer Specialist
Tim Fulton	Marine Lab Specialist (Photographer)
Edwin Garrett	Marine Lab Specialist (Paleomagnetics)
Dennis Graham	Lab Officer
Gus Gustafson	Assistant Lab Officer/Marine Lab Specialist (Downhole Tools)
Michiko Hitchcox	Marine Lab Specialist (Yeoperson)
Craig Kerr	Computer Programmer (Janus)
John Lee	Marine Lab Specialist (Chemistry)
Kevin MacKillop	Marine Lab Specialist (Physical Properties)
Eric Meissner	Marine Electronics Specialist
Bob Olivas	Marine Lab Specialist
Chieh Peng	Marine Lab Specialist (Chemistry)
Hervé Richen	Marine Lab Specialist
Don Sims	Assistant Lab Officer/Marine Lab Specialist (X-ray)
Lorraine Southey	Marine Lab Specialist (Curator)
Larry St. John	Marine Electronics Specialist
Chris Stephens	Marine Computer Specialist

GENERAL LEG INFORMATION

The participants of Leg 173 cored and analyzed 453 m of core from five drill sites.

The *JOIDES Resolution* docked in Lisbon, Portugal on April 15, 1997, ending Leg 172. The Leg 173 technical staff joined the ship the following morning, April 16. The technical crews completed crossover by midday. At 1800 hours on April 21, lines were cast and the ship got under way for the 171 nmi transit to the drilling location. Five sites were drilled in the vicinity. The leg's drilling operations were completed June 7, and the ship was under way at 0430 for the 2283 nmi transit to Halifax.

Port Call Activities Overview

Port call logistics included customs clearance of personnel and shipments, and onloading and offloading of science and operations supplies. A service representative from Fisons Inc. repaired the x-ray fluorescence unit. A representative from Tracor attended port call to instruct shipboard scientists on the use of the JANUS database and help get the database prepared for the acceptance leg. A special VIP tour of the ship was conducted to commemorate Portugal's joining ODP. Catermar held a dinner for all port call and shipboard participants at the castle of King George.

Transit Activities

The technical staff collected bathymetric data and Earth's magnetic field data during the transit to the drill area and during the transit to Halifax at the end of the leg. Seismic surveys were not required to meet the scientific objectives. Global Positioning System (GPS) fix coordinates were recorded every minute for the entire leg.

Safety

The Marine Emergency Technical Squad (METS) participated in all ship's emergency drills. The METS was the primary response team for all laboratory emergencies and the third backup hose team for all other ship emergencies. There were no actual emergencies this leg.

LAB ACTIVITIES

The 453 m of recovered core consisted of sediment, breccia, and hard rock. Physical properties, magnetic properties, mineral and elemental properties, and structural properities were investigated on the core material. The technical staff carefully curated the material for the shipboard scientific participants as well as future investigators. The scientists and curator strategically planned the sampling of all core material to maximize the scientific return of core analysis. Two new ODP technicians sailed this leg, two temporary technicians, and the underway technician filled in as acting lab officer.

Chemistry Lab

A relatively small number of samples, three per hole, were taken for interstitial water analysis. Most of the holes were drilled to just above the acoustic basement before coring began. At this point the sediments were too lithified to contain a substantial quantity of interstitial water. The chemistry technicians analyzed the samples for salinity, chlorinity, sulphate, magnesium, calcium, potassium, sodium, lithium, and strontium. The chemistry technicians analyzed each core for its gas content using the headspace technique. An average of thirty-five samples per hole were analyzed for total carbon and inorganic carbon. The chemistry technicians extensively serviced the natural gas analyzer and performed routine maintenance on the other lab equipment.

The chemists assisted SEDCO to determine the magnitude of diesel fuel contamination in the potable water supply. The lab did not have the proper equipment to test potable water and the tests were inconclusive.

Computer Services

In addition to the regular two marine computer specialists (MCS), an ODP programmer sailed this leg to assist with the JANUS acceptance. The JANUS program ran smoothly for the majority of applications. The paleontologists required the most assistance because of the complexity of the application and documentation. The X-ray application did not work, apparently because of a lack of proper documentation. Other bugs were reported to ODP where a comprehensive bug checklist is being compiled. This was Chris Stephens’ (MCS) first leg with ODP.

The network fiber connection between the underway lab and machine room was activated to bypass the troublesome bridge in the downhole measurements lab.

The MCSs provided routine computer support for the scientific, technical, and operations staff. Maintenance requirements were common but not abnormal for the harsh environment of the North Atlantic. The MCSs put five new Power Mac 7600/132 computers into service, replacing older machines.

Core Lab

The core material processed this leg was both lithified sediment and hard rock. The technicians split all the core sections with the supersaw. The hard-rock label program developed on Leg 172 made labeling these rocks less tedious. To complete the upgrade, we need to print the labels on label stock and avoid the very tedious job of cutting out the labels with scissors. The core lab technicians made use of the sometimes long waits between cores by performing maintenance on the core saws, drill presses, and cut-off saws.

AppleCore v0.7.5b was used for barrel sheets. Because the hard rock lithologies were so variable and complex, the standard ODP descriptions used for fine-grained or coarse-grained rocks did not apply. The petrologists used a slightly modified format for their descriptions.

A scientist brought a DMT color core scanner to use on this leg. The portable unit provided comprehensive digital core images of both split-half core and whole-round core. Core flow was altered to accommodate this nonroutine procedure. The whole-round pieces were removed from the liner before labeling; this is potentially dangerous because core pieces could be misplaced. The scientists scanned nearly all the core recovered this leg.

Curation

Curation on a low-recovery leg is usually problematic and this leg was no exception. The scientists had too little material to share and several of the sample requests overlapped. The co-chiefs, staff scientists, and curator spent many hours resolving the conflicts over sample requests. Early in the leg the scientific party decided to defer taking personal samples until the end of the leg. This approach made scientific sense. Practically speaking, waiting until the end delayed resolving sample conflicts and put a greater workload on the technical staff during the time when the emphasis was to prepare the labs for the next group of scientists. The new sample policy went into effect this leg. We still attempted to operate under the old policy in most cases unless justification was provided. We attempted to maintain one half the working section and limit hard rock samples to 100 per investigator. The Leg 149 archive sections were shipped from the east coast repository for use on this leg.

Downhole Measurements Lab

The lab was used exclusively by the logging scientists. There were no measurements taken using the ODP downhole measurement tools.

Electronics Services

The electronics technicians assisted in all laboratories with equipment repair and maintenance. They also repaired and then collected data from sensors in the derrick. This data will be used to model drill string movement and stresses for the diamond coring system. Larry St. John, electronics tech, sailed for the first time this leg.

Microscope/Paleontology Lab

The scientists used the microscopes for paleontology and petrology. Usage was normal except for a large number of photomicrographs.

Paleomagnetics Lab

This lab saw heavy use of the thermal demagnitizer unit as well as many passes through the cryo AF demagnitizer. The paleomagnetics technician performed tests on the cryo helium level gauge. He also configured the Windows NT computer to make file transfer of paleomagnetics data easier.

Photography Services

Normal photography services were required this leg. All core sections were photographed using color and black and white film and processed on board. A more than average number of closeup photographs were requested by the scientific staff. The photographer assisted the scientists with the setup and use of microscopes.

Physical Properties Lab

The physical properties scientists and technician measured magnetic susceptibility and natural gamma radiation using the multisensor track. They determined thermal conductivity by the half space method on split sections. Discrete velocity and index properties were taken at selected core intervals. An electronics technician built a pulse generator for the *P*-wave velocimeter.

Thin Section Lab

The scientists requested 195 thin sections from such diverse materials as sand, silt, clay, chalk, limestone, granite, gabbro, and periodite. The requests came from sedimentologists, petrologists, and paleontologists.

Underway Geophysics Lab

We received the first of four replacement thermal graphic line scanning recorders purchased for the underway lab. The EPC recorder was used with the 3.5 kHz depth profiling system. The underway technician wrote a LabVIEW program to control the recording parameters and interface to a GPS receiver for annotation. The 3.5 kHz record is annotated every five minutes with GPS time, latitude, longitude, course, and speed. The EPC signal quality was much improved compared to the old Raytheon line scan recorders. The electronics techs and underway tech tested the multichannel streamer system to diagnose the problems encountered on the previous leg. All the lab equipment tested satisfactorily. One of the ITI six channel streamers had a faulty channel and was returned for repair at the end of the leg. The other ITI streamer tested satifactorily during deck tests. A quick water test at the end of the leg indicated that this streamer was not being towed at a proper depth. Further tests are needed to establish the correct towing depth.

X-ray Lab

The scientists requested 213 bulk powder samples for X-ray diffraction analysis. The rocks recovered this leg were highly altered; therefore, the X-ray technician received a small number of samples for major and trace element identification on the X-ray flourescence unit.

LEG 173 LABORATORY STATISTICS

General:

Sites:	6
Holes:	6
Meters Drilled:	2994 m
Meters Cored:	1188 m
Meters Recovered:	453 m
General Samples:	4240 m

Lab Analysis:

Magnetics Lab:	
Cryomagnetometer:	500 sections
Discrete Measurements:	200
Oriented cores	0
Physical Properties:	
MST:	329 sections
Discrete Velocity:	238
Strength:	0
Thermal Conductivity:	28
Moisture/Density:	207
Chemistry:	
Rock Eval:	0
Water Chemistry:	13
Head Space/Vacutainer:	82
Inorganic Carbonate:	187
Carbon Nitrogen Sulfur:	187
X-ray:	
XRF:	25
XRD:	213
Downhole:	
Adara:	0
WSTP:	0
Davis-Villenger Temp	0
Thin Sections:	195

Underway Geophysics:

Total Transit	2522 nmi
Bathymetry:	2000 nmi
Magnetics:	2000 nmi
Seismic	0 nmi