OCEAN DRILLING PROGRAM

LEG 185 PRELIMINARY REPORT

IZU-MARIANA MARGIN

Dr. Terry Plank
Co-Chief Scientist
Department of Geology
120 Lindely Hall
University of Kansas
Lawrence, KS 66045
U.S.A.

Dr. John Ludden
Co-Chief Scientist
Centre de Recherches
Petrographiques et
Geochimiques (CNRS)
Nancy, 54501
France

Dr. Carlota Escutia
Staff Scientist
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
U.S.A.

Dr. Jack Baldauf
Deputy Director of
Science Operations
ODP/TAMU

Dr. Carlota Escutia
Leg Project Manager
Science Services
ODP/TAMU

September 1999

Preliminary Report No. 85

First Printing 1999

Distribution

Electronic copies of this publication may be obtained from the ODP Publications Homepage 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 Ocean Drilling
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, and Switzerland)
Marine High-Technology Bureau of the State Science and Technology Commission of the People's Republic of China

The following scientists were aboard the *JOIDES Resolution* for Leg 185 of the Ocean Drilling Program:

Terry Plank
Co-Chief Scientist
Department of Geology
University of Kansas
120 Lindley Hall
Lawrence, KS 66045
U.S.A.
Internet: tplank@kuhub.cc.ukans.edu
Work: (785) 864-2725
Fax: (785) 864-5276

John N. Ludden
Co-Chief Scientist
CRPG-CNRS
15 rue Notre-Dame des Pauvres, B.P.20
Vandoeuvre-les-Nancy, 54501
France
Internet: ludden@crpg.cnrs-nancy.fr
Work: (33) 3-83-594213
Fax: (33) 3-83511798

Carlota Escutia
Staff Scientist
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
U.S.A.
Internet: carlota_escutia@odp.tamu.edu
Work: (409) 845-0506
Fax: (409) 845-0876

Lewis Abrams
Physical Properties Specialist
Department of Earth Sciences
University of North Carolina
601 South College Road
Wilmington, NC 28403-3297
U.S.A.
Internet: abramsl@uncwil.edu
Work: (910) 962-7422
Fax: (910) 962-7077

Jeffrey C. Alt
Igneous Petrologist
Department of Geological Sciences
University of Michigan
2534 C.C. Little Building
425 E. University
Ann Arbor, MI 48109-1063
U.S.A.
Internet: jalt@umich.edu
Work: (313) 764-8380
Fax: (313) 763-4690

Robin N. Armstrong
Inorganic Geochemist
Southampton Oceanography Centre
University of Southampton
Empress Dock, European Way
Southampton SO14 3ZH
United Kingdom
Internet: rxa@soc.soton.ac.uk
Work: (44) 1703-59-6133
Fax: (44) 1703-593-052

Samantha Barr
Igneous Petrologist
Department of Geology
University of Leicester
Universitiy Road
Leicester LE1 7RH
United Kingdom
Internet: srb7@leicester.ac.uk
Work: (44) 116-252-3608
Fax: (44) 116-252-3918

Annachiara Bartolini
Paleontologist (radiolarians)
Institut de Geologieet Paleontologie
Universite de Lausanne
BFSH-2 UNIL
Lausanne, VD 1015
Switzerland
Internet: abartoli@igp.unil.ch
Work: (41)21-692-4343
Fax: (41)21-692-4305

Graeme Cairns
LDEO Logging Trainee
Laboratoire de Mesures en Forage
ODP/Naturalia et Biologia (NEB)
BP 72
13545 Aix-en-Provence Cedex 4 13545
France
Internet c/o: louvel@lmf-aix.gulliver.fr
Work: (33) 4-42-97-11-22
Fax: (33) 4-42-97-11-21

Martin R. Fisk
Microbiologist/Igneous Petrologist
College of Oceanic and Atmospheric Sciences
Oregon State University
104 Ocean Administration Building
Corvallis, OR 97331-5503
U.S.A.
Internet: mfisk@oce.orst.edu
Work: (541) 737-5208
Fax: (541) 737-2064

Gilles Guèrin
LDEO Logging Scientist
Lamont-Doherty Earth Observatory
Columbia University
Palisades, NY 10964
U.S.A.
Work: (914) 365-8671
Fax: (914) 365-3182
Internet: guerin@ldeo.columbia.edu

Shelley A. Haveman
Microbiologist
Institute for Cell and Molecular Biology, Microbiology
Göteborgs Universitet
Box 462
Göteborg 405 30
Sweden
Internet: shelley.haveman@gmm.gu.se
Work: (46) 31-773-2586
Fax: (46) 31-773-2599

Tetsuro Hirono
Physical Properties Specialist
Department of Earth and Planetary Sciences
Tokyo Institute of Technology
Okayama 2-12-1
Meguro-ku
Tokyo, 152-8551
Japan
Internet: t-hirono@spa.att.ne.jp
Work: (81) 11-816-5099
Fax: (81) 35-734-3543

José Honnorez
Metamorphic Petrologist
Institut de Géologie
Université Louis Pasteur
1 rue Blessig
Strasbourg, Cedex 67084
France
Internet: honnorez@illite.u-strasbg.fr
Work: (33) 3-88-35-85-38
Fax: (33) 3-88-36-72-35

Katherine A. Kelley
Igneous Petrologist
Department of Geology
University of Kansas
120 Lindley Hall
Lawrence, KS 66045
U.S.A.
Internet: kelley@eagle.cc.ukans.edu
Work: (785) 864-7714
Fax: (785) 864-5276

Roger L. Larson
JOIDES Logging Scientist
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882-1197
U.S.A.
Internet: rlar@gsosun1.gso.uri.edu
Work: (401) 874-6165
Fax: (401) 874-6811

Francesca M. Lozar
Paleontologist (nannofossils)
Centro di Studi Sulla Geodinamica delle Catene Collisionali
Consiglio Nazionale delle Ricerche
via Accademia delle Scienze 5
Torino, 10123
Italy
Internet: f.lozar@csg.to.cnr.it
Work: (39) 11-562-8928
Fax: (39) 11-541-755

Richard W. Murray
Inorganic Geochemist
Department of Earth Sciences
Boston University
685 Commonwealth Avenue
Boston, MA 02215
U.S.A.
Internet: rickm@bu.edu
Work: (617) 353-6532
Fax: (617) 353-3290

Thomas K. Pletsch
Sedimentologist
Geologisch-Paläontologisches Institut
Christian-Albrechts-Universität zu Kiel
Olshausenstraþe 40-60
Kiel 24118
Federal Republic of Germany
Internet: tp@zaphod.gpi.uni-kiel.de
Work: (49) 431-880-2938
Fax: (49) 431-880-4376

Robert A. Pockalny
JOIDES Logging Scientist
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882-1197
U.S.A.
Internet: robp@bobbyorr.gso.uri.edu
Work: (401) 874-6926
Fax: (401) 874-6811

Olivier Rouxel
Igneous Petrologist
Centre de Recherches Pétrographiques et Géochimiques
15 rue Notre-Dame des Pauvres, B.P. 20
Vandoeuvre-lés-Nancy, Cedex 54501
France
Internet: rouxel@crpg.cnrs-nancy.fr
Work: (33) 03-83-59-42-23
Fax: (33) 03-83-51-17-98

Angelika Schmidt
Igneous Petrologist
GEOMAR
Department of Volcanology and Petrology
Christian-Albrechts-Universität zu Kiel
Wischhofstrasse 1-3
Kiel 24148
Federal Republic of Germany
Internet: aschmidt@geomar.de
Work: (49) 431-600-2644
Fax: (49) 431-600-2949

David C. Smith
Microbiologist
Graduate School of Oceanography
University of Rhode Island
South Ferry Road
Narragansett, RI 02881-1197
U.S.A.
Internet: dcsmith@gso.uri.edu
Work: (401) 874-6172
Fax: (401) 874-6240

Arthur J. Spivack
Inorganic Geochemist
Department of Earth Sciences
University of North Carolina
601 South College Road
Wilmington, NC 28403-3297
U.S.A.
Internet: spivack@uncwil.edu
Work: (910) 256-3721
Fax: (910) 256-8856

Hubert Staudigel
Igneous Petrologist
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0225
U.S.A.
Internet: hstaudigel@ucsd.edu
Work: (619) 534-8764
Fax: (619) 534-8090

Maureen B. Steiner
Paleomagnetist
Department of Geology and Geophysics
University of Wyoming
P.O. Box 3006, University Station
Laramie, WY 82071
U.S.A.
Internet: magnetic@uwyo.ed
Work: (307)766-6584
Fax: (307)766-6679

Robert B. Valentine
Sedimentologist
Department of Earth and Planetary Sciences
Washington University
One Brookings Drive
Campus Box 1169
St. Louis, MO 63130
U.S.A.
Internet: rbvalent@artsci.wustl.edu
Work: (314) 935-7292
Fax: (314) 935-5610

SCIENTIFIC REPORT

ABSTRACT

Subduction zones are the primary regions on Earth today where crust recycling takes place, and through geological time they have been the sites of continent formation. Many of the key elements (e.g., Th, rare earth elements, Ba, and Be) that are important in understanding crustal growth are sequestered in the sedimentary column and in the uppermost oxidized portions of the volcanic section of oceanic basement (K, B, U, CO_2, H_2O). The principal objective of Leg 185 was to core two sites in Mesozoic crust in the west Pacific, which is being subducted into the Mariana and Izu-Bonin subduction systems, in order to determine the inputs into the "west Pacific subduction factory." Hole 801C was first drilled in the oldest (~165 Ma) crust in the Pacific Ocean during Ocean Drilling Program (ODP) Leg 129. During Leg 185 the hole was deepened to nearly 500 meters below seafloor (mbsf), and at Site 1149, located on magnetic Anomaly M11 (~132 Ma) 100 km east of the Izu-Bonin Trench, the entire sedimentary sequence (410 m) and an additional 133 m of highly altered volcanic basement was drilled.

Using the recovered core and the logging results, it is possible to reconstruct the volcanic section for Hole 801C. Seven volcanic sequences have been defined, some with massive lava flows up to 20 m thick and others with thin pillows and sheet flows of <1 m. The uppermost unit is a series of alkali basalts drilled during Leg 129 and dated at ~155 Ma. These are separated from the underlying tholeiites of normal oceanic crust by an ocherous Si-Fe–rich hydrothermal deposit. A similar deposit is 100 m lower in the hole. These hydrothermal deposits and numerous interpillow sediments observed in the upper volcanic sequences define the alteration character of the basement, which is confined to three zones downcore and appears to be controlled by local permeability structures. The pattern of alteration for basement at Site 801 contrasts with that from other deeply drilled sections in oceanic crust where oxidative alteration decreases continuously with depth. The estimated seafloor spreading rate for Site 801 is 160 km/m.y. Thus, both the alteration and lava sequences may be typical of fast-spreading environments, such as the present-day East Pacific Rise.

Site 1149 basement is dramatically different in character. It is pervasively altered at low temperatures to red dusky brown and preserves multicolored halos around veins and fractures. The volcanic facies are dominated by thin flows, hyaloclastite, and flow breccia.

Preliminary estimates of the geochemical budget for K were made for Site 801 volcanic sections of ocean basement using gamma-ray intensities from downhole logs and multisensor track (MST) measurements, in addition to chemical analyses of core samples and estimates of the volume percentages of veins and alteration types. The K content of the entire core indicates a three- to fourfold enrichment as a result of low-temperature alteration. Similar estimations will be possible for other key elements following shore-based analyses.

The deep basement penetration in Hole 801C provided ideal samples for probing the causes of the Jurassic Quiet Zone (JQZ). From paleomagnetic measurements on cores and geophysical logs we discovered a series of reversals downhole. Given the spreading rates estimated for the region, the reversals must relate to rapid fluctuations in field polarity. Thus, at Site 801 the JQZ may represent a canceling out of normal and reversed polarities associated with an unstable and relatively weak magnetic field.

The sediments being subducted into trenches must, in part, control geochemical differences in the composition of arc magmas. Both the Mariana and Izu-Bonin margins are characterized by complete subduction of the sedimentary section on the downgoing plate, thus simplifying the dynamics of the subduction problem. Although the subducting sediments have been reasonably well sampled in the Pigafetta Basin (Mariana region), earlier drilling attempts to recover the sedimentary section in the Nadezhda Basin, seaward of the Izu-Bonin Trench, had largely been thwarted by difficult drilling conditions. Thus, an important objective of Leg 185 was met by continuously coring and logging the ~400 m sedimentary section at Site 1149. The uppermost sediments consist of pelagic clays with admixtures of volcanic ash and biosiliceous material for which paleomagnetic data define an excellent record of 6 m.y. of sedimentation in the west Pacific. These are underlain by barren pelagic clays characterized by low sedimentation rates, which overlie radiolarian cherts and clays and a lower unit of chert intercalated with marl and chalk above basement. The basal sediments have been dated from nannofossil assemblages (*Tubodiscus verenae* and *Rucinolithus wesei*) as lowermost Hauterivian to uppermost Valanginian, in accord with the assigned M-11 magnetic lineation. The lower sedimentary units preserve a record of high rates of biogenic sedimentation (~18 m/m.y.) as the site passed beneath equatorial zones of high biological productivity.

The sedimentary sequence at Site 1149 is substantially different from that being subducted at the Mariana Trench, the latter being characterized by an extensive mid-Cretaceous volcaniclastic sequence derived from the local seamounts and as being carbonate free, which may explain some of the geochemical differences between the two arc systems.

Leg 185 was the first ODP leg to conduct a series of in-hole contamination tests while undertaking a systematic study of the deep biosphere in oceanic sediments and basement in an attempt to establish the *JOIDES Resolution* as a platform for microbiological studies. Deep-biosphere contamination tests involved adding highly sensitive tracers (i.e., perfluorocarbons and fluorescent microspheres) to the drilling fluids and the core barrel to evaluate the extent of contamination of the cores by microbes introduced by the drilling process. Results of the tests revealed that the centers of advanced hydraulic piston corer (APC) cores are essentially uncontaminated during coring, whereas rotary core barrel (RCB) cores in sediment and basement contain variable amounts of introduced tracer. In addition, samples of sediments and basalts were placed in cultures aboard ship for shore-based study. Nonetheless, possible microbial tracks observed in 170-Ma volcanic glass are intriguing evidence for a deep biosphere still active at the extreme depths (>930 mbsf) sampled during Leg 185.

INTRODUCTION

The primary objective of Leg 185 was to determine the geochemical composition of the sediments and upper volcanic section of oceanic crust being subducted into the western Pacific arc system. These data are required as part of the subduction equation, which involves quantifying the inputs and outputs, both into the arc and back into the mantle, of the subduction factory (Fig. 1). These processes are important, as it is in the subduction factory that the majority of chemical recycling is currently taking place on Earth. These “factories” were probably the main sites of crustal production through geological time (Armstrong, 1968; Karig and Kay, 1981; Reymer and Schubert, 1984; McLennan, 1988), and despite the fact that there is good evidence for transport of fluid and melt from the subducted plate to the arc system (Morris et al., 1990; Hawkesworth et al., 1997; Elliott et al., 1997), there are few quantitative constraints on the recycling equation and its effect on the dynamics of crust formation and destruction. The ODP program since the late 1980s has, as a part of several drilling legs, tackled this problem (see “Historical Perspectives” section), but Leg 185 was the first ODP leg for which the objectives were specifically applied to coring oceanic crust and sedimentary sections representative of the different inputs into the subduction factory; in this case the Mariana and Izu-Bonin arcs of the west Pacific ocean (Fig. 2).

Many of the key elements that are important in understanding crustal growth (e.g. Th, rare earth elements [REEs], Ba, and Be) are sequestered in the sedimentary column and in the uppermost oxidized portions of the volcanic section of oceanic basement (K, B, U, CO_2, and H_2O). The input of these and other elements may vary as a function of sediment composition (Plank and Langmuir, 1998) or the nature of the volcanic basement (Staudigel et al., 1986 ; Alt and Teagle, 1999). For example, the absence of significant carbonate in the sediments may influence the CO_2 content of an arc. The presence of organic-rich sediments or hydrothermal sediment may influence the input of metals in different arcs. Alkaline off-axis volcanics and associated volcaniclastic sediments, when subducted, may significantly affect the alkali inventory to the subduction factory.

The igneous section of ocean crust inherits many of its physical and geochemical characteristics at the spreading ridge. Significant differences in eruption style, ridge morphology, and structure occur depending on the rate of spreading (see review in Perfit and Chadwick, 1998). Similarly, the hydrothermal systems vary as a function of the longevity and depth of the magma chamber (e.g., Gillis, 1995; Haymon et al., 1991), and, on average, the alteration characteristics and, therefore, the geochemical inventory of crust, must vary as a function of spreading rate. As crust ages and moves away from the spreading axis, it is initially cooled by hydrothermal activity and later warms again as it equilibrates with the geothermal gradient. The chemical changes occurring during this transition are important, not only in controlling the compositions of the oceans (Staudigel et al., 1986; Alt and Teagle, 1999), including the retro-actions between continental erosion and oceanic composition, but also in fixing key elements that will later be recycled into the subduction factory. Some of these elements will migrate into the arc crust, whereas others will be recycled into the mantle, possibly to return to the oceanic crust as hot-spot magma. Although the chemical maturation of crust must continue for several tens of millions of years after its formation (Stein and Stein, 1994) and probably throughout its history, the most significant alteration is at the ridge axis and for about 10–30 m.y. following crustal accretion (Staudigel et al., 1986; Alt et al., 1986; Alt et al., 1992).

In an analogous fashion, the history of sedimentation on the oceanic crust as it transits different oceanic regimes will influence the composition of the input into the subduction factory (Plank and Langmuir, 1998). The sedimentary sequence in subduction regimes in nonequatorial zones will differ significantly in composition from those where the oceanic crust has “resided” mainly in equatorial regimes. The presence of intraplate volcanoes may result in a significant flux of volcaniclastic material into the sedimentary sequence. This may have very different characteristics in key isotope ratios, especially Pb, that the arc may inherit or that may be recycled back into the mantle. When proximal to active margins, the upper sediments may contain significant quantities of terrigenous turbidites. As the oceanic plate approaches the trench, the final contribution to the sedimentary pile will include ash from the volcanic arc. For margins that are not accreting sediments, this component will be recycled into the mantle or created beneath the forearc.

The oldest oceanic crust on Earth is subducting into the Izu-Mariana arc system, and in addition to providing geochemical data to input into the subduction equation, the two sites studied provide important geochemical constraints on the nature and history of Mesozoic ocean crust. Both sites are shown in Figure 2. Site 801 is in the Pigafetta Basin, which is in the Jurassic Quiet Zone (JQZ) and is dated as ~170 Ma (Pringle, 1992). It is the oldest crust drilled by ODP or the Deep Sea Drilling Project (DSDP). The second site, Site 1149 in the Nadezhda Basin, is on the same flow line as Site 801 but is on magnetic Anomaly M11 and, as such, has an estimated age of ~135 Ma. Both sites originated at spreading centers in the Southern Hemisphere and then migrated northward, but at different times and durations. Thus, in addition to the “Subduction Factory experiment,” Leg 185 scientists had an unparalleled opportunity to (1) assess the paleoequatorial sedimentation history of the Pacific Ocean since Mesozoic time, (2) place limits on the ages of the oldest magnetic anomalies in the ocean basins, and (3) study the nature of the JQZ.

With the exception of relatively soft oozes and clays, drilling in oceanic crust rarely recovers the entire sedimentary and igneous section; thus, calculating the geochemical inventory is problematic. The gaps in the data have to be filled in by combining detailed core description and logging the drill hole both for physical parameters, such as resistivity, porosity, and velocity, and for geochemical composition. In addition to the regular inventory of ODP logs, the geochemical logging tool was used during Leg 185.

The ultimate long-term goal of studies of the subduction factory is to create a complete geochemical mass balance of the inputs, outputs, and residues lost from the system. Geochemists and geophysicists argue strongly for the recycling of oceanic crust and sediments to the mantle (Hofmann, 1997; Van der Hilst et al., 1997). Given adequate control on the subduction equation, it may ultimately be possible to identify the recycled products of the factory, not only in the arc volcanoes, but as they reappear as mantle plumes on the Earth's surface after being recycled into the mantle. The Izu-Mariana system was chosen as the first of these studies because it is relatively simple:

1. It is characterized only by limited sediment accretion.
2. It has a well-defined subduction geometry, which is relatively steep in the Mariana arc, and penetrates the 670 km discontinuity and is shallower in the Izu-Bonin arc (Van der Hilst et al. (1997).
3. It has a wide aperture from forearc across the arc to the backarc.
4. The region has already been the subject of ODP drilling in serpentinite mounds associated with forearc dewatering (Leg 125; Fryer, 1992) and has a well-studied deep-sea ash and volcanic record (Legs 125 and 126)

Too often postcruise research on ODP samples produces a data set dispersed among many individual investigators. During Leg 185 a novel approach was that the investigators chose to work on a common set of samples. The geochemical database thus developed for Leg 185 will be a unique contribution to the Geochemical Earth Reference Model (GERM) and to the MARGINS Program initiative, and the communal samples will be a legacy of the leg. The two sites drilled during Leg 185 provide critical information on the input to the "subduction factory" system. In particular, Hole 801C, now at a depth of 934 mbsf remains as an ODP legacy hole in the oldest ocean crust on Earth.

An important objective not directly related to the problem of geochemical recycling involved the study of the deep biosphere at both sites. Bacteria have been located in association with ridge axis hydrothermal systems within the sediment column as deep as 800 m (Parkes et al., 1994). In addition, textural evidence suggests that bacteria living off nutrients associated with basaltic glass alteration may thrive in the basaltic crust (Thorseth et al., 1995; Fisk et al., 1998; Furnes and Staudigel, 1999). The fascinating possibility that bacterial activity may persist in oceanic crust as old and as deep as that at Sites 801 and 1149 provided the motivation for sampling the basement for bacteria culturing and DNA extraction in the search for extremophile life. To control the extent of contamination from surface waters, drilling mud, and drilling tools, a series of tests for contaminants were undertaken as part of the operations at Sites 801 and 1149.

HISTORICAL PERSPECTIVES

The two sites drilled during this leg are in Mesozoic crust, in the oldest part of the Pacific Ocean Basin and in extreme water depths, which provided a challenge in terms of drilling technology. These sites are the most recent part of an unfolding drama of drilling by DSDP and ODP in the west Pacific abyssal plains over the past three decades.

It was apparent in 1968 after DSDP Leg 3 that the deep ocean basins were formed by seafloor spreading and, thus, were very young relative to the age of the Earth. The same evidence from rifted continental margins that led Wegner and DuToit to propose continental drift then could be used to infer that the Atlantic and Indian Ocean Basins were no older than ~200 m.y. and probably somewhat younger. However, no such clues applied to the Pacific basin, because it is geologically isolated from the surrounding continents by subduction zones. Thus, in the late 1960s it seemed possible that the world's oldest deep ocean rocks lay somewhere in the western Pacific more than 10,000 km away from the nearest spreading ridge.

DSDP Legs 6 and 7 in 1969 were the first to search the western Pacific for the Earth's oldest oceanic crust and sediments. The search ultimately took 20 yr and 10 legs of DSDP/ODP (Legs 6, 7, 17, 20, 32, 33, 60, 61, 89, and 129) to achieve the final goal. Many people were involved; the most persistent members of the "Old Pacific Club" include B.C. Heezen, E.L. Winterer, S.O. Schlanger, R. Moberly, I. Premoli Silva, W. Sliter, D. Bukry, R.G. Douglas, and H.P. Foreman. During the early legs, drilling sites were targeted with single-channel seismic records characterized by acoustically opaque chert layers that obscured the underlying volcanic basement. Often the coring was frustrated by these impenetrable cherts, as well as by volcaniclastic sediments and basalts of Cretaceous age. To those who went out repeatedly and came back with more questions than answers, what had started as an oceanographic exercise turned into an ongoing adventure.

Leg 129 brought the *JOIDES Resolution*, with improved station keeping and heave compensation that proved capable of penetrating the cherts, where the *Glomar Challenger* would have failed. Also, preparations for Leg 129 led by Yves Lancelot and Roger Larson included four multichannel seismic expeditions to the area searching for seismic "windows" through the Cretaceous volcaniclastic sediments and solid basalts. This combination of improved science and technology was finally successful 10 yr ago, in 1989, at Site 801 in the Pigafetta Basin where Jurassic sediments of Bajocian–Bathonian age were discovered overlying ~170-Ma oceanic crust (Lancelot, Larson, et al., 1990). If older material exists in the area, tectonic reconstructions suggest it would not exceed that at Site 801 by more than 10 m.y. By comparison, the next oldest deep-ocean sites are ~5–15 m.y. younger: Site 534 near the continental margin of North Carolina in the North Atlantic and Site 765 in the Argo Abyssal Plain, in the Indian Ocean (Table 1). Thus, the original suggestion that the Earth's oldest deep-ocean deposits lie in the western Pacific is correct but, coincidently, not by much.

Just before Leg 129 in the Pacific Ocean, Plank and Ludden (1992) completed the first attempt at quantifying the global geochemical budget in an ODP Leg 123 drill core. Drilling at Site 765 penetrated ~1000 m of sediment, derived from the northwestern Australian margin, and ~250 m into the basement. The main objective was to characterize the crust subducting into the Sunda Arc of Indonesia. The idea of characterizing the inputs to subduction zones arose from a proposition by J. Natland and C. Langmuir in 1987–1988. The idea was extensively debated in the ODP Planning Committee and the Indian Ocean and West Pacific Ocean Regional Panels. Despite the fact that Leg 123 had been successful, the idea took several years to root itself firmly within the panel structure as a viable scientific approach. One remark was particularly pointed: "How can you learn something about milk by studying grass when you don't know anything about cows?"

The "cow model" is in fact an excellent way to convey the competing models for subduction recycling studies. The grass control model is that the same breed of cow eating different flavors of grass will produce different flavors of milk (Fig. 3A). The cow control model emphasizes the cow over the grass—different breeds will produce different flavors of milk, even if they eat the same kind of grass (Fig. 3B). In the context of subduction recycling studies, the cow is the subduction factory, the grass is the oceanic crust and sediment being subducted, and the milk is the volcanic output at the arc. The grass control model predicts that the "flavor" of the subducted input (carbonate-rich pelagic or volcaniclastic sediments) has a strong effect on the flavor of the volcanic output despite slight differences in subduction style from one margin to the next. The cow control model would predict that given similar subducted input, the different characteristics of the subduction zone (dip of the subducted plate, thermal structure, convergence rate) will lead to differences in the volcanic output. Thus, the central question is whether the grass or the cow is the dominant control on the flavor of the milk—whether the subducted sediments or the physics of the subduction zone are the dominant control on the volume and composition of the volcanic output. Subduction factory studies need excellent control on the subducted input before we can answer this question.

Drilling into the serpentinite mounds and the ash record in the Izu-Bonin forearc (Leg 126; Leg 125; Fryer, 1992) recorded the magmatic output of the arc and the early dewatering of the subducting plate in the Izu-Bonin arc. Leg 170 in the Costa Rica accretionary prism (Kimura, Silver, et al., 1997) focused on problems of sediment accretion and fluid evolution in an accretionary prism and was a continuation of initiatives over the past 10 yr by ODP in active margin accretionary assemblages (e.g., Barbados, Nankai, and Cascadia)

Thus, ODP has come to embrace the idea of using drilling to understand geochemical mass balance. Hopefully, Leg 185 will be the first of several legs dedicated to this problem in arc systems of different tectonic regime and sedimentary input. The U.S. MARGINS project and the international Geochemical Earth Reference Model (GERM) have adopted this approach as an essential part of their strategy.

IZU-MARIANA ARC

The Izu-Mariana arc system involves subduction of the ancient Pacific plate beneath the relatively young Philippine Sea plate with the resulting production of a classic island arc chain of volcanoes and marginal backarc basins (Fig. 2).

There are several reasons why the Izu-Mariana margin is favorable for studying material recycling in subduction zones. The first is that significant progress has already been made on many parts of the flux equation. Serpentine seamounts, which represent forearc sites of fluid outflow, have already been drilled (Leg 125; Fryer, 1992), as have most of the sedimentary components being subducted at the Mariana Trench (Leg 129; Lancelot, Larson, et al. 1990; see below). The Izu and Mariana volcanic arcs and the Mariana Trough and Sumisu Rift backarcs are among the best characterized intraoceanic convergent margins, both in space and time (Legs 125 and 126; Gill et al., 1994; Arculus et al., 1995; Elliott, et al., 1997; Ikeda and Yuasa, 1989; Stern et al., 1990; Tatsumi et al., 1992; Woodhead and Fraser, 1985). Thus, major parts of the forearc, arc, and backarc output, as well as the sedimentary input have already been characterized. The other advantage to the Izu-Mariana system is that the problem is simplified here because the upper plate is oceanic—therefore, upper crustal contamination is minimized, and sediment accretion in the forearc is nonexistent (Taylor, 1992)—so sediment subduction is complete.

Despite the simple oceanic setting and the shared plate margin, there are clear geochemical differences between the Izu and Mariana arcs. The Mariana arc erupts basalts in which both subducted sedimentary and altered oceanic crustal components can be identified (e.g., Elliott et al., 1997), and the arc conforms well to the global trend in Ba sediment input vs. Ba arc output (Fig. 4A). On the other hand, the Izu arc erupts basalts that are among the most depleted of any global arc in trace element concentrations (e.g., REEs, Ba, and Sr). In addition to the contrast in elemental concentrations, there are also clear differences in the isotopic composition of Mariana and Izu basalts, such as 207/204 and 206/204, which may derive from isotopic differences in the input to the two trenches (Fig. 4B).

The divergence of compositions between the volcanics of these two oceanic arcs provides the simplest test for how the composition of the subducting crust affects them. The key missing information is the composition of the incoming crustal sections, specifically the basaltic basement subducting at the Mariana Trench, and the sediment and basement sections subducting at the Izu Trench. The low trace element concentrations of Izu volcanics may derive from a lower flux of these elements at the trench, and their distinctive isotopic composition may be inherited from the composition of the sediments subducting there. These hypotheses can be tested by drilling the subducting sediment and basement sections feeding the two arc systems. Alternatively, differences in the fluxes cycled to the arcs may derive from different operations of the subduction factory in the two areas. For example, along-strike changes (e.g., dip, age, and depth) in the subducting slab could affect where material exits the slab and enters the arc melting regime. The changes in the geometry of the slab, and its relationship to the volcanic arc, may signal a change in where the volcanoes are sampling the slab fluids. Distinguishing between these two models—the input model vs. the slab model—requires good control on the subducted inputs, which was the primary objective of Leg 185.

WESTERN PACIFIC STRATIGRAPHY

The ancient crust of the western Pacific plate is the primary input to the >2000-km-long Izu-Mariana subducting margin. Ideally, this input would be constrained by drilling several holes through the sedimentary section and deeply into oceanic crust along the length of the trench. Because of the great expense and time it takes to drill in ~6000-m water depth, we are limited in practice to a few drill holes and extending this information regionally using sedimentation and plate-motion models, along with seismic stratigraphy. It is thus important to understand the context of sedimentation and plate history in the western Pacific in order to maximize the information gained from a small number of reference sites, such as Leg 185 Sites 801 and 1149.

The crust subducting into the Mariana Trench includes Jurassic seafloor of the East Mariana and Pigafetta Basins (Fig. 5). Based on magnetic anomaly lineations, this region was thought to contain the Earth's oldest in situ oceanic crust formed at ultra fast spreading rates (160 km/m.y. at Site 801). The basic goal of Leg 129 was to sample Jurassic oceanic crust. Earlier attempts to recover Jurassic sediments and basement in the western Pacific had been thwarted by extensive mid-Cretaceous volcanics and sills and by problems with the drill string sticking in chert horizons. While drilling two holes (ODP Sites 800 and 801) that also bottomed in Cretaceous basalt, Leg 129 was the first to succeed in recovering Jurassic oceanic basement in the Pacific Ocean, and Hole 801C rocks are still the oldest sampled in the ocean basins, at 167 ± 5 Ma (Pringle, 1992).

During Leg 129 entire sedimentary columns at three sites in the East Mariana and Pigafetta Basins (ODP Sites 800–802; Fig. 5) were also successfully sampled. Before this leg, the recovery from nine DSDP and ODP sites averaged <50 m each. Taking Hole 801C as typical of the region, the sedimentary stratigraphy consists of Cenozoic brown pelagic clay overlying Coniacian to Campanian cherts and porcellanite, Albian seamount volcaniclastics, and Bajocian to Valanginian radiolarites (Fig. 6; Lancelot, Larson, et al., 1990). This sedimentary history reflects the plate history, which begins in the Southern Hemisphere in a zone of high biological productivity, as recorded by the Jurassic radiolarites (Fig. 7; Lancelot, Larson, et al., 1990). The plate then moved southward until the Early Cretaceous when it began to move northward again, collecting volcaniclastics from the nearby Albian Magellan Seamounts and then more siliceous sediments as it again crossed the high-productivity zone 5°–10° south of the paleoequator. The Cenozoic was characterized by very slow accumulation of deep brown pelagic clays, very depleted in biogenic, terrigenous, or eolian input, as is expected for the open-ocean environment. This history is typical for the East Mariana and Pigafetta Basins, and this stratigraphy, particularly the clay/chert and volcaniclastic intervals, can be traced regionally from seismic records (Abrams, et al., 1992). Although recovery was generally low (<30%), Leg 129 provided adequate sampling of the different sedimentary components to characterize the sedimentary geochemical flux into the Mariana Trench. This contrasts with the existing information to the north, along the entire 1000 km of the Izu margin.

Previous drilling in the Nadezhda Basin, seaward of the Izu-Bonin Trench, was about as successful as drilling to the south prior to Leg 129. The chert horizons plagued drilling during Leg 20, which placed five holes in the region, none of which was to hit basement except DSDP Hole 197, where only 1 m of undatable tholeiite was recovered. Thus, the M-series magnetic anomaly ages have never been tested in this region. Along the Izu Trench, magnetic anomalies predict that the oceanic crust decreases in age from Jurassic (>M18) in the south to Early Cretaceous (M11) at Site 1149 (Fig. 5). It was unknown if the extensive mid-Cretaceous volcanism that took place in the south extended north into the Nadezhda Basin.

Average recovery of sediments in the Nadezhda Basin was extremely low (<15 m) for previous DSDP sites, again because of sticking problems and spot coring. Leg 20 cores indicate an upper ash- and diatom-rich clay unit overlying a brown pelagic clay and Cretaceous chert and chalk. The paleolatitude history for Site 1149 predicts a longer duration beneath equatorial zones of high biological productivity, and thus, extensive chert and chalk sequences (Fig. 7). Water-gun seismic profiles collected during a presite seismic survey show a prominent reflection at ~0.2 s two-way traveltime (TWT) that corresponds to the chert horizon and another prominent reflection at 0.42 s TWT (Fig. 8) that corresponds with probable basement. These two reflections/horizons are prominent features, which are well correlated across the Nadezhda Basin.

Thus, a primary objective of Leg 185 was to drill the missing inputs (i.e., subducting sediments and oceanic crust) to the Izu-Mariana recycling equation. Mariana sediments had already been adequately sampled; the remaining component was altered oceanic crust. For the Izu margin, both sediment and oceanic crust were virtual unknowns. Thus, the goal of Leg 185 was to drill a basement site seaward of the Mariana Trench and a sediment and basement site seaward of the Izu Trench. Hole 801C was chosen for the Mariana site because it is the only certain window into Jurassic basement in the western Pacific with a re-entry cone set and ~60 m already drilled into the upper mid-ocean-ridge basalt (MORB) tholeiites. Other sites could have been chosen closer to the trench, but this would likely require drilling through a significant section of Cretaceous volcanics or intrusives above Jurassic basement. Deepening the MORB section at Hole 801C would help to characterize the chemical fluxes into the Mariana subduction zone as well as define the aging and architecture of Layer 2 in fast-spreading crust.

Site 1149 lies within the same spreading compartment as Site 801, along a flow line in crust ~30 m.y. younger (Fig. 5), formed at a spreading rate slower than Site 801 (100 mm/yr full rate). Roughly 100 km from the trench, Site 1149 lies seaward of the main faulting of the plate as it bends into the subduction zone. The main objective at Site 1149 was to drill through the inferred

400-m-thick sedimentary sequence and into basement subducting along the Izu margin, which would enable a comparison with the fluxes to the south into the Mariana Trench.

SCIENTIFIC OBJECTIVES

As discussed above, previous drilling has already laid the foundation to much of the crustal flux equation at the Izu and Mariana subduction systems and provided a strong rationale for continuing the effort to determine the mass balance fluxes across the subduction zones. The missing part of the flux equation is largely the input: (1) the altered oceanic crust seaward of the Mariana Trench—Site 801—and (2) both the incoming sediment and basaltic sections approaching the Izu-Bonin Trench—Site 1149. In addition, both sites are located along the same flow line in Mesozoic Pacific oceanic crust (from ~170 to 130 Ma) and provide an unparalleled opportunity to study the geochemical and physical nature of old Pacific crust and its tectonic, sedimentation, and magnetic histories.

Site 801

The primary motivation for returning to Hole 801C, seaward of the Mariana Trench (Fig. 5), was to sample the upper oxidative zone of alteration of this oldest in situ oceanic crust. Previous drilling during Leg 129 only penetrated 63 m into “normal” Jurassic basement. Based on basement rocks from Hole 504B and other basement sites with sufficient penetration, the upper oxidative zone of alteration, which contains the lion’s share of some element budgets (e.g., K, B, etc.), lies in the upper 200–300 m of the basaltic crust. The objectives of coring and logging at this site involved

5. Characterizing the geochemical fluxes and geophysical aging attending the upper oxidative alteration of the oceanic crust in Hole 801C;
6. Comparing igneous compositions, structure, and alteration with other drilled sections of in situ oceanic crust (in particular Hole 504B, contrasting a young site in Pacific crust with the oldest site in Pacific crust);
7. Helping to constrain general models for seafloor alteration that depend on spreading rate and age (Hole 801C is in the world’s oldest oceanic crust that was formed at a fast-spreading ridge, so it embodies several end-member characteristics); and
8. Testing models for the magnetic Jurassic Quiet Zone.

Site 801 is located in an area of very low amplitude magnetic anomalies, the JQZ. This quiet zone has been suggested to result from (1) oceanic crust of a single polarity with only small anomalies from field intensity fluctuations, (2) oceanic crust with magnetic reversals so numerous as to “cancel each other out” when measured at the sea surface, or (3) oceanic crust with a more normal frequency of magnetic reversals acquired when the dipole field intensity was anomalously low. Deepening Hole 801C permitted testing of the above hypotheses, and in particular, the third hypothesis of magnetic reversals during a period of anomalously low field intensity as fresh, unaltered volcanic glass was obtained. Such material can yield reliable paleointensity information (Pick and Tauxe, 1993) on the very fine, single-domain grains of titanium-free magnetite within the volcanic glass.

Site 1149

The primary motivation for drilling at Site 1149, a site ~100 km seaward of the Izu Trench, was to provide the first complete section of sediment and altered oceanic crust entering this subduction zone. Previous drilling in the Nadezhda Basin failed to penetrate resistant cherts, so most of the sediment column is unsampled. Only 1 m of basalt has been recovered from basement in this vast area. Core and logging data from this site was to

1. Provide estimates of the sediment inputs and altered basalt inputs (geochemical fluxes) into the Izu subduction zone;
2. Contrast crustal budgets for the Izu-Bonin arc with those for the Mariana arc, to test whether along-strike differences in the volcanics can be explained by along-strike variations in the crustal inputs;
3. Compare basement alteration characteristics with those at Hole 801C (on 170-Ma crust along the same flow line);
4. Provide constraints on the Early Cretaceous paleomagnetic time scale; and
5. Provide constraints on mid-Cretaceous carbonate compensation depth (CCD) and equatorial circulation fluctuations.

In addition to serving as an important reference site for crustal inputs to the Izu-Bonin Trench, Site 1149 can also address additional paleomagnetic and paleoceanographic problems. Because the subduction cycling objectives have already been discussed in some detail above (see "Introduction"), we elaborate more in the following paragraphs on the paleomagnetic and paleoceanographic objectives.

According to Nakanishi et al. (1988), Site 1149 is approximately on magnetic Anomaly M12. Its basement age should be ~133 Ma and should correspond to the Valanginian Stage of the Early Cretaceous, according to recent time scale calibrations (Harland et al., 1990; Gradstein et al., 1994; Channell et al., 1995). However, those age estimates are poorly known and can be tested by drilling at Site 1149. Specifically, a reasonably precise date on Anomaly M12 at Site 1149 could test the proposed new time scale of Channell et al. (1995).

Based on its theoretical Cretaceous paleolatitude history, Site 1149 may have formed at ~5°S, drifted south to 10°S in its early history, and then gradually drifted north, crossing the paleoequator as the Pacific plate accelerated its northward motion ~85–90 Ma (Fig. 7). A site such as Site 1149 with an Early Cretaceous basement age (~135 Ma), an equatorial paleolatitude history during the mid-Cretaceous, and a predictable subsidence history for the Cretaceous is ideal for testing proposed CCD variations (Theirstein, 1979; Arthur et al., 1985). In addition, Erba (1992), following Roth (1981), has shown that certain species of nannoplankton can be characterized as “high fertility indices” and used as approximate indicators of the paleoequatorial upwelling zone. Using these nannoflora, potential fluctuations in the equatorial circulation system could be studied at Site 1149 for the mid-Cretaceous, when it was nearly stationary near the paleoequator (especially from 115 to 95 Ma).

Microbiology Objectives for Both Sites

The deep water (~6000 m) and proposed penetration into old oceanic basement provided an intriguing target in the search for hidden bacterial life forms. Leg 185 was the first ODP leg to incorporate microbiology as a major new initiative. The microbiology objectives for Leg 185 included

1. Determining the amount of biological contamination created by the APC, XCB (extended core barrel), and RCB coring processes;
2. Developing a sample-handling strategy for routine microbiological sampling; and
3. Conducting culturing experiments with several media at both atmospheric and in situ pressure.

DRILLING STRATEGY

The mass balance equation and continental growth from the study of the input and output fluxes of chemical elements cycled through the subduction factory can be determined by: (1) the study of the various parts of the mass balance equation at multiple margins and (2) the study of the inputs and outputs across a selected margin. The latter approach is the strategy chosen for drilling in the Mariana and the Izu-Bonin arc systems during Leg 185. The Mariana and Izu margins are nonaccretionary margins where old, cold slabs of oceanic crust (sediments and basement) are completely subducted, and backarc spreading is present. Although the Marina and Izu-Bonin arcs share the same subducting plate, they have distinct geochemical differences. Because, as stated in previous sections, significant progress had been made on many aspects of the chemical flux equation through previous DSDP and ODP drilling (i.e., ODP Legs 125, 126, and 129) on both sides of the trench, Leg 185 was designed to drill two sites to fill in the missing gaps of the recycling equation. These were deep water sites: (1) an existing ODP hole (Hole

801C) located seaward of the Mariana Trench and (2) a new site, Bon-10A (Site 1149), east of the Izu-Bonin Trench (Table 2).

The drilling strategy for Hole 801C, an ODP legacy hole drilled during Leg 129 (Lancelot, Larson, et al., 1990), was to re-enter and to deepen the hole by an additional 250 m (to a maximum of 400 m total basement depth) past the upper oxidative alteration zone of the basaltic crust (Fig. 9). During Leg 129 only 63 m of the normal tholeiites was cored. Based on data from Hole 504B and other basement sites with sufficient penetration, the upper oxidative zone of alteration, which contains most important element budgets (e.g., K, B), lies in the upper 200–300 m of the basaltic crust (Alt et al., 1986; Staudigel et al., 1995). The transition from volcanics to sheeted dikes may not lie much deeper: 500–600 m in Hole 504B (Detrick et al., 1994); 450 m to Layer 2b (Carbotte et al., 1997); and only a few hundred meters at Hess Deep (Francheteau et al., 1992). During Leg 185 Hole 801C was deepened by an additional 332 m into basaltic crust with the RCB system, and by an additional 7 m with the diamond core barrel (DCB) system to a new total depth of 935.7 mbsf, placing this site as the DSDP and ODP drill hole with the sixth greatest penetration into normal oceanic crust. Average core recovery was 47%, and a complete suite of ODP downhole logs was run to 850 mbsf. After six reentries the hole conditions remained good for coring operations, although greater difficulty was experienced by cuttings filling the hole in increasing amounts between reentries. With that exception, the hole is in good condition for future reoccupation and deepening.

The drilling strategy at Site 1149 was to core the entire sedimentary section, inferred to be ~470 m thick, and as far into the upper oxidative alteration zone of the basaltic basement as possible, to a maximum of 430 m (Fig. 9). Previous drilling had failed to penetrate successfully through resistant cherts, so most of the sediment column was still unsampled. During Leg 185 a total thickness of ~410 m was cored in the four holes that were drilled. To a depth of 180 mbsf, recovery of sediments with the APC and the XCB systems was good (91%). However, low recovery (32%) and numerous hole problems were encountered when drilling the chert and porcellanite units. Although poorly recovered, the units were logged, which will allow for a continuous record to calculate chemical fluxes to the trench. The sediment/basement contact was recovered in two holes (Holes 1149B and 1149C), and successful penetration into the basaltic crust was achieved at Hole 1149C where a total of 133 m was cored, with an average recovery of 21%.

SITE 801 PRINCIPAL RESULTS

Site 801: A Jurassic Basement Reference Site

Leg 185, Hole 801C

Days on site: 28 April–19 May 1999

Latitude: 18°38.53798′N

Longitude: 156°21.58813′E
Water depth (m): 5673.60
Total cored section (m): 339.3
Interval drilled (mbsf): 594.3–935.7
Core recovery (%): 47

ODP Hole 801C was first drilled during Leg 129 in December 1989 as part of a series of drill sites aimed at recovering Jurassic sediment and oceanic crust in the Pacific Ocean (Lancelot, Larson et al., 1990). Rocks from Hole 801C are the oldest sampled in the ocean basins (at ~170 Ma) (Pringle, 1992). During Leg 144, the hole was reentered and logged, and a drill-string packer experiment was conducted (Haggerty, Silva, Rack, et al.,1995; Larson et al., 1993). Leg 185 succeeded in deepening Hole 801C by an additional 359 m, to a total depth in basement of 474 m, placing this site as the DSDP and ODP drill hole with the sixth greatest penetration into normal oceanic crust. Recovery was good (47%), and a complete suite of ODP downhole logs was run to 850 mbsf. Although the reentry cone needs to be cleared of cuttings, which hampered logging by flowing back into the hole, it is in good condition and remains as ODP's legacy site in the Earth's oldest ocean crust.

Basement Stratigraphy and Geochemistry

The basaltic section in Hole 801C is overlain by a sedimentary section characterized by an upper (56 m) pelagic clay unit, which overlies a 63-m-thick chert-porcellanite unit. These units are underlain by thick (192 m) volcaniclastic turbidites of probable Albian age, which represent redeposited material from the Magellan Seamounts. A second chert-radiolarite unit (125 m) underlies the volcaniclastics and gives way to 20 m of Callovian red radiolarites and claystones. These overlie basement at 461.6 mbsf in Hole 801C.

A stratigraphic column of the entire basement section is given in Figure 10. This section includes a composite of the rocks drilled on both Leg 129 and Leg 185. The uppermost basement (Sequence I) is alkaline in character and is composed of basaltic to doleritic sills (Floyd et al., 1992; Floyd and Castillo, 1992). Ar-Ar radiometric ages on laser-fused samples (Pringle, 1992) give a weighted mean age of 157 Ma. The igneous units are intercalated with chert-rich sediments, which are often baked at the contact with the basalt. The sediments contain siliceous microfossils that define ages of early Bathonian to late Bajocian (~170 Ma; Channell et al., 1995) and confirm the intrusive nature of the alkaline suite. This alkaline division is 60.2 m thick and overlies a Si- and Fe-oxyhydroxide–rich hydrothermal horizon (Sequence II) for which logging results (see resistivity log in Fig. 11) indicate a thickness of ~20 m. During Leg 129, ~63 m of volcanic rock was drilled below the hydrothermal deposit. The alteration intensity is highly variable in these rocks, and their colors vary from gray black to green gray and to light brown. Parts of these cores clearly were altered under a high fluid-flux regime (see section, "Basement Alteration"). These lavas are thin flows and pillows, but they lie above a series of thick flows;

both are included as part of Sequence III, the Upper Massive Flows (Fig. 10). These thick flows have an exceptionally high resistivity (Fig. 11), although they appear to be similar in lithologic and geochemical character to other thick flows lower in the stratigraphy. Ar/Ar fusion dates on two samples from Sequence III define an age for these lavas as <171 Ma, >157 Ma (Pringle, 1992).

The Upper Massive Unit also defines a clear magmatic evolutionary trend toward more mafic, MgO-rich, and Zr-poor lavas from its base at ~580 mbsf to the overlying hydrothermal deposit (Fig. 12). The MgO-rich lavas contain abundant olivine phenocrysts, which are only rarely observed deeper in the section. The most evolved lavas, those with the lowest MgO and highest Zr, are commonly triple saturated in olivine, plagioclase, and clinopyroxene. In general, phenocrysts are scarce in the entire section drilled during Leg 185. Plagioclase is the most common phase, but most of the lavas are classified as aphyric. Figure 12, although intended to highlight the alteration characteristics in Hole 801C, shows the typical occurrence of plagioclase phenocrysts. Notwithstanding the paucity of phenocrysts, mineralogical examination and X-ray fluorescence (XRF) analyses for major and trace elements permitted definition of 18 geochemical units, which probably correspond to discrete magmatic episodes.

A second Si-rich hydrothermal unit is present deeper in the section at 630 mbsf. This unit marks a change in magma composition and, thus, probably represents a significant hiatus in the volcanic evolution. Between 600 and 720 mbsf the section is characterized by a pillow-dominated zone with well-developed interpillow horizons (Sequence IV—Upper Pillows and Flows). The amount of interpillow material of probable sedimentary origin decreases significantly downsection in this sequence. This is evident in the gamma-ray log (Fig. 11), which is smooth and of low intensity throughout Sequence IV. Although not as distinct as for Division III, there is again a trend toward more mafic lavas of increasingly younger age through Sequence IV.

Below 720 mbsf, to the end of the hole at 934 m, a tectonic breccia separates the Lower Massive Flows (720–890 mbsf) and a series of thin, generally <1-m-thick sheet flows and pillows, the Lower Pillows and Flows (890–934 mbsf). The thickest flow in the former exceeds 20 m. Once more, the breccia zone also coincides with a change in geochemistry (Fig. 12), indicating that the lithologic breaks in eruption style also correlate with the evolution in the magma composition.

In Figure 11, the major changes in the resistivity and the natural gamma logs correspond to the major sequence divisions defined by lithology and geochemistry. The logging data along with the FMS images will be integrated with the core descriptions to create as complete a section as possible from which the bulk geochemical composition of the upper oceanic crust at this site will be calculated.

This igneous sequence represents a key section recovered from fast-spreading crust (total basement penetration = 470 m) and will thus serve as an important type section with which to compare to the modern East Pacific Rise. The entire section between 530 and 890 mbsf is tholeiitic and extrusive in character. The tholeiites are all normal (N) MORB (Fig. 12), with most falling on the same crystal fractionation trend from 7.5% MgO to 6% MgO (1200°–1130°C). Although it is highly altered, the capping tholeiite is very primitive, with abundant chrome spinel and up to 10% MgO. Overall, from the base to the top of the section there is a decrease in MgO (Fig. 12). During Leg 185, we recovered abundant, fresh basaltic glass in more than >20 cores, which represent the oldest volcanic glass in the oceans, and will be critical in assessing the primary magma compositions and possible changes in MORB melting parameters during the Jurassic. The presence of frequent sediment intervals in the upper volcanic section and low-temperature hydrothermal units (see below) may not be unusual for fast-spreading crust, whereas high-temperature focused hydrothermal deposits and low-temperature diffuse interval areas are very common along the spreading axis.

Basement Alteration

The ocherous hydrothermal units are a significant characteristic of Site 801. Although similar types of deposits exist near the modern East Pacific Rise, they have never been drilled in oceanic basement elsewhere. Fluid temperatures of formation calculated for the upper hydrothermal deposit (Sequence II) give temperatures of ~16°–60°C (Alt et al., 1992). These fluids controlled the alteration budget of the underlying pillow basalt.

A primary objective for Leg 185 was to quantify the chemical alteration of Jurassic basement in the west Pacific in order to calculate geochemical fluxes to the Mariana “Subduction Factory.” Thus, detailed work was done aboard ship logging vein types, breccia, hyaloclastite, interpillow units, and alteration color, as well as using the continuous MST data and downhole logs to identify K- and U-rich zones from the natural gamma emission. Figure 13 provides a good overview, although not exhaustive, of the major alteration types observed in the cores. In addition, this core shows one of the interpillow sediments, which are clearly evident on the gamma logs (Fig. 11) and must contribute in a significant way to the alkali budget of the hole. The dominant alteration minerals are calcite, smectite, pyrite, silica, celadonite, and Fe-oxyhydroxides; and, as shown in Figure 13, different mixtures of these minerals define the alteration color of the cores.

In tandem with the major change in the igneous units at ~720 mbsf, there is a change in the style of alteration. It is marked by a higher frequency of veins (27/m) and silica-rich interpillow material and sediment at <720 mbsf, to less frequent veins (20/m) and more hyaloclastites at >720 mbsf. The most extreme alteration is in the alkalic unit at the top of the basement and adjacent to the ocherous hydrothermal zones. This is characterized by pervasive alteration of the igneous material to bleached pale green and buff-colored rocks, with significant concentration of calcite, smectite, and celadonite, resulting in increases in K, CO_2, and H_2O contents. In the pale green and buff-colored rocks all of the ferromagnesian minerals have been destroyed, and there are losses of Mg, Fe, and trace metals and gains in alkalis. Four oxidative alteration zones are in Hole 801C: at the top of the basement in the brown alteration of the alkalic unit; adjacent to the upper hydrothermal zone (462–550 mbsf); adjacent to the lower hydrothermal zone at 610–630 m; and deep in the hole at ~750–900 mbsf. These oxidative zones are flanked by gray basalt minimally altered at anoxic conditions (pyrite, calcite, and saponite). The alternating oxidative zones with high fluid/rock ratios and anoxic alteration assemblages of lower fluid/rock ratios is unusual given what is more typically a general decrease downhole in oxidative alteration, as found at some other drill sites into oceanic crust (Staudigel et al., 1995; Alt et al., 1986). The pattern of alteration found in Hole 801C was controlled by the local permeability structure, which may have been influenced by clogging of circulation pathways with secondary minerals as the result of early low-temperature hydrothermal activity associated with the formation of the Fe-Si-hydrothermal deposits. This may be typical of very fast spreading oceanic crust.

Calculating Element Budgets

Reconstructing the geochemistry of an incomplete sequence, which is heterogeneous in particular for most of the elements of interest in subduction fluxes (e.g., K, U, Ba, CO_2, and H_2O), is a challenging procedure. The logging information allows reconstruction of the section, particularly for quantifying brecciated and massive flow units. The gamma log provides quantitative information for K, U, and Th. Quantifying the number of veins and breccia intervals and integrating these data with geochemical information over the section also provides a means of calculating a mathematical average of the geochemistry of the cored section. The geochemical and isotope data will be obtained from a suite of 118 samples taken downhole on which several scientists will work to provide a data base. Some of these samples will also be mixed together to provide composite samples of the different sequences identified in the core.

Two preliminary attempts were made shipboard to quantify the potassium content of the core. They both underline the difficulties involved in making these estimations.

Firstly, using shipboard measurements for K_2O and the estimation of vol% alteration (halos, 1.7%; breccia and hyaloclastite, 1.5%; celadonite veins, 0.05%), and 96.75% relatively unaltered rock, indicates that the total section cored during Leg 185 has experienced ~17% increase in K_2O and Rb contents as the result of seawater alteration. Adding interpillow sediment to this estimate increases the bulk K_2O content of the Leg 185 section to 60% greater than in fresh basalt alone, with 27% of the total alkali budget residing in interpillow sediment.

Secondly, by calibrating the MST results for the natural-gamma spectrometry tool (NGT) signal with respect to K_2O analyses in altered and fresh rocks, it was shown to be possible to integrate the K_2O signal for a section of core. Intercalibration of the MST-NGT signal and the gamma log are in reasonable agreement, with a cutoff in the detection limit at ~0.45 wt% K_2O. Whereas this cutoff is higher than much of the background value in the least-altered rock, it provides an effective way of integrating the signal for all of the K-enriched zones downhole. The bulk K_2O calculated from the MST-NGR data for the entire tholeiitic section is 0.31 wt%, and from the logged interval it is 0.36 wt%. The MST estimate would require that the 97% of the core that did not contain patent alteration features has 0.27 wt% K_2O. An average K_2O of 0.31

wt% is lower than that calculated for DSDP Site 417 (0.56 wt%; Staudigel et al., 1995). The technique laid out in this report could be used to calculate bulk K_2O at the few other ODP sites drilled deeply into basement (Holes 504B, 765C, 332) to start to form a better understanding of the controls on seafloor alteration fluxes.

Character of the Jurassic Quiet Zone

Hole 801C was also unique in providing the opportunity to examine the causes for an absence of magnetic anomalies, a characteristic of Jurassic basement—the so-called Jurassic Quiet Zone. The JQZ has been hypothesized variously as a time of no geomagnetic field reversals, of anomalous low geomagnetic field intensity, or numerous rapid reversals. In combination with the previous results from Leg 129, the basement in Hole 801C shows a series of polarity reversals downhole. The results from the continuous shipboard measurement downhole and the magnetic signature in the geophysical logs are shown in Figure 11 relative to the different basement sequences. The cores analyzed with the shipboard magnetometer show a gradual change in the magnetic field direction from one polarity interval to the other. In both the magnetic logs and the shipboard analyses, numerous flows between those of opposite polarities display zero inclination values. These results indicate that the lavas were erupted in a period of rapid polarity fluctuations of the Earth's magnetic field. Although analysis of the core and logging data is incomplete, there appears to be a correlation between polarity changes and the different volcanic sequences. From the bottom of the hole upward, the first reversal corresponds to a change from thin pillows and sheet flows to the Lower Massive Flows (from the stratigraphic column this change may be best placed at ~870 mbsf rather than at the breccia at 850 mbsf). The second polarity change is at the transition from the Lower Massive Flow sequence to the Upper Pillows and Flows. Given the spreading rate estimate for the ridge axis of 160 km/m.y, and therefore, the rate at which the volcanic sequences must have formed, the lavas must be recording rapid fluctuations of the magnetic field. The fields have the effect of canceling each other out and registering an average zero polarity. The reason for and the rate of these rapid fluctuations require further research. The volcanic glass that is preserved in small amounts down the hole will be used to evaluate the intensity of the magnetic field in the Jurassic, a parameter that is perhaps related to the rapid fluctuations.

SITE 1149 PRINCIPAL RESULTS

Site 1149: Early Cretaceous Seafloor Subducting at the Izu-Bonin Trench

Leg 185, Site 1149, Holes 1149A–1149D

Days on site: 23 May–13 June 1999

Hole 1149A

Latitude: 31°20.519′N
Longitude: 143°21.078′E
Water depth (m): 5818
Total cored section (mbsf): 0–191.2
Core recovery (%): 91

Hole 1149B

Latitude: 31°20.532′N
Longitude: 143°21.060′E
Water depth (m): 5818
Total cored section (mbsf): 160.6–445.2
Core recovery (%): 12

Hole 1149C

Latitude: 31°20.550′N
Longitude: 143°21.060′E
Water depth (m): 5818
Total cored section (mbsf): 283.6–322 and 388.2–426.7
Core recovery (%): 8.3

Hole 1149D

Latitude: 31°18.792′N
Longitude: 143°24.024′E
Water depth (m): 5867
Total cored section (mbsf): 272.2–440.4
Core recovery (%): 17

Introduction

Although previous drilling was plagued by hole stability problems in chert horizons, Site 1149 was the first to be continuously cored through sediment to basement in the Nadezhda Basin, a ~1000 km × 1000 km region seaward of the Izu-Bonin Trench. The sediment/basement contact was cored in three Holes (1149B, 1149C, and 1149D), and a total of 133 m of basement penetration was achieved in Hole 1149D. Thus, the site objectives to core and log the entire sedimentary sequence and to core the upper oxidative alteration zone in basement were successfully carried out after 20 days of operation. A presite seismic survey produced an excellent seismic stratigraphy that will enable correlation of sedimentary units at Site 1149 across the Nadezhda Basin and along the Izu-Bonin Trench.

APC coring recovered ~100% of the uppermost 160 m in Hole 1149A, whereas a combination of XCB, MDCB, and RCB systems completed coring in the 410-m-thick sedimentary section in Holes 1149A and 1149B, albeit with much lower recovery rates (<15%). An excellent set of geophysical geochemical logs from Hole 1149B will enable reconstruction of the sedimentary strata not recovered during drilling. Holes 1149C and 1149D were drilled primarily to penetrate as much basement as time allowed. Only 26 m of basement was cored in Hole 1149C before chronic sticking problems prompted abandoning the hole. A thinner sedimentary section and basement high was located on seismic line C2005 a few miles to the southeast of Holes 1149A, 1149B, and 1149C, where conditions were more promising for basement drilling. Despite some sticking and hole collapse problems, which slowed drilling and prevented logging of the basement section, 133 m of basement were successfully cored at Hole 1149D with 17% recovery. Site 1149 is one of only six other ODP/DSDP sites with significant (>100 m) penetration of basement into Mesozoic oceanic crust.

Site 1149 Geophysics

Site 1149 is located on the Pacific plate in the Nadezhda Basin southeast of Japan. It is on a slight bathymetric high ~100 km east of the Izu-Bonin Trench where the Pacific plate is flexed upward before it enters the subduction zone. Although Nakanishi et al. (1988) identified magnetic Anomaly M12 in the vicinity of Site 1149, close inspection of the lineation pattern suggests instead that Site 1149 lies on the older portion of magnetic lineation M11. This stratigraphic position has a paleontological age of late Valanginian and a radiometric age of ~132 Ma on the Channell et al. (1995) time scale. A model consistent with other portions of the magnetic lineation pattern of this age gives a constant spreading rate of 51 km/m.y. for this portion of the seafloor. These rates are comparable to the lower end of the range of spreading rates for the modern East Pacific Rise.

The seismic stratigraphy at Site 1149 is based on two 1976 vintage multichannel seismic lines and sonobuoy data obtained during cruise C2005 of the *Robert Conrad,* as well as a short, pre-site single-channel seismic survey conducted aboard the *JOIDES Resolution.* Site 1149 acoustic stratigraphy conforms to that originally described by Ewing et al. (1968) for large portions of the western Pacific, consisting of (1) an upper transparent layer (weakly reflective), (2) an upper opaque layer (highly reflective or stratified), and (3) acoustic basement, or Horizon B. Early DSDP investigations (e.g., Legs 6, 7, 17, and 20) found that the upper transparent layer corresponds to a variety of lithofacies: pelagic clay with ash in the west Pacific, pelagic clay in the central Pacific, turbidite sequences in the north and east, and biogenic oozes along the equator. At Site 1149, this top acoustic layer corresponds to ash and diatom/radiolarian-bearing clay. The upper opaque seismic layer has been correlated to the uppermost abundant chert in much of the North Pacific. Drilling at Site 1149 encountered this chert at ~180 mbsf, where it corresponds to a continuous, high-amplitude reflection at ~0.2 seconds below seafloor (sbsf). Within the opaque layer, there is a change in seismic character at ~0.28 sbsf to discontinuous, chaotic to hummocky reflections, which corresponds to a change from chert/clay to chert/chalk (+ marl) at Site 1149.

It was not until Legs 129 and 185 that material below “Horizon” B was sampled in the Mariana, Pigafetta, and Nadezhda Basins. Horizon B in large areas of the Nauru, Pigafetta, and East Mariana Basins correlates to middle Cretaceous volcanic material (sills, flows, volcanogenic turbidites), and it was not clear if this material would be encountered at Site 1149 below Horizon B at ~0.42 sbsf, or whether this would correspond to true oceanic basement. Weak and discontinuous reflections at ~0.7 sbsf in the original multiseismic measurement (MSM) air-gun records at preliminary site BON-10 also prompted concern that basement could lie as deep as 700 mbsf. Drilling in Holes 1149B and 1149C, however, encountered oceanic basement at 410 and 401 mbsf, respectively, thus demonstrating that Horizon B in the Nadezhda Basin corresponds to true oceanic crust. Based on the few records available, the seismic stratigraphy of the Nadezhda Basin is laterally continuous and correlates well with the lithostratigraphy developed for Site 1149.

Site 1149 Sediments

The sedimentary section (between 0 and ~410 mbsf) recovered at Site 1149 consists of carbonate-free clays with variable admixtures of volcanic ash and siliceous microfossils, cherts porcellanites, and calcareous nannofossil chalks or marls. On the basis of the distribution of these lithologies, the sedimentary column above the basaltic crust has been divided from top to bottom into five lithologic units (Fig. 14):

Unit I (0–118.20 mbsf) consists of carbonate-free ash and diatom/radiolarian-bearing clay. Volcanic ash is present as both discrete ash layers and disseminated throughout the clay sequences. Thickness of the discrete ash layers typically varies from a few millimeters to 5 cm; thicker layers (20–45 cm), however, are also present. This unit has been dated late Miocene (i.e., 6.5 Ma) to late Pleistocene, based on an excellent magnetostratigraphic record (Fig. 15). Sedimentation rates during deposition of Unit I as derived from the shipboard magnetostratigraphy were on the order of 18 m/m.y. (Fig. 16). The abundant assemblage of siliceous plankton, mainly diatoms, silicoflagellates, and radiolarians yield a preliminary age of Pliocene for Core 185-1149A-9H, in agreement with the paleomagnetic data.

Unit II (118.20–179.1 mbsf in Hole 1149A and 160.6–180 mbsf in Hole 1149B) consists of undated dark brown pelagic clay with several discrete ash layers present only in the upper 30 m of the unit (Unit IIa) and notable palygorskite in the lower half (Unit IIb). Unit II clays are also noted by a change in porosity, pore-water chemistry, and bulk sediment chemistry. Clays from Unit II are barren of siliceous or calcareous microfossils, and thus their ages at this point remain undetermined. These clays, however, contain ichthyolith assemblages that increase in abundance downhole, probably as a result of a decreased sedimentation rate. Shore-based analyses of the ichthyolith assemblages should allow for relative ages for this unit to be determined. Clays in Units I and II indicate pelagic deposition below the CCD.

Unit III (180–191.2 mbsf in Hole 1149A; 180–282.30 mbsf in Hole 1149B). The top of this unit is marked by the first occurrence of indurated siliceous lithologies (i.e., chert and porcellanites). This unit is characterized by very low recoveries (<5%). The recovered sediments consist of radiolarian chert, porcellanite, and zeolite-bearing clay, whose age is undetermined at this point. These sediments are typical of a predominantly siliceous depositional environment.

Unit IV (282.30–416.40 mbsf) consists of radiolarian chert, porcellanite, marlstone, and chalk with intercalated calcareous lithologies. Shipboard biostratigraphy of carbonates recovered in Cores 185-1149B-16R to 29R yielded well to poorly preserved calcareous nannofossil assemblages with average high diversity and good preservation. Preliminary ages are assigned from the Hauterivian *Lithraphidites bolli* Zone from 311 to 340 mbsf (Core 185-1149B-18R to 21R). Downhole assemblages are dominated by *Watznaueria barnesae, Cruciellipsis cuvillieri,* and *Tubodiscus* sp. The first occurrence of *T. verenae* is in Core 185-1149B-24R and indicates the lowermost Hauterivian–uppermost Valanginian. *Rucinolithus wisei,* a species that may be restricted to the Valanginian, is present from Core 185-1149B-25R downhole. Persistence of *T. verenae* downhole to Core 185-1149B-29R confirms a Valanginian age for the basement/sediment contact, consistent with the assigned M11 seafloor magnetic anomaly (132 Ma). The sedimentation rates during this time interval (i.e., 125.8–~132 Ma), derived from calcareous microfossil biostratigraphy, is ~20 m/m.y. (Fig. 16). Sediments from this lower unit were likely deposited when the site reached subequatorial paleolatitudes, which were characterized by high primary productivity.

The relatively simple stratigraphy and sedimentological changes at Site 1149 provide an exceptional natural laboratory to examine diagenetic processes operating over a long time scale (~135 m.y.) in a sequence bounded by basaltic crust and the oceanic reservoir. Interstitial waters recovered in sediment from the seafloor to the basement from Holes 1149A and 1149B reflect a low supply of organic matter, alteration of volcanic ash and authigenic clay formation at mid-depths, diagenesis of biogenic opal and carbonate, and on-going basement alteration. Dissolved phosphate and ammonium have well-defined shallow maxima, although absolute concentrations are relatively low, reflecting low organic matter contents. Alkalinity remains <3 mM throughout the entire sequence, and sulfate is present at all depths (minimum value of 19 mM). The deep brown pelagic clays of Unit II define a sequence that is undergoing active authigenesis, acting as a sink for dissolved silica, strontium, and potassium, and as a source of alkalinity, ammonium, and lithium. X-ray diffraction (XRD) results and the concentration profile of dissolved silica together reflect the diagenetic transformations of opal-A to opal-CT (at ~170 mbsf) and of opal-CT to diagenetic quartz (at ~310 mbsf). Basement alteration and the relatively low diffusivity of Units IV and V lead to strong diffusive gradients in Ca and Mg, with extreme enrichments in Ca recorded (135 mM) in interstitial waters from a few meters above the basement contact (407 mbsf in Hole 1149B). Uptake of potassium and sodium, and high dissolved Cl (638 mM near basement) reflect hydration and alteration of the oceanic crust. These dramatic gradients and fluxes in the interstitial waters record ongoing alteration in the oceanic crust ~135 Ma after it formed.

Bulk chemical analyses of the sediments at Site 1149 corroborate several of the processes inferred from the interstitial-water analytical results, as well as reveal others that are better recorded in the bulk solid phase. In stratigraphic order, Site 1149 sediments preserve a well-developed metalliferous sedimentary profile in Fe/Al variations in the lower 130 m of section (280–410 mbsf), which documents clearly the decreasing influence of plume precipitation with lateral distance from the ridge. The biogenic-rich sediments Units III and IV are high in Ba/Al, signaling an increase in biological productivity as the site lingers near the paleoequator. Unit II pelagic clays are highly enriched in K_2O (> 4 wt%), recording the complement to the K uptake inferred from the pore waters, possibly because of authigenic formation of K-rich zeolites in these sediments. In addition to the discrete ash layers observed throughout Unit I and Subunit IIa, a depletion in Nb/Al with respect to average shales indicates a significant (25%–35%) dispersed ash component in upper sediments. Shore-based studies will help to identify the source of these ashes, most probably as either the Izu-Bonin or Japan volcanic arcs.

Downhole measurements in Hole 1149B were made after completion of drilling. Five logging runs were performed, consisting of one pass with the geophysical tool string, two passes with the geochemical string, and two passes with the Formation MicroScanner (FMS) sonic tool string. The geophysical string provided the most physically complete logging run from ~10 m above the volcanic-basement contact at 400 mbsf (Core 185-1149B-28R) to within the clay–volcanic ash section at ~65 mbsf (Core 185-1149A-8H). The subsequent logs were limited by additional fill in the bottom of the hole and/or a 20-m-thick section of tight hole in the pelagic clays at 140–160 mbsf (Cores 185-1149A-16H to 18H) just above the uppermost cherts. Overall, the logging data agree very well with the lithologic units identified from cored intervals. Geophysical properties (e.g., resistivity, density, and *P*-wave velocity) delineate well the clay/ash layers, and the chert/clay layers. The radioactive element data identify regions predominantly composed of pelagic clay. The geochemical log data correlate Si-rich zones with chert layers, Ca-rich zones with the presence of nannofossil marls, and Al-rich zones with clay and ash layers. Calcium from the geochemical log is the best indicator of carbonate-rich sediment, a feature that the other logs do not distinguish well. The logging data will be essential to reconstructing the sedimentary section, which suffered from 6% average recovery in Units III and IV. Over 90% of Site 1149 was logged or recovered.

In contrast to the East Mariana and Pigafetta Basin sediments subducting at the Mariana Trench, the Nadezhda Basin sediments subducting at the Izu-Bonin Trench lack a mid-Cretaceous volcaniclastic section and contain more siliceous and carbonate-rich biogenic material because of its longer passage beneath zones of high biological productivity. Shore-based geochemical studies will demonstrate the extent to which these clear differences in sedimentary lithologies can be traced to the volcanic output from the two arc systems.

Site 1149 Basement

The sediment/basement boundary was recovered in three holes: at 410 mbsf in Hole 1149B, at 401 mbsf in Hole 1149C, and at 307 mbsf in Hole 1149D. Approximately 35 and 26 m of basement was drilled in Holes 1149B and 1149C, respectively, before hole conditions halted operations; a thinner sedimentary sequence in Hole 1149D may have contributed to better hole conditions there, where 133 m of basement was drilled. The contact zone between the sediments and basement in Hole 1149B is brecciated and filled with interfragment sediment. Igneous units in all three holes consist of aphyric basalt pillows, thin flows, and interpillow breccia. Cooling units are on average <50 cm thick, in contrast with Hole 801C, where the cooling units averaged >50 cm. The predominance of these thin, fractured, and brecciated units at Site 1149 may have contributed to the overall low recovery of basalt (<20%). Plagioclase and olivine phenocrysts are rare (usually <1%). Most basaltic glass has been highly altered; fresh glass exists on a few pieces (~10), most of which are in Core 185-1149D-9R. The chemical compositions of the least altered lavas in Hole 1149B are fairly primitive (>7.9 wt% MgO) and low in Fe_2O_3 (<10 wt%) but otherwise typical of MORBs from the modern East Pacific Rise.

The volcanic rocks at Site 1149 are spectacularly altered with a pervasive dusky red alteration, which commonly displays a light gray to brown mottling. Complex, multicolored alteration halos also are present along fractures and other surfaces that were exposed to circulating fluids. The halos are up to 2 cm wide and range in color from brown to dark green. In addition to the abundant alteration halos, another striking feature of the basalt from all three holes is an abundance of reddish fracture surfaces. In general, the alteration is more intense at Site 1149 than at Site 801. At Site 1149, alteration halos comprise 34 vol% of the recovered basalts, as opposed to ~2 vol% at Site 801. Veining is also more intense, with 35 veins/m at Site 1149 compared to ~25 veins/m at Site 801. Finally, flow breccias and hyaloclastites are a common feature in the cored interval at Site 1149, whereas unlike Hole 801C, massive flows and interpillow sediments are uncommon. The more intense alteration at Site 1149 may lead to greater overall budgets for K than at Site 801 (e.g., >0.3 wt% K_2O).

Although Hole 1149D was drilled in a basement high, the recovered basalts are similar in their igneous and alteration characteristics to Holes 1149B and 1149C basalts. Thus, the basement topography near Hole 1149D is probably related to near-ridge processes (abyssal high formation?) rather than off-axis magmatism.

SAMPLING THE DEEP BIOSPHERE

The fascinating possibility that microbial activity may inhabit oceanic crust as old and as deep as that at Site 801 provided the motivation for sampling the subseafloor in the search for extremophilic life. Water, sediment, and rock samples were collected to determine cell abundance and community composition. Samples were examined microscopically and used to establish cultures and to extract and characterize DNA. Sample protocols were established and tracer tests conducted to determine the extent of microbial contamination introduced during drilling and sample preparation.

Shipboard Sampling

Water samples were collected to determine background microbial populations introduced in the drilling process. Undisturbed water in Hole 801C was viewed as a potentially excellent in situ microbial culture, and was thus sampled using the water-sampling temperature probe (WSTP) before the hole was disturbed; ~300 mL of water was recovered from a depth of 540 m in the hole. Water samples were also collected from the drill pipe and from the sea surface (from the z-boat) upwind of the *JOIDES Resolution.*

A series of samples of different rock types were collected for culturing, DNA and Adenosine triphosphate (ATP) analyses, and total cell counts. Figure 17 shows an example of a bacterial population contaminated with fluorescent microspheres. Whole-round samples of basement rocks, including glass samples, were (1) taken and transported to an anaerobic chamber where they were cracked open and interior pieces were used to inoculate cultures and (2) also used for shore-based microscopic analyses and DNA extraction. Cultures have also been started at in situ pressure, and some samples have been stored under pressure for shore-based analyses.

Hole 801C, and to a lesser extent volcanic rocks from Site 1149 preserve small amounts (several grams to a few grains) of fresh basaltic glass. These samples were studied microscopically for traces of microbial activity. Several samples preserve filament-like textures that are identical to textures attributed to microbes in deep-sea basalt from young oceanic pillow basalt. Whether these textures are trace fossils of past microbial activity or signs of extant microbes living in this high-pressure seafloor environment remains a fascinating subject of shore-based study.

Tracer Tests

The issue of core contamination often makes interpretation of observations in deep subsurface microbiology difficult because nonindigenous microorganisms can be introduced during the drilling and sampling processes. This concern is amplified for extremely deep environments where the abundance of microorganisms is generally very low and the potential for contamination is great. Because the Ocean Drilling Program ventures into the realm of deep biosphere research, the issue of sample contamination, especially as it pertains to the drilling process on board the *JOIDES Resolution,* must be addressed.

The drilling fluids (mud and/or surface seawater), the drill string itself, and sample handling procedures on deck are all possible sources of contamination. Quantitative contamination tests have been conducted in other drilling operations using a variety of chemical, microbiological, and particulate tracers (see review by Griffin et al., 1997). An ideal chemical tracer is inert, not found naturally in the environment, and easily detected at extremely low concentrations. One of the goals during Leg 185 was to establish shipboard procedures on the *JOIDES Resolution* to deliver perfluorocarbon tracers (PFTs) and fluorescent microspheres 0.5–1.0 µm in size during drilling and to detect the tracers in recovered cores. Sediment and igneous rock require different drilling techniques, and tracer experiments were performed in both types of formations.

PFT data, along with the measured concentration of microbial cells in surface waters, can be used to estimate the extent of potential microbial contamination. The measured number of cells in the surface water at Site 801 was 4.2×10^2 cells/µL. Based on this value, microbial contamination is less than one cell per gram when there is less than ~0.0025 µL of drilling fluid contamination per gram of sample. For interior samples, this is the case for five of the 12 unconsolidated sediments cored by APC, one of the five basalt analyses, and one of the four consolidated sediments analyzed that were cored by RCB.

Caution must be used in the interpretation of the PFT contamination tests. Although low PFT values can be taken as proof of minimal contamination, high PFT levels do not unequivocally prove microbial contamination. There are two reasons for this. First, the PFT is able to penetrate much smaller pores than contaminating microorganisms. Second, perfluoro (methylcyclohexane) is volatile at room temperature and can cause contamination during handling via gas-phase transfer of the tracer from drilling fluid on the exterior sediment and rock surfaces to the interior samples.

The microspheres are not a perfect mimic of microorganisms. Whereas microspheres are similar in size to microorganisms, they have different surface properties and, therefore, may behave differently as they migrate through the formation or attach to mineral surfaces. Microspheres are dispersed in the core barrel when rock passes through the core catcher, so the rocks are exposed to the tracer only after it has been saturated with drilling fluid and the physical disturbance of the formation by drilling. Thus, microspheres are less likely to be introduced into cracks than PFTs.

The rapid analysis and high sensitivity of PFTs makes it possible to quickly check samples for the possibility of contamination before performing the microbiological manipulations and, therefore, avoid wasting resources on contaminated samples. In addition, if samples are routinely taken, it may be possible to build up a database correlating the probability of contamination with different types of sediment and rock formation characteristics (e.g., porosity, percent veins, and mineralogy) and type of drilling. As little as 10^{-12}g of PFT is detectable. Higher sensitivity may possibly be achieved by using a smaller bore column on the gas chromatograph. This should sharpen the peaks and improve the signal to noise ratio. The use of a less volatile PFT may also improve the reliability of the method as an indicator of microbial contamination.

The processing of hard rock relies on the use of water as a lubricant and cooling fluid, both during subseafloor drilling and sample preparation in the laboratory. Water can introduce microbial contamination to the core as well as transfer surface contaminants into the interior of a sample during the processing of wet samples. For this reason, to sample core interiors core surfaces should be dried before handling and broken with a rock splitter, which does not require water, instead of a rock saw.

Because rock saws and polishing grits are required to make thin sections, it is critical that contamination is controlled during these processes as well. Establishing a protocol for the cutting and polishing of thin sections, without the introduction of microbial contaminants, is essential.

On average, the sediments cored with the APC showed less susceptibility to contamination, and several core interiors were entirely free of contaminants. RCB coring resulted in the presence of chemical, but not particulate, tracers in the interior of the cores. This difference is probably, though not unequivocally, because of the nature of the coring. The APC core barrel is fired into the sediment in less than a second, whereas the RCB can take several hours to cut a 9.5-m core with drilling fluid continuously flowing through the bit.

As more research on microbial activity in the deep biosphere is conducted, it is important to remain cognizant of the issue of contamination. Although the absolute quantity of the contaminant seems very small, unlike chemical contamination, microbial contamination can be amplified after the sample has been taken. This is a concern with nonindigenous microorganisms growing in cultures inoculated with material from the deep biosphere, as well as in samples where the DNA of nonindigenous microbes may be amplified using the polymerase chain reaction. Therefore, continued, routine testing for microbial contamination during drilling on board the *JOIDES Resolution* will provide the scientific community with quality data on deep biosphere microbiology.

SUMMARY

The operational and scientific objectives of Leg 185 were achieved. Two sites were drilled in deep water and into the oldest crust of the Pacific Ocean (Fig. 18). Hole 801C in the Pigafetta Basin was re-entered and deepened in order to drill the upper oxidative alteration zone in basement. Four holes at Site 1149 in the Nadezhda Basin were drilled through sediment and into basement in order to characterize seafloor subducting at the Izu-Bonin Trench. In addition to satisfying these basic drilling objectives, the Leg 185 scientific party made a number of scientific achievements.

A Legacy Site into Pacific Jurassic Crust

Hole 801C was deepened by 340 m into basement, providing a total basement section of 470 m, making it the sixth deepest ODP or DSDP site into normal oceanic crust. Our conservative drilling objectives, to deepen the hole by 250 m, were exceeded. Recovery was very good (47%), and a high quality set of logs were run to 388 m in basement. Hole 801C is the only site to drill into Jurassic Pacific oceanic crust. The hole is in good condition, and it remains a legacy site into the Earth’s oldest oceanic crust. Hole 801C is an important geochemical, geophysical, and biological reference site into old (~165 Ma), ultrafast spreading crust being subducted into the Mariana subduction zone. The basalts from Hole 801C have been sampled using a coordinated strategy to develop a common set of samples for all geochemical investigators, as well as composite samples, which will be another legacy of the site. This is a novel approach, which will lead to an unprecedented geochemical data set for this unique section of oceanic crust.

A Complete Sedimentary Sequence in the Nadezhda Basin, Western Pacific

Drilling at Site 1149 satisfied a primary objective of providing the first complete section through the pelagic sediments (~400 m) of the Nadezhda Basin, a ~1000 km × 1000 km region in the western Pacific. More than 90% of the sedimentary section was either recovered or logged, and sedimentary units at Site 1149 can be traced seismically across the basin. Thus, Site 1149 is an important reference site for Mesozoic equatorial sedimentation from the upper Valanginian and for sediment that is being subducted along the entire 1000 km Izu Trench.

Early Cretaceous Seafloor Subducting at the Izu-Bonin Trench

Basement drilling at Site 1149 achieved significant (133 m) penetration into Anomaly M11 (132-Ma oceanic crust), ranking this as one of the few ODP sites to drill >100 m into Mesozoic oceanic crust. Thus, Site 1149 will serve as an important reference site for fast-spreading, Mesozoic Pacific crust (102 mm/yr full rate) and its associated alteration and igneous composition as it subducts at the Izu-Bonin Trench.

A Mass Balance Equation for Crustal Recycling at the Mariana Arc

After drilling Hole 801C, the remaining piece of the crustal input inventory is complete for the Mariana subduction factory. Shore-based geochemical analyses of the basement section in Hole 801C will provide the first robust estimates for subducting oceanic crust with which to compare to volcanic outputs at the Mariana backarc. The basaltic inventory for K, U, Ba, CO_2, and H_2O will provide not only seawater-basalt fluxes but also crust-mantle fluxes for these key tracers and volatiles.

Comparisons of the Input and the Output at the Mariana and Izu Arcs

Having provided the first continuous sedimentary section to basement of sediments subducting along the Izu-Bonin margin, Leg 185 data enables comparison of the inputs to the Mariana and Izu arcs. In contrast to the East Mariana and Pigafetta Basin sediments subducting at the Mariana Trench, the Nadezhda Basin sediments subducting at the Izu-Bonin Trench lack a mid-Cretaceous volcaniclastic section and contain more siliceous and carbonate-rich biogenic material because of its longer passage beneath zones of high biological productivity. Shore-based geochemical studies will demonstrate the extent to which these different sedimentary histories can be traced to the volcanic output from the two arc systems. For example, does the sedimentary and basaltic input on the incoming plate provide suitable Pb isotope mixing end-members for the

Izu arc volcanics, or are other mantle and upper plate sources required? Does the extensive biogenic section in the lower half of Site 1149, which is highly depleted in alkali elements, contribute to the low alkali content of the Izu arc? The coordinated shipboard sampling and analytical effort organized by Leg 185 scientists will provide an unprecedented geochemical data set (major elements, trace elements, and Pb, Nb, Sr, Os, Hf, Li, B, Be, Cl, S, Se, C, N, O, H, and S isotopes) of crustal inputs to the two subduction factories.

The Jurassic Quiet Zone

Hole 801C Jurassic basement records up to six geomagnetic reversals. Not only are there several reversals, but some sections preserve gradual changes in the magnetic field direction from one polarity interval to the other. Thus, igneous basement at Hole 801C was extruded at a time of rapid polarity alternations of the geomagnetic field. Hence, these data may provide an explanation for the JQZ in a series of superposed flows with opposite polarity, essentially canceling out one another. The presence of fresh basaltic glass at depth in Hole 801C will also provide suitable material for paleointensity studies, to test the hypothesis that the JQZ was a time of low geomagnetic field intensity.

Deep Biosphere

Leg 185 was the first ODP leg to invest a significant effort in conducting microbial contaminant tests, equipping a microbiology laboratory, and establishing techniques for core handling of biological samples. Contaminant tests using perfluorocarbon and fluorescent microsphere tracers demonstrated that sediments cored with the APC showed less susceptibility to contamination than RCB coring. Several APC core interiors were entirely free of contaminants. These tests, which demonstrate that biological contamination can be assessed and surmounted, pave the way for establishing ODP as a new platform for microbiological studies. Leg 185 samples were used to start culturing experiments in various media at both atmospheric and in situ pressure and for shore-based DNA extraction and community characterization. Several glass samples from Hole 801C showed textural evidence for microbial alteration and leave the intriguing question of whether there is still microbiological activity in 165-Ma volcanic basement.

Calibrating Magnetic Anomaly M11

Based on a re-evaluation of existing seafloor magnetic anomaly lineations, Site 1149 lies in crust of Anomaly M11, which is consistent with the presence of *T. verenae* found in the basal core in Hole 1149B. Obtaining a radiometric date on the basement at Site 1149 could provide a reasonably precise date of Anomaly M11 and help to refine the time scale during this age near the breakup of Gondwana.

Mesozoic and Cenozoic Pelagic Sequences

The equatorial paleolatitude history of Site 1149 during the mid-Cretaceous, combined with a predictable subsidence history, is ideal for testing variations in the Cretaceous CCD. Site 1149 sediments record a well-developed metalliferous sedimentary profile, which clearly documents the decreasing influence of plume precipitation with lateral distance from the ridge. Very high sediment accumulation rates (~30 m/m.y.) and the mineral composition of the youngest sediments suggest that Site 1149 was in the reach of the Asian dust plumes after the early Pleistocene.

Petrology of Mesozoic Crust

Fresh basaltic glass was recovered from both Site 1149 and Site 801, providing pristine samples of the igneous liquid that forms Mesozoic Pacific crust. These are valuable samples that record mid-ocean ridge processes, mantle composition, and mantle temperature at a time preceding the Cretaceous superplume event in the Pacific.

Architecture of Fast-Spreading Crust

Sites 801 and 1149 provide the first sections into Mesozoic fast-spreading crust, Layer 2A. Geochemical alteration of the volcanic section in Hole 801C is found in several discrete zones associated with ocherous Si-Fe–hydrothermal deposits and thick massive flows. These zones control the alteration pattern of crust and contrast with “accepted” models for a gradual decrease downhole in the alteration of oceanic basement. The pattern of alteration at Site 801, controlled by local pathways for hydrothermal fluids, may be a feature of fast-spreading crust.

Continued Diffusive Exchange between Basement and Sediments

Although it is generally accepted that there is diffusive exchange between interstitial waters in the volcanic section of oceanic crust and the overlying sediments, the organic-poor nature of the sediments at Site 1149 allows modeling of S and metal budgets between basement and sediments, as well as assessing the potential for bacteria in the basement to affect the redox state of the overlying sediments.

DISCUSSION OF SAMPLING STRATEGY

Communal and Composite Geochemical Samples

Too often ODP cores are sampled by individual investigators who perform a unique set of analyses. This process produces a dispersed data set, and it is often difficult to relate the different studies. Our overall objective is to have the investigators work on a common set of samples. This is a novel approach and requires good organization, communication, and cooperation at all stages. The benefits, however, are substantial, and the geochemical database archived for Leg 185 will be a unique contribution to the GERM initiative.

In addition to personal samples taken for specific studies in the cores, such as vein-rock interaction, microbiology, in situ laser, and ion probe analyses, a representative suite of rocks was sampled for use by the scientific party for geochemical analysis. These samples were taken to represent the major lithologies in the cores: massive flows, pillowed or sheet flows, interflow material, breccia, and also the different alteration types: veins, halos, and pervasively altered basalt. A representative group of samples were taken for each of the different lithologic divisions. In all, the sample set comprises 118 samples.

Each sample was described, crushed, and powdered. Each sample was subdivided for a thin section, a slab for crushing and powdering, and an archive piece. For most samples an aliquot of clean chips was also archived. A summary description of each sample, the sampling interval, and the weight of powder and rock chips were recorded. The communal samples will serve as the base sample set for all geochemical work. The geochemical results, in combination with the geophysical logs, core descriptions, and physical properties data, will be used to construct a numerical average for all elements for the composition of Hole 801C basement. A subset of these samples will be used to construct a physical mixture of different lithologies, “a composite” sample, which will be prepared following standard procedures. The composite samples will also be analyzed by various geochemical procedures to determine the bulk geochemistry of Hole 801C basalts. The composite samples will also be large enough in volume to accommodate future analytical efforts, and therefore, represent the legacy of the site.

Initial shore-based analyses of the communal samples will focus on inductively coupled plasma–mass spectrometry analysis for major elements and selected trace elements (Sr, Ba, and some trace metals), and CO_2 and H_2O determinations. In addition, a selection of 20 samples will be taken for representative key lithologies and will be distributed for general analysis. Using the geochemical data, additional subsets will be selected for more detailed geochemical and isotopic analysis. Although subject to interpretation of the shore-based geochemical data and detailed analysis of logs, a composite sample will be prepared that is representative of each of the major divisions. The analyses proposed for the communal samples and the composites are given in Table 3. The data will be updated on a regular basis on the Leg 185 World Wide Web site and distribution and curation of the samples will be controlled by the Leg 185 co-chief scientists.

Glass Samples

Fresh glass is important for determining the chemical composition of magmas because it is unaffected by mineral accumulation and posteruption alteration. Glass is also usually chemically homogenous so that chemical analyses made with microbeam techniques are applicable to the bulk sample. Fresh glass from flow and pillow margins and from hyaloclastites were identified under the binocular microscope during the routine description of the cores. The locations of most of the pieces that contain glass are given in Table 4. A subset of ~50 glasses was sampled on board ship for a coordinated effort to obtain a wide variety of analyses on the same samples (Table 4). Glass chips and thin sections will be analyzed first by electron microprobe for 10 major elements (Si, Al, Fe, Mg, Ca, Na, K, P, Ti, and Mn). This will determine how many different compositions are present in the cores. Based on the major element analyses, selected thin sections and chips will be distributed among the other investigators who wish to conduct laser and ion beam microanalyses and water measurements by Fourier transform infrared spectroscopy. Also, based on the major elements, samples will be distributed for mass spectroscopy for heavy isotopes, halogens, Li, and B. Some samples were distributed on board the ship for magnetic intensity measurements, and additional samples will be distributed after thin-section billets are cut from the samples. Thin sections examined for evidence of microbial activity (Fisk) will also be measured for the relative chemical and microbial alteration (Staudigel).

Analysis of Logs

An important aspect of the construction of a reference site involves integrating the geophysical and chemical logs with the core information to create a complete crustal section. In the case of the basement logging at Site 801, of particular interest is determining the relative proportions of interflow material, thick flows, and thin sheet flows or pillows. The strategy involves an integration of the FMS logs, geochemical data, and core lithology data for the Hole 801C basement. The porosity-sensitive logs (resistivity, velocity, density, and neutron porosity) will be studied for Hole 801C to characterize very old oceanic crust formed at a very fast spreading rate. In addition, a modeling study of the temperature log in Hole 801C will be undertaken to further constrain the porosity/permeability of basement.

Given the interest in the magnetic reversal history of Jurassic ocean crust, the magnetic logs will be used to establish the magnetic polarity stratigraphy of Hole 801C basement from the log data and to construct a model of the surface magnetic field using the various polarity intervals as input.

Paleomagnetic and Paleointensity Analysis

A number of the fresh glass samples from flow and pillow margins and from hyaloclastites were distributed on board the ship for magnetic intensity measurements.

Microbiology

The majority of the microbiology data will be generated in shore-based studies. The major efforts will be to determine community composition by DNA extraction, in situ hybridization, characterization of microbes isolated from enrichment cultures, and culturing of microbes from samples maintained at in situ pressure. Culturing at high pressure and at 1 atm will be done at different shore-based laboratories. These studies will be coordinated with additional study of igneous rocks, veins, and sediment from which biological samples were collected. Rock samples will be examined by scanning electron microscope for microbes and microbial alteration textures. The amount of microbial vs. chemical alteration will be measured in thin sections, and the types and compositions of secondary minerals will be determined by electron microprobe. The lithology of sediments used for cultures and ATP measurements will be determined from smear slides.

REFERENCES

Abrams, L.J., Larson, R.L., Shipley, T.H., and Lancelot, Y., 1992. The seismic stratigraphy and sedimentary history of the East Mariana and Pigafetta basins of the Western Pacific. *In* Larson, R., Lancelot, Y., et al., *Proc. ODP, Sci. Results*, 129: College Station, TX (Ocean Drilling Program), 551-570.

Alt, J.C., and Teagle, D.A.H., 1999. The uptake of carbon during alteration of oceanic crust. *Geochim. Cosmochim. Acta.,* 63:1527–1535.

Alt, J.C., Honnorez, J., Laverne, C., and Emmermann, R., 1986. Hydrothermal alteration of a 1 km section through the upper oceanic crust, Deep Sea Drilling Project Hole 504B: mineralogy, chemistry, and evolution of seawater-basalt interactions. *J. Geophys. Res.,* 91:10309–10335.

Alt, J.C., France-Lanord, C., Floyd, P.A., Castillo, P., and Galy, A., 1992. Low-temperature hydrothermal alteration of Jurassic ocean crust, Site 801. *In* Larson, R.L., Lancelot, Y., et al., *Proc. ODP, Sci. Results,* 129: College Station, TX (Ocean Drilling Program), 415–427.

Arculus, R.J., Gill, J.B., Cambray, H., Chen, W., and Stern, R.J., 1995. Geochemical evolution of arc systems in the Western Pacific: the ash and turbidite record recovered by drilling. *In* Taylor, B., and Natland, J. (Eds.), *Active Margins and Marginal Basins of the Western Pacific.* Am. Geophys. Union, 88:45–65.

Armstrong, R.L., 1968. A model for Sr and Pb isotopic evolution in a dynamic earth. *Rev. Geophys.*, 6:175–191.

Arthur, M.A., Dean, W.E., and Schlanger, S.O., 1985. Variations in global carbon cycle during the Cretaceous related to climate volcanism and changes in atmospheric CO_2. *In* Sundquist, E.T. and Broecker, W.S. (Eds.), *The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present,* Am. Geophys. Union, Geophysical Mon., 32:504-529.

Carbotte, S.M., Mutter, J.C., and Xu, L., 1997. Contribution of volcanism and tectonism to axial and flank morphology of the southern East Pacific Rise, 17°10'–17°40'S, from a study of layer 2A geometry. *J. Geophys. Res.,* 102:10165–10184.

Castillo, P.R., Floyd, P.A., and France-Lanord, C., 1992. Data Report: Summary of geochemical data for Leg 129 igneous rocks. *In* Larson, R.L., Lancelot, Y., et al., *Proc. ODP, Sci. Results,* 129: College Station, TX (Ocean Drilling Program), 653–670.

Channell, J.E.T., Erba, E., Nakanishi, M., and Tamaki, K., 1995. Late Jurassic–Early Cretaceous time scales and oceanic magnetic anomaly block models. *In* Berggren, W.A., et al. (Eds.), *Geochronology, Time Scales and Global Stratigraphic Correlation.* Spec. Publ.—Soc. Econ. Paleontol. Mineral., 54:51–63.

Detrick, R., Collins, J., Stephen, R., and Swift, S., 1994. *In situ* evidence for the nature of the seismic layer 2/3 boundary in oceanic crust. *Nature,* 370:288–290.

Elliott, T., Plank, T., Zindler, A., White, W., and Bourdon, B., 1997. Element transport from subducted slab to volcanic front at the Mariana Arc. *J. Geophys. Res.,* 102:14991–15019.

Erba, E., 1992. Middle Cretaceous calcareous nannofossils from the Western Pacific (Leg 129): Evidence for paleoequatorial crossings. *In* Larson, R.L., Lancelot, Y., et al. (Eds.), *Proc. ODP, Sci. Results,* 129: College Station, TX (Ocean Drilling Program), 189-201.

Ewing, J., Ewing, M., Aitken, T., and Ludwig, W.J., 1968. North Pacific sediment layers measured by seismic profiling. *In* Knopoff, L., Drake, C.L., and Hart, P.J. (Eds.), *The Crust and Upper Mantle of the Pacific Area.* Geophys. Monogr., Am. Geophys. Union., 12:147–173.

Fisk, M.R., Giovannoni, S.J., and Thorseth, I.H., 1998. Alteration of oceanic volcanic glass: textural evidence of microbial activity. *Science,* 281:978–980.

Floyd, P.A., and Castillo, P.R., 1992. Geochemistry and petrogenesis of Jurassic ocean crust basalts, Site 801. *In* Larson, R.L., Lancelot, Y., et al., *Proc. ODP, Sci. Results,* 129: College Station, TX (Ocean Drilling Program), 361–388.

Floyd, P.A., Winchester, J.A., and Castillo, P.R., 1992. Geochemistry and petrography of Cretaceous sills and lava flows, Sites 800 and 802. *In* Larson, R.L., Lancelot, Y., et al., *Proc. ODP, Sci. Results,* 129: College Station, TX (Ocean Drilling Program), 345–359.

Francheteau, J., Armijo, R., Cheminée, J.L., Hekinian, R., Lonsdale, P., and Blum, N., 1992. Dyke complex of the East Pacific Rise exposed in the walls of Hess Deep and the structure of the upper oceanic crust. *Earth Planet. Sci. Lett.,* 111:109–121.

Fryer, P., 1992. A synthesis of Leg 125 drilling of serpentinite seamounts on the Mariana and Izu Bonin forearcs. *In* Fryer, P., Pearce, J.A., Stokking, L.B., et al., *Proc. ODP, Sci. Results,* 125: College Station, TX (Ocean Drilling Program), 593–614.

Furnes, H., and Staudigel, H., 1999. Biological mediation in ocean crust alteration: how deep is the deep biosphere? *Earth Planet. Sci. Lett.*, 166:97–103.

Gill, J.B., Hiscott, R.N., and Vidal, P., 1994. Turbidite geochemistry and evolution of the Izu-Bonin arc and continents. *Lithos*, 33:135–168.

Gillis, K.M.,1995. Controls on hydrothermal alteration in a section of fast spreading oceanic crust. *Earth Planet. Sci. Lett.*,134:473–489.

Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1994. A Mesozoic time scale. *J. Geophys. Res.*, 99:24051-24074.

Griffin, W.T., Phelps, T.J., Colwell, F.S., and Fredrickson, J.K., 1997. Methods for obtaining deep subsurface microbiological samples by drilling. *In* Amy, P.S., and Haldeman, D.L. (Eds.), *The Microbiology of the Terrestrial and Deep Subsurface:* Boca Raton, FL. (CRC Press), 23–43.

Haggerty, J.A., Premoli Silva, I., Rack, F., and McNutt, M.K. (Eds.), 1995. *Proc. ODP, Sci. Results,* 144: College Station, TX (Ocean Drilling Program).

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G., 1990. *A Geologic Time Scale, 1989,* Cambridge University Press, Cambridge, U.K.

Hawkesworth, C.J., Turner, S.P., McDermott, F., Peate, D.W. , and van-Calsteren, P., 1997. U-Th isotopes in arc magmas: implications for element transfer from the subducted crust. *Science*, 276:551–555.

Haymon, R.M., Fornari, D.J., Edwards, M.H., Carbotte, S.M., Wright, D., and Macdonald, K.C., 1991. Hydrothermal vent distribution along the East Pacific Rise crest (9°09´–54´N) and its relationship to magmatic and tectonic processes on fast-spreading mid-ocean ridges. *Earth Planet. Sci. Lett.*, 104:513–534.

Hofmann, A., 1997. Mantle geochemistry: the message from oceanic volcanism. *Nature,* 385:219–229.

Ikeda, Y., and Yuasa, M., 1989. Volcanism in nascent back-arc basins behind the Shichito Ridge and adjacent areas in the Izu-Ogasowara arc, Northwest Pacific: evidence for mixing between E-type MORB and island arc magmas at the initiation of back-arc rifting. *Contrib. Mineral. Petrol.*, 101:377–393.

Karig, D.E., and Kay, R.W., 1981. Fate of sediments on the descending plate at convergent margins. *Philos. Trans. R. Soc. London,* 301:233–251.

Kimura, G., Silver, E., Blum, P., et al., 1997. *Proc. ODP, Init. Repts.,* 170: College Station, TX (Ocean Drilling Program).

Lancelot, Y., Larson, R.L., et al., 1990. *Proc. ODP, Init. Repts.*, 129: College Station, TX (Ocean Drilling Program).

Larson, R.L., Fisher, A.T., Jarrard, R.D., Becker, K., and Ocean Drilling Program Leg 144 Shipboard Scientific Party, 1993. Highly permeable and layered Jurassic oceanic crust in the western Pacific. *Earth Planet. Sci. Lett.,* 119:71–83.

McLennan, S.M., 1988. Recycling of the continental crust. Pure Appl. Geophys., 128:683–724.

Morris, E.L., Tanner, I., Meyerhoff, H.A., and Meyerhoff, A.A., 1990. Tectonic evolution of the Caribbean region: alternative hypothesis. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region.* Geol. Soc. Am., Geol. of North Am. Ser., H:433–457.

Nakanishi, M., Tamaki, K., and Kobayashi, K., 1988. Mesozoic magnetic anomaly lineations and seafloor spreading history of the northwestern Pacific, *J. Geophys. Res.*, 94:15,437-15,462.

Parkes, R.J., Cragg, B.A., Bale, S.J., Getliff, J.M., Goodman, K., Rochelle, P.A., Fry, J.C., Weightman, A.J., and Harvey, S.M., 1994. A deep bacterial biosphere in Pacific Ocean sediments. *Nature,* 371:410–413.

Perfit, M.R., and Chadwick, W.W., 1998. Magmatism at Mid-Oceanic Ridges: constraints from volcanological and geochemical investigations. *In* Buck, W.R., Delaney, P.T., Karson, J.A., and Lagabrielle, Y. (Eds.), *Faulting and Magmatism at Mid-Ocean Ridges.* Geophys. Monogr., Am. Geophys. Union., 106:50–115.

Pick, T., and Tauxe, L., 1993. Geomagnetic paleointensities during the Cretaceous normal superchron measured using submarine basaltic glass. *Nature*, 366:238-242.

Plank, T., and Langmuir, C.H., 1998. The chemical composition of subducting sediment: implications for the crust and mantle. *Chem. Geol.,* 145:325–394.

Plank, T., and Ludden, J.N., 1992. Geochemistry of sediments in the Argo Abyssal Plain at Site 765: a continental margin reference section for sediment recycling in subduction zones. *In*

Gradstein, F.M., Ludden, J.N., et al., *Proc. ODP, Sci. Results,* 123: College Station, TX (Ocean Drilling Program), 167–189.

Pringle, M.S., 1992. Radiometric ages of basaltic basement recovered at Sites 800, 801, and 802, Leg 129, western Pacific Ocean. *In* Larson, R.L., Lancelot, Y., et al., *Proc. ODP, Sci. Results,* 129: College Station, TX (Ocean Drilling Program), 389–404.

Reymer, A., and Schubert, G., 1984. Phanerozoic addition rates to the continental crust and crustal growth. *Tectonics,* 3:63–77.

Roth, P.H., 1981. Mid-Cretaceous calcareous nannoplankton from the central Pacific: Implication for paleoceanography. *In* Tiede, J., Vallier, T.L., et al., *Init. Repts. DSDP,* 62: Washington (U.S. Govt. Printing Office), 471-489.

Staudigel, H., Davies, G.R., Hart, S.R., Marchant, K.M., and Smith, B.M., 1995. Large scale Sr, Nd, and O isotopic anatomy of altered oceanic crust: DSDP sites 417/418. *Earth Planet. Sci. Lett.,* 130:169–185.

Staudigel, H., Kastner, M., and Sturz, A., 1986. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ of calcites from the basaltic basement of Deep Sea Drilling Project Site 597: timing and temperature of alteration. *In* Leinen, M., Rea, D.K., et al., *Init. Repts. DSDP,* 92: Washington (U.S. Govt. Printing Office), 499–503.

Stein, C.A., and Stein, S., 1994. Constraints on hydrothermal heat flux through the oceanic lithosphere from global heat flow. *J. Geophys. Res.,* 99:3081–3095.

Stern, R.J., Lin, P.-N., Morris, J.D., Jackson, M.C., Fryer, P., Bloomer, S.H., and Ito, E., 1990. Enriched back-arc basin basalts from the northern Mariana Trough: implications for the magmatic evolution of back-arc basins. *Earth Planet. Sci. Lett.,* 100:210–225.

Tatsumi, Y., Murasaki, M., and Nodha, S., 1992. Across-arc variation of lava chemistry in the Izu-Bonin Arc: identification of subduction components. *J. Volc. Geotherm. Res.,* 49:179–190.

Taylor, B., 1992. Rifting and the volcanic-tectonic evolution of the Izu-Bonin-Mariana arc. *In* Taylor, B., Fujioka, K., et al., *Proc. ODP, Sci. Results,* 126: College Station, TX (Ocean Drilling Program), 627-651.

Theirstein, H.R., 1979. Paleoceanographic implications of organic carbon and carbonate distribution in Mesozoic deep-sea sediments. *In* Talwani, M., Hay, W.W., Ryan, W.B.F. (Eds.), *Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*, Amer. Geophys. Union, Maurice Ewing Series, 3:249-274.

Thorseth, I.H., Torsvik, T., Furnes, H., and Muehlenbachs, K., 1995. Microbes play an important role in the alteration of oceanic crust. *Chem. Geol.,* 126:137–146.

Van der Hilst, R.D., Widiyantoro, S., Engdahl, E.R., 1997. Evidence for deep mantle circulation from global tomography. *Nature,* 386:578–584.

Woodhead, J.D., and Fraser, D.G., 1985. Pb, Sr, and ^{10}Be isotopic studies of volcanic rocks from the Northern Mariana Islands: implications for magma genesis and crustal recycling in the western Pacific. *Geochim. Cosmochim. Acta,* 49:1925–1930.

TABLE CAPTION

Table 1. The oldest crust drilled by ODP and DSDP in the different ocean basins.

Table 2. Leg 185 operational summary.

Table 3. Analyses of the communal and composite samples, Hole 801C.

Table 4. Analyses on communal glass samples.

FIGURE CAPTIONS

Figure 1. Input to and output from “The Subduction Factory.”

Figure 2. Perspective map of Izu-Mariana arcs and Leg 185 drilling sites.

Figure 3. Competing models for input-output studies. **A.** The grass control model indicates that the kind of milk (dark vs. light) is controlled by the kind of grass (dark vs. light) that the cow eats. **B.** In the cow control model the breed of the cow is the important control in determining the kind of milk produced. Different cows (Guernsey vs. Jersey) eating the same kind of grass may still produce different kinds of milk (dark vs. light). These models are directly analogous to subduction recycling studies, where the grass is the subducted input (sediments and oceanic crust), the milk is the volcanic arc output and the cow is the subduction zone.

Figure 4. Correlation between Ba flux in subducted sediment and Ba enrichment of arc basalts for various arcs (Ant = Northern Antilles, Mar = Mariana, T= Tonga, Mex = Mexico, J = Java, Al = Aleutians, and G = Guatemala) around the world (after Plank and Langmuir, 1993). Open circles = three different sediment flux estimates for the Mariana, based on the three ODP Sites drilled during Leg 129 (800–802) (Plank and Langmuir, 1998). Although there are variations from site to site, the average sediment input to the Mariana is fairly well constrained (± 20%). Note Izu volcanics are lower in Ba/Na than Mariana volcanics by a factor of two. **B.** Contrasting Pb isotopic composition of Mariana (open circle) and Izu-Bonin (solid circle) arc volcanics. Mariana volcanics form a mixing trend (arrow), almost perfectly coincident with mixtures of ODP Hole 801C sediment (open boxes) and basalt (solid boxes) averages.

Figure 5. Map showing all sites and proximity to magnetic anomaly lineations, basins, and land masses.

Figure 6. Lithologic columns for Hole 801C, Leg 20 sites, and Site 1149. Val-Haut = Valanginian-Hauterivian; Kimm-Barr = Kimmeridgian-Barremian.

Figure 7. Paleogram comparing Sites 801 and 1149.

Figure 8. Seismic profiles that intersect Site 1149.

Figure 9. Cartoon showing drilling strategy chosen to achieve scientific objectives at Hole 801C and Site 1149.

Figure 10. Stratigraphic column showing all of the basement subunits drilled during Legs 129 and 185. The sequences correspond to major lithologic changes but are also related to the presence of breccia zones, hydrothermal deposits, and changes in magma chemistry.

Figure 11. Hole 801C comparison of recovery, resistivity and natural gamma logs, magnetic logs of vertical and horizontal intensity, and the magnetic inclination measured in half-round cores. The major lithologic sequences for the section are also given.

Figure 12. Downhole variation for MgO **(A)** and Zr **(B)**, demonstrating the magmatic trends of increasing MgO and decreasing Zr toward more primitive liquids upsection. In addition, smaller scale variation is observed within the various core divisions. The alkaline suite in the sequence above the upper hydrothermal unit (upper shaded area) is identified by enrichment in Zr relative to the tholeiites. The Zr/Y diagram demonstrates that the Hole 801C basalts are normal MORB comparable in chemistry to modern East Pacific Rise (EPR) tholeiites (Leg 185). MAR = Mid-Atlantic Ridge.

Figure 13. Section 185-801C-15R-7 showing the extreme alteration types observed. The pale green alteration separates an interflow sediment. The gray-green alteration at the bottom of the core is typical of much of the background alteration in the cores from this site. The proportions of the main secondary minerals are given, as are photomicrographs in which saponite, smectite, and calcite are visible. The two photomicrographs of the pale green alteration show a plagioclase phenocryst, found only rarely in dominantly aphyric lavas.

Figure 14. Summary of the lithostratigraphic section from holes drilled at Site 1149.

Figure 15. Magnetic reversal stratigraphy in the upper 120 m at Site 1149.

Figure 16. Summary of sedimentation rates at Site 1149 calculated from magnetostratigraphy and calcareous nannofossils.

Figure 17. An example of a bacterial population contaminated with fluorescent microspheres.

Figure 18. Summary of the age and nature of stratigraphic units cored at Sites 801 and 1149 during Leg 185.

Table 1. The oldest crust drilled by ODP and DSDP in the different ocean basins.

Leg 185, Site 801: West Pacific, Pigafetta Basin

Water depth (m): 5674
Total depth (m): 6620.7
Penetration (m): 935.7
Basement (mbsf): 461.6
Basement penetration (m): 474.1
Magnetic lineation: >M36
Oldest sediment: Bajocian–Bathonian (166 Ma)
Basement age: Alkalic cap (155 Ma)
Tholeiites: >155, <171 Ma

The oldest basement drilled in the oceans

Leg 76, Site 534: mid-Jurassic, West Atlantic Blake-Bahama Basin

Water depth (m): 4973
Total depth (m): 6639.5
Penetration (m): 1666.5
Magnetic lineation: M28
Oldest sediment: mid-Callovian (~155 Ma)
Basement: core catcher, no radiometric age

Oldest Atlantic basement drilled
The deepest penetration

Leg 123, Site 765: Argo Abyssal Plain, Indian Ocean

Water depth (m): 5713.8
Total depth (m): 6919.2
Penetration (m): 1194.9
Casing string (m): 937
Basement (mbsf): 947.9
Basement penetration (m): 247
Magnetic lineation: M25a
Oldest sediment: early Berriasian (140 Ma)
Basement age > 156 Ma Ar/Ar fusion
Celadonite age 155 Ma K/Ar

The oldest Indian Ocean basement drilled
The greatest total depth

Table 2. Leg 185 operational summary (continued on next page).

Hole	Latitude (N)	Longitude (E)	Water depth (m)	Number of cores	Interval cored (m)	Core recovered (m)	Recovery (%)	Drilled (m)	Penetration (m)
801C	18°38.538'	156°21.588'	5674	40	339.3	160.4	47.3	0	935.7
801D	18°38.538'	156°21.646'	5673.6	0	0	9.4	0.0	0	19.3
801 summary	18°38.538'	156°21.618'	5673.8	40	339.3	169.8	50.0	0	955.0
1149A	31°20.52'	143°21.07'	5817.6	23	191.2	174.4	91.2	0	191.2
1149B	31°20.520'	143°21.06'	5817.5	31	284.6	36.7	12.9	151.1	445.2
1149C	31°20.55'	143°21.06'	5817.6	8	76.9	8.7	8.3	0	426.7
1149D	31°18.79'	143°24.03'	5817.5	18	168.2	29.9	17.8	0	445.2
1149 summary	31°20.095'	143°21.805'	5817.6	80	720.9	249.8	32.6	151.1	1508.3
Leg 185 totals			Mean 5745.7	120	1060.2	410.2	Mean 41	151.1	2463.3

Table 2. (continued).

Time on hole	Hole	APC cores (number)	XCB cores (number)	RCB cores (number)	DCB cores (number)	MDCB cores (number)	Seafloor (mbrf)	Rig floor elevation (m)	Total penetration (mbrf)
485.00 hr	801C	0	0	36	4	0	5685.0	11.0	935.7
22.50 hr	801D	0	0	0	0	0	5685.0	11.4	19.3
21.1 d	801 summary	0	0	36	4	0	5685.0	11.2	477.5
64.42 hr	1149A	18	4	0	0	1	5829.3	11.7	6020.5
180.58 hr	1149B	0	0	31	0	0	5829.3	11.8	6274.5
103.00 hr	1149C	0	0	8	0	0	5829.3	11.7	6256.0
155.00 hr	1149D	0	0	18	0	0	5829.3	11.8	6274.5
21.0 d	1149 summary	18	4	57	0	1	5829.3	11.8	6206.4
42.1 d	Leg 185 totals	18	4	93	4	1	5757.2	Mean 11.5	6683.9

Table 3. Analyses of the communal and composite samples, Hole 801C.

Measurements	Investigator	aliquot (g)
Major Elements (ICP-AES)	Kelley/Plank	Composites
Trace Elements (ICP-MS)	Kelley/Plank	Composites
EMP, SEM, Petrography	Alt	TSB
XRD, EMP, Petrography	Honnorez	Adjacent
S, Se, metals (MC-ICP-MS)	Rouxel/Ludden/Armstrong	Composites
Trace Elements (LAM-ICPMS)	Plank	Veins
Hf isotopes	Ludden/Chauvel	Composites
Os isotopes	Ludden/Reisberg	Composites
Sr, Nd, Pb	Schmidt/Staudigel	Composites
Cl isotopes and halogens	Spivack	Composites
Li, B isotopes	Valentine	Composites
		Veins
C, O, H, S isotopes	Alt	Composites
		Veins
N isotopes	Bebout/Emilio	Composites
Ion Probe (C, O, S, traces)	Ludden/Rouxel	Veins

Note: Total number of communal samples = 118; total number composite samples = 12.

Table 4. Analysis of communal glass samples.

Measurement	Investigator	Number of analyses	Aliquot
FTIR water	Armstrong, Robin	5–10	5 mm chips
Microprobe for major elements	Fisk, Martin	30–40 + 20 thin sections	5 mm chips and TS
Microprobe and optical microscopy for biological alteration	Fisk, Martin	20 thin sections	thin sections
Ion probe for C, S, and trace element distribution and Pb isotopes	Ludden, John	10–20	1 to 5 mm bio + chips
LA-ICPMS for trace elements	Plank, Terry	20–30	>1 mm chips
Ion probe for S, Se, metals	Rouxel, Olivier	use same 10–20 chips Ludden	1–5 mm bio + chips
Mass spectrometry Sr, Nd, Pb	Schmidt, Angelika	1	0.5 g
Cl isotopes and halogens	Spivack, Arthur	2–3	250 mg
Microscopy of biological alteration	Staudigel, Hubert	same as/share with Fisk	thin sections
Magnetic intensity	Steiner, Maureen	10–12	50 mg
Li, B isotopes	Valentine, Robbie	2	1 g
N isotopes	Bebout	-	-

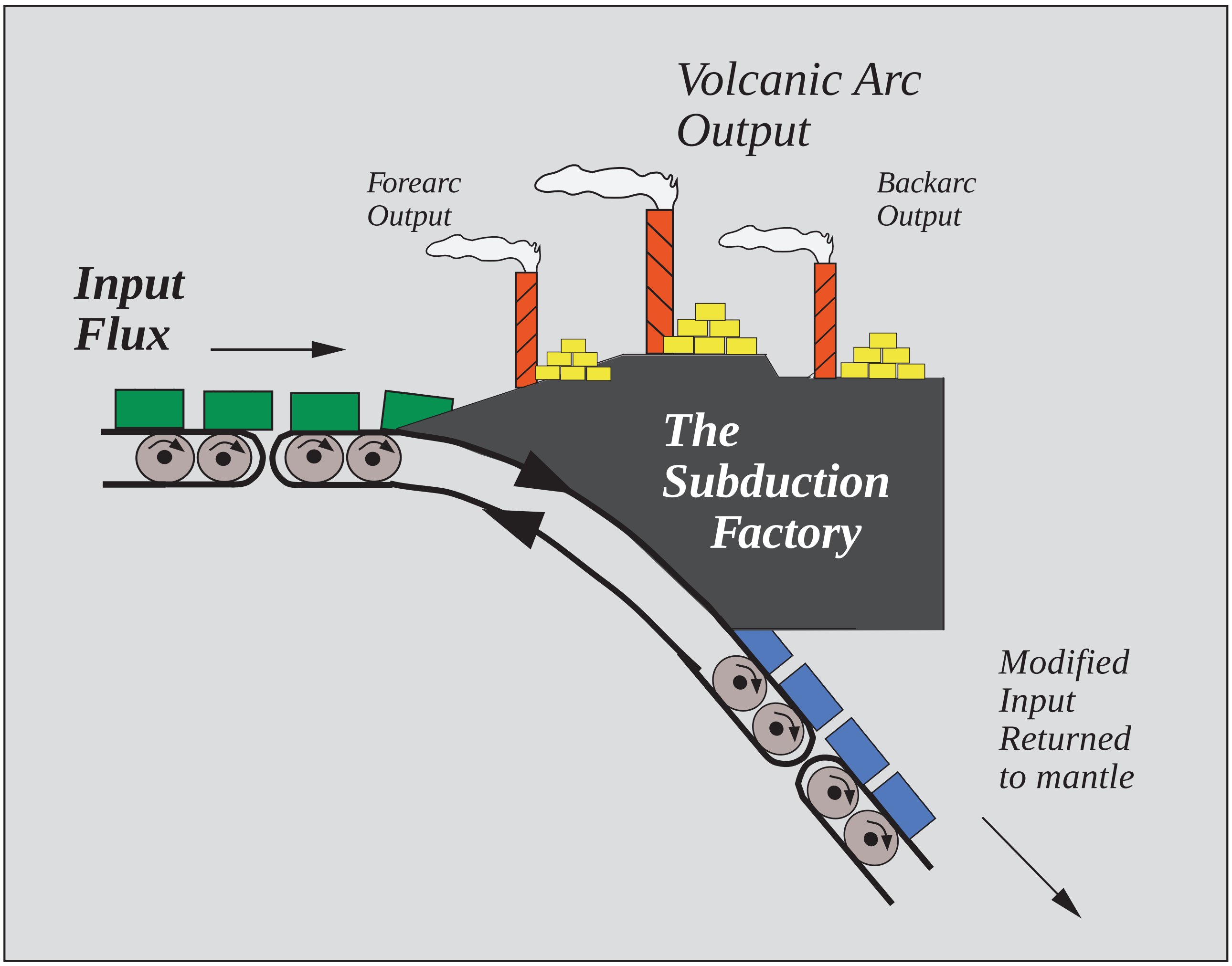

Volcanic Arc
Output
Forearc
Output
Backarc
Output
Input
Flux
The
Subduction
Factory
Modified
Input
Returned
to mantle

Figure 1

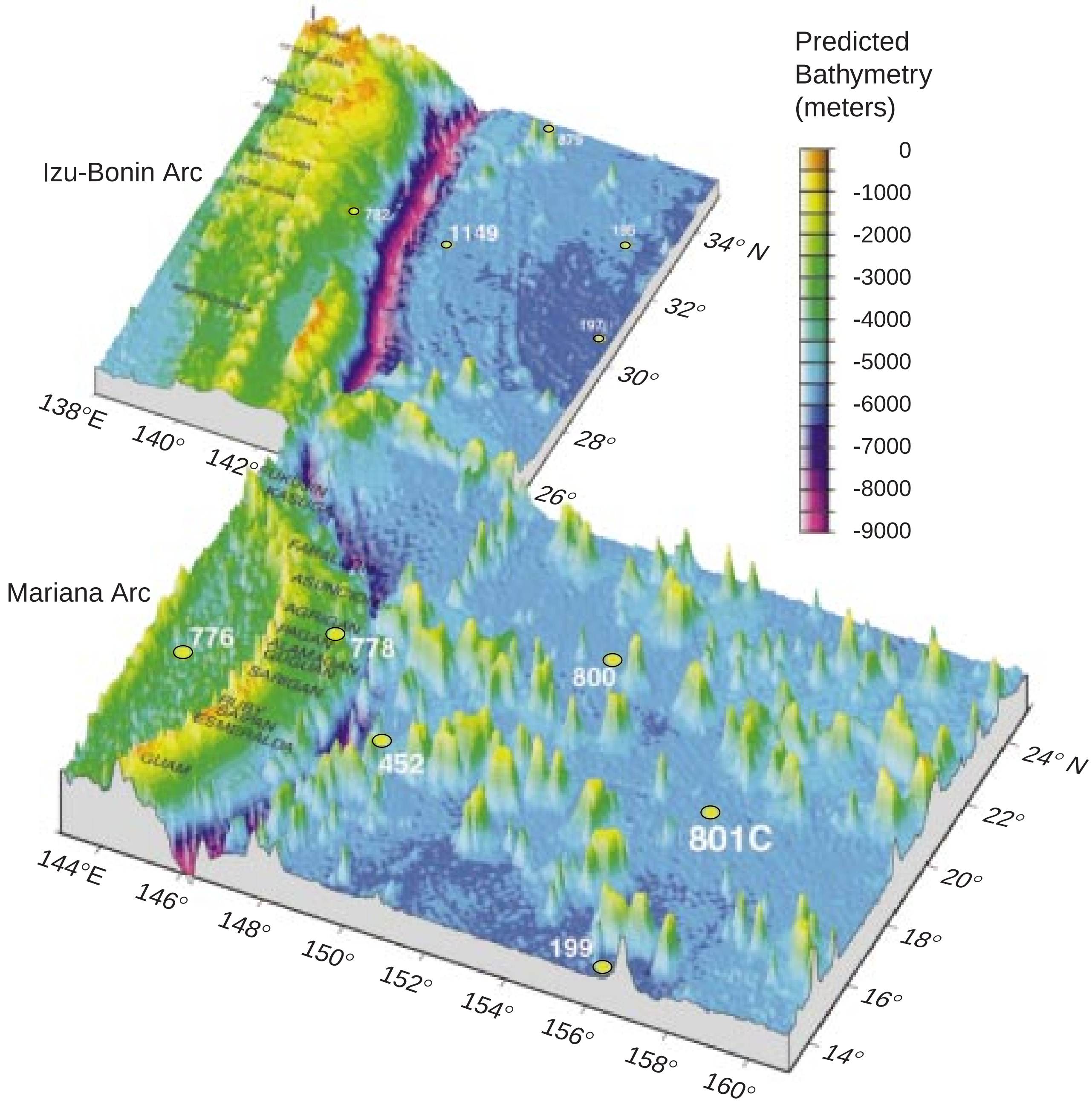

Predicted
Bathymetry
(meters)
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
Izu-Bonin Arc
Mariana Arc
1149
776
778
800
452
801C
199
138°E
140°
142°
144°E
146°
148°
150°
152°
154°
156°
158°
160°
34° N
32°
30°
28°
26°
24° N
22°
20°
18°
16°
14°
GUAM

Figure 2

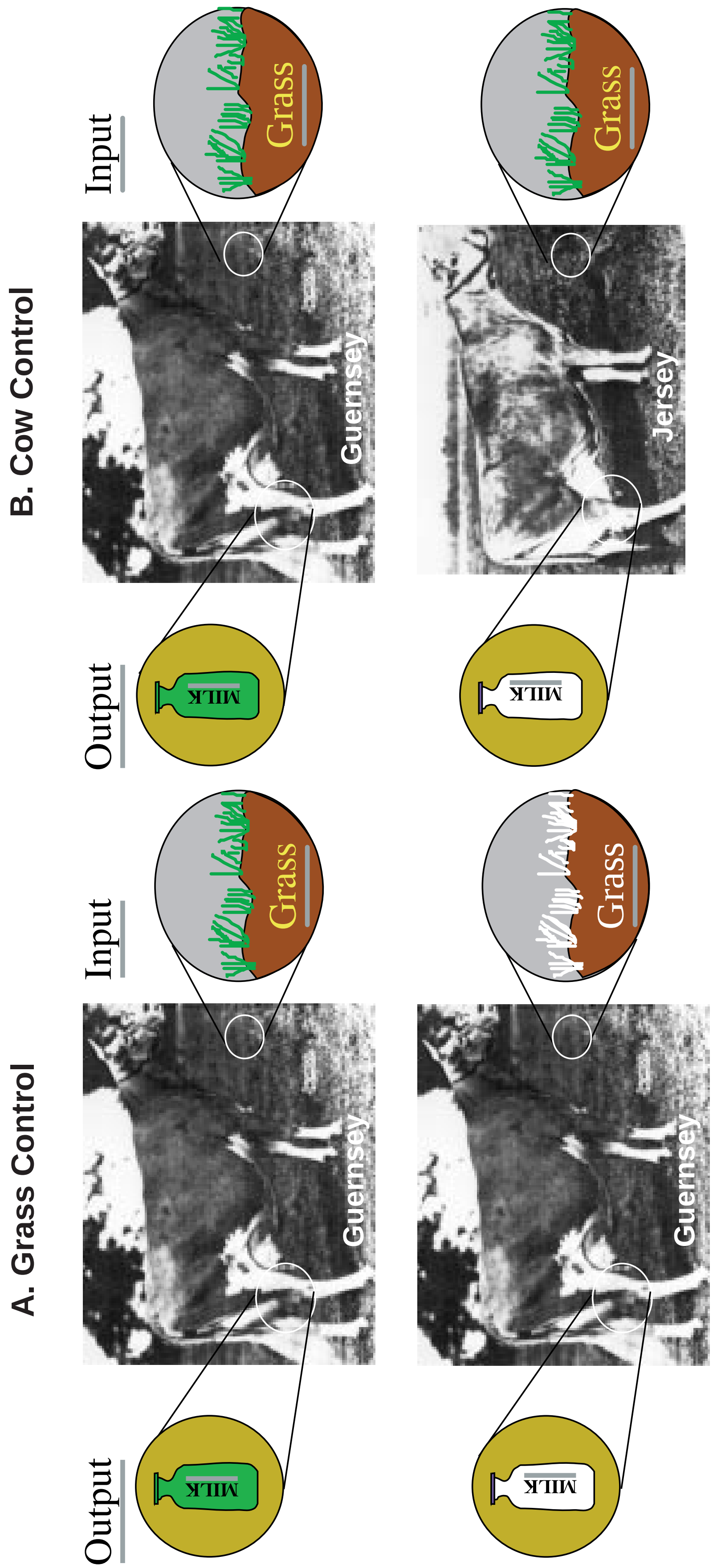

A. Grass Control
B. Cow Control
Input
Output
Grass
Guernsey
Jersey

Figure 3

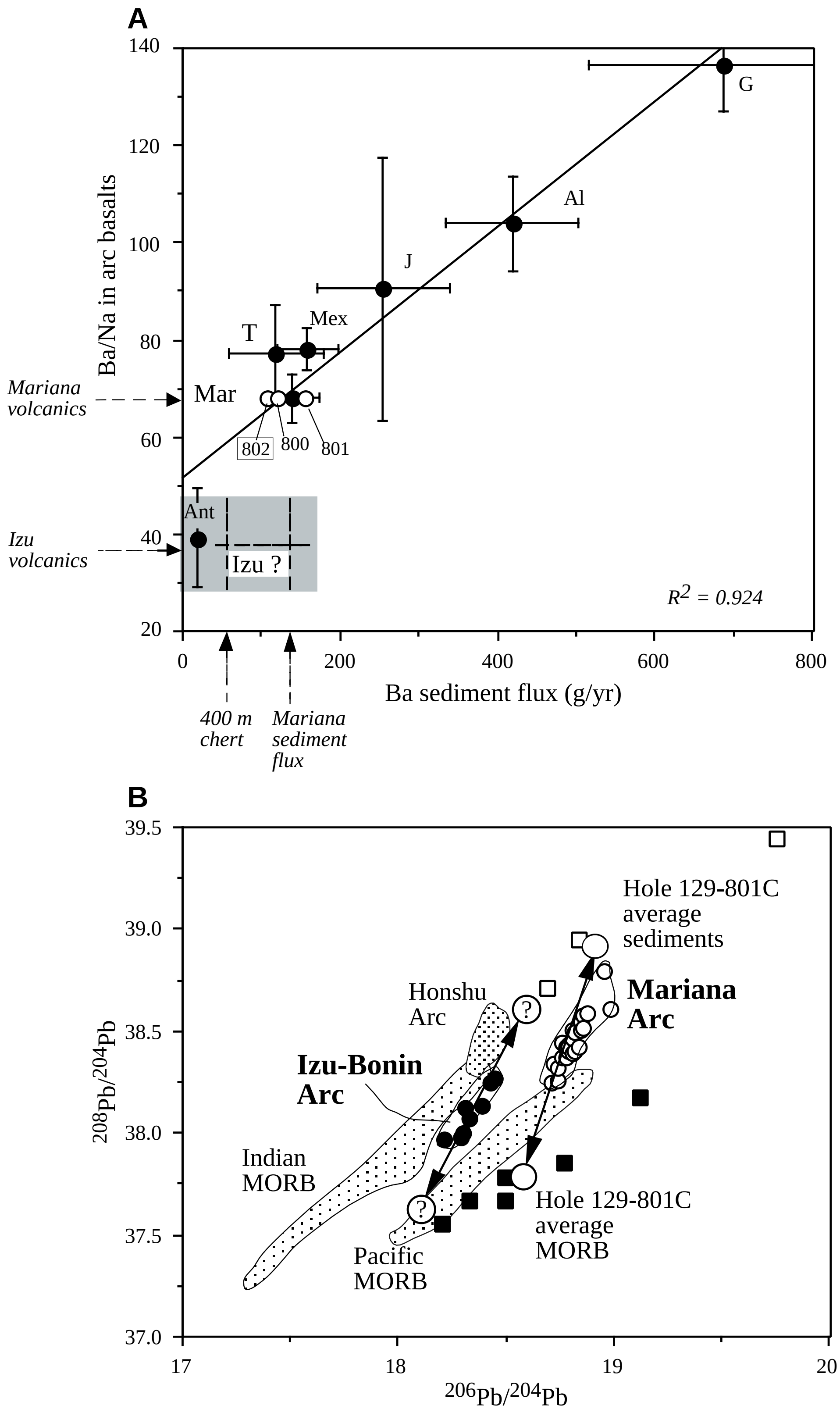

A
Ba/Na in arc basalts
Ba sediment flux (g/yr)
140
120
100
80
60
40
20
0
200
400
600
800
G
Al
J
Mex
T
Mar
802
800
801
Ant
Izu ?
$R^2 = 0.924$
Mariana volcanics
Izu volcanics
400 m chert
Mariana sediment flux
B
$^{208}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$
39.5
39.0
38.5
38.0
37.5
37.0
17
18
19
20
Hole 129-801C average sediments
Mariana Arc
Honshu Arc
Izu-Bonin Arc
Indian MORB
Pacific MORB
Hole 129-801C average MORB
?

Figure 4

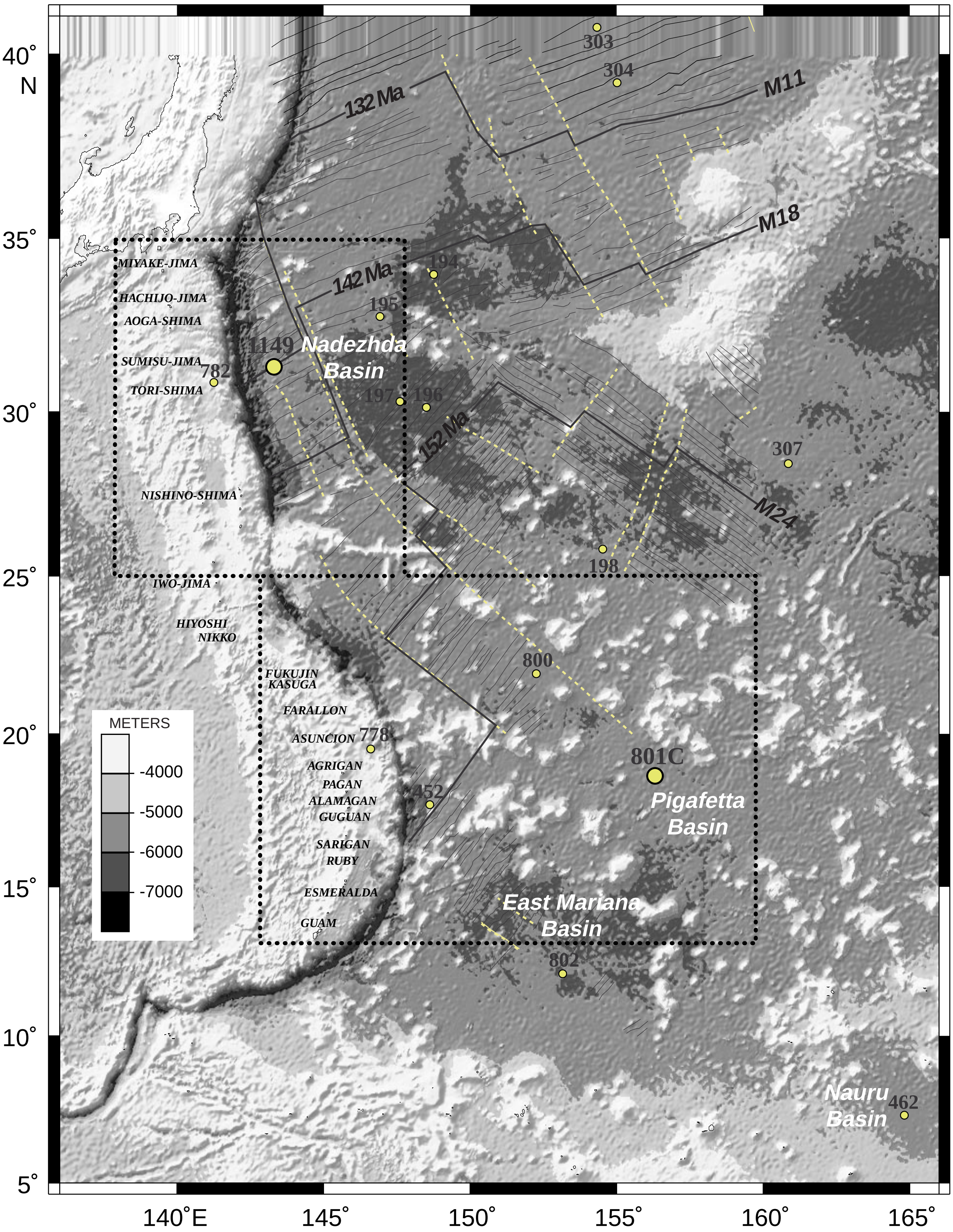
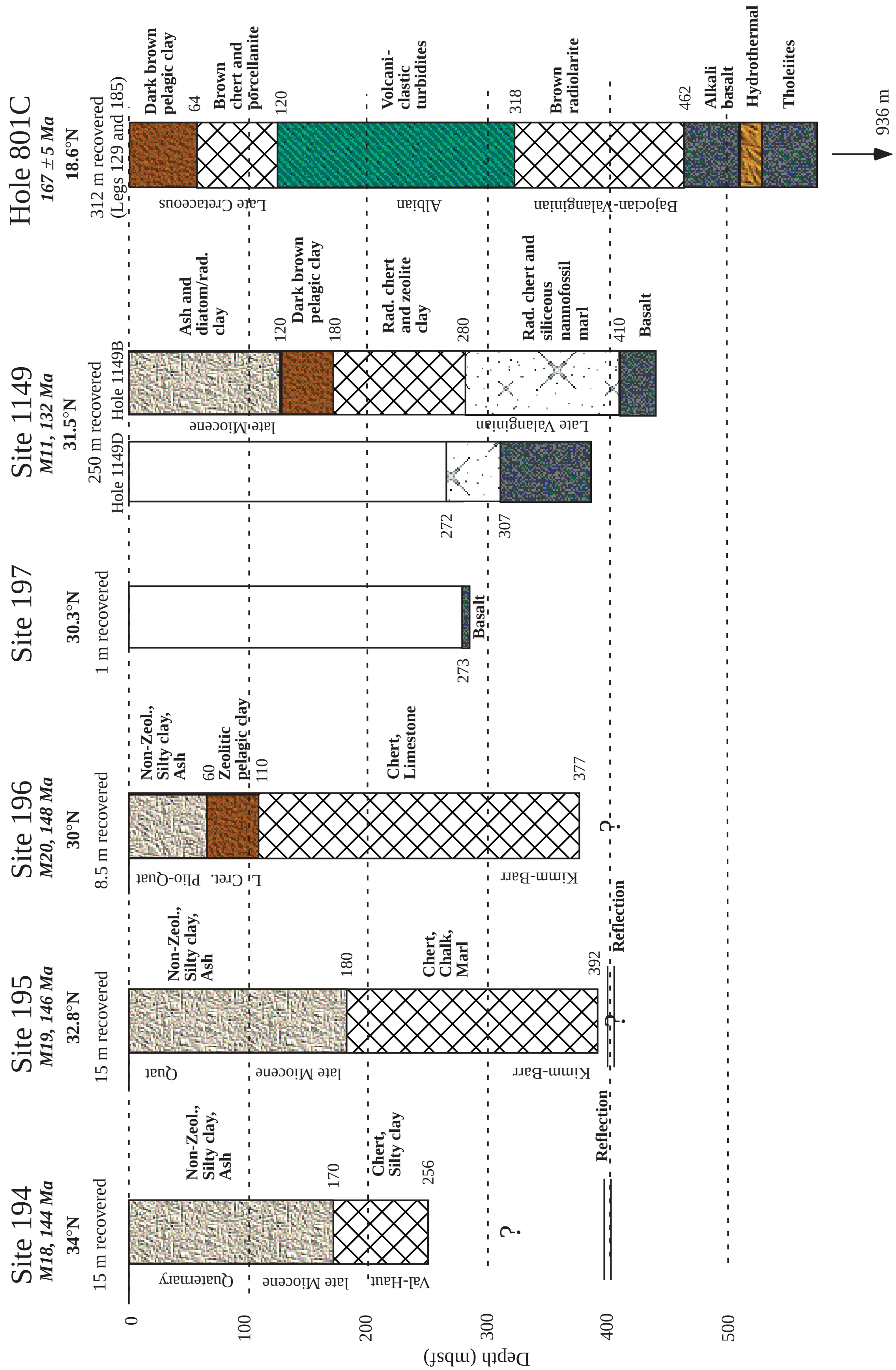

40° N
35°
30°
25°
20°
15°
10°
5°
140°E
145°
150°
155°
160°
165°
303
304
M11
132 Ma
M18
142 Ma
194
195
1149
Nadezhda Basin
782
197
196
152 Ma
307
M24
198
MIYAKE-JIMA
HACHIJO-JIMA
AOGA-SHIMA
SUMISU-JIMA
TORI-SHIMA
NISHINO-SHIMA
IWO-JIMA
HIYOSHI
NIKKO
FUKUJIN
KASUGA
FARALLON
ASUNCION
778
AGRIGAN
PAGAN
ALAMAGAN
GUGUAN
SARIGAN
RUBY
ESMERALDA
GUAM
452
800
801C
Pigafetta Basin
East Mariana Basin
802
Nauru Basin
462
METERS
-4000
-5000
-6000
-7000

Figure 5



Hole 801C
167 ± 5 Ma
18.6°N
312 m recovered
(Legs 129 and 185)
Site 1149
M11, 132 Ma
31.5°N
250 m recovered
Hole 1149B
Hole 1149D
Site 197
30.3°N
1 m recovered
Site 196
M20, 148 Ma
30°N
8.5 m recovered
Site 195
M19, 146 Ma
32.8°N
15 m recovered
Site 194
M18, 144 Ma
34°N
15 m recovered
Depth (mbsf)
Dark brown pelagic clay
Brown chert and porcellanite
Volcani-clastic turbidites
Brown radiolarite
Alkali basalt
Hydrothermal
Tholeiites
936 m
Late Cretaceous
Albian
Bajocian-Valanginian
Ash and diatom/rad. clay
Dark brown pelagic clay
Rad. chert and zeolite clay
Rad. chert and siliceous nannofossil marl
Basalt
late Miocene
Late Valanginian
Non-Zeol., Silty clay, Ash
Zeolitic pelagic clay
Chert, Limestone
Plio-Quat
L. Cret.
Kimm-Barr
Chert, Chalk, Marl
Reflection
Quat
Chert, Silty clay
Quaternary
Val-Haut,

Figure 6

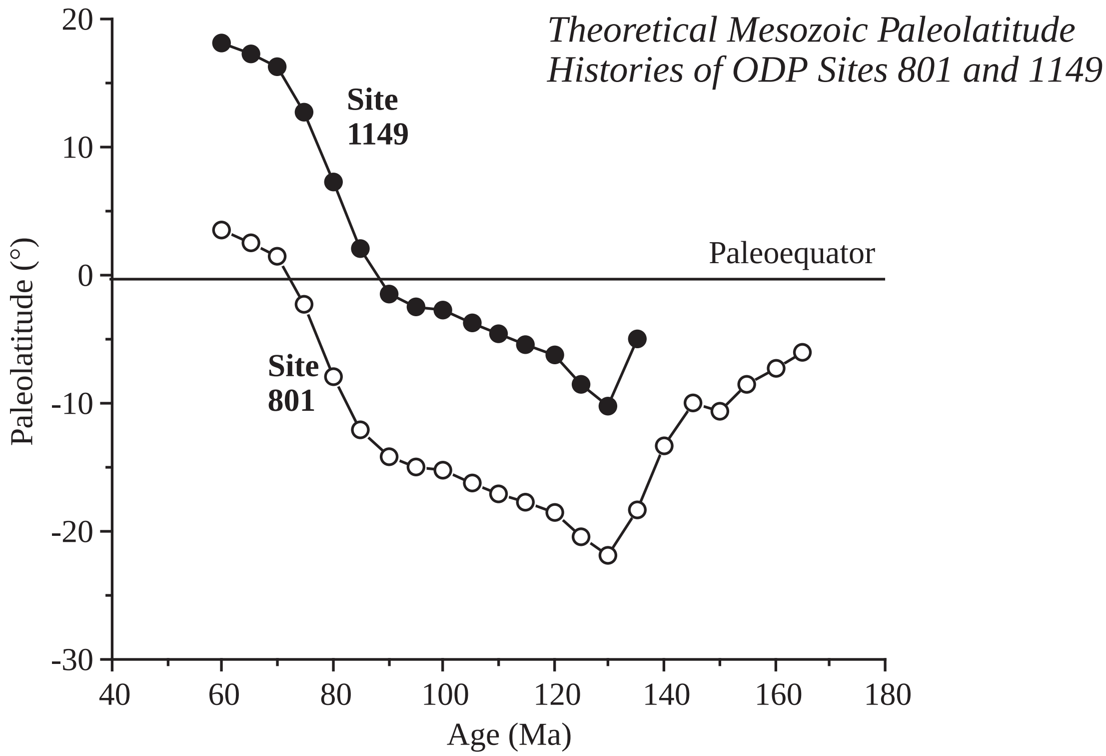

Theoretical Mesozoic Paleolatitude
Histories of ODP Sites 801 and 1149
Site
1149
Site
801
Paleoequator
Paleolatitude (°)
20
10
0
-10
-20
-30
40
60
80
100
120
140
160
180
Age (Ma)

Figure 7

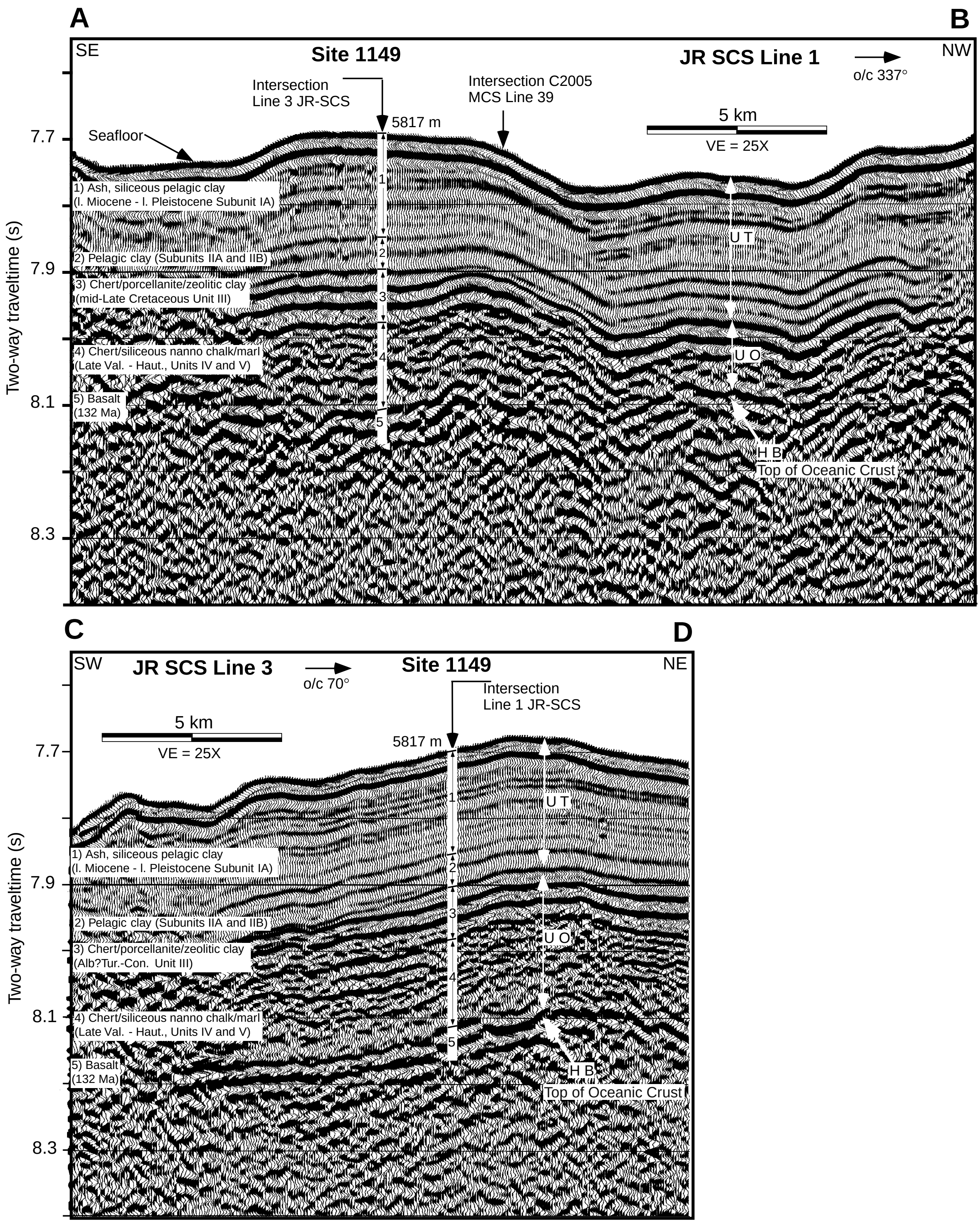

A
B
SE
Site 1149
JR SCS Line 1
NW
o/c 337°
Intersection
Line 3 JR-SCS
Intersection C2005
MCS Line 39
5817 m
5 km
VE = 25X
Seafloor
7.7
7.9
8.1
8.3
Two-way traveltime (s)
1) Ash, siliceous pelagic clay
(l. Miocene - l. Pleistocene Subunit IA)
2) Pelagic clay (Subunits IIA and IIB)
3) Chert/porcellanite/zeolitic clay
(mid-Late Cretaceous Unit III)
4) Chert/siliceous nanno chalk/marl
(Late Val. - Haut., Units IV and V)
5) Basalt
(132 Ma)
U T
U O
H B
Top of Oceanic Crust
C
D
SW
JR SCS Line 3
o/c 70°
Site 1149
NE
Intersection
Line 1 JR-SCS
5 km
VE = 25X
5817 m
1) Ash, siliceous pelagic clay
(l. Miocene - l. Pleistocene Subunit IA)
2) Pelagic clay (Subunits IIA and IIB)
3) Chert/porcellanite/zeolitic clay
(Alb?Tur.-Con. Unit III)
4) Chert/siliceous nanno chalk/marl
(Late Val. - Haut., Units IV and V)
5) Basalt
(132 Ma)
U T
U O
H B
Top of Oceanic Crust

Figure 8

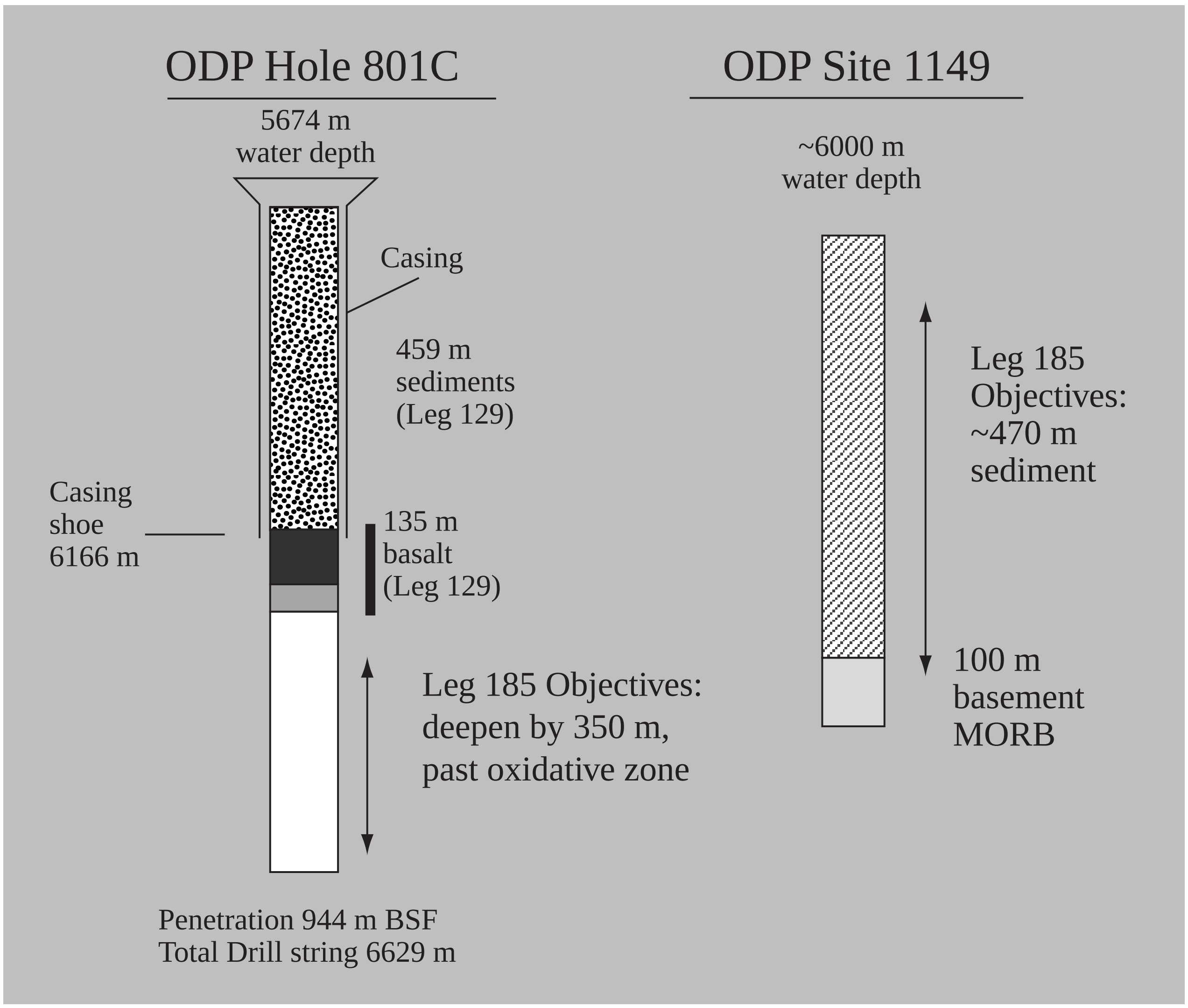

ODP Hole 801C
5674 m
water depth
Casing
459 m
sediments
(Leg 129)
Casing
shoe
6166 m
135 m
basalt
(Leg 129)
Leg 185 Objectives:
deepen by 350 m,
past oxidative zone
Penetration 944 m BSF
Total Drill string 6629 m
ODP Site 1149
~6000 m
water depth
Leg 185
Objectives:
~470 m
sediment
100 m
basement
MORB

Figure 9

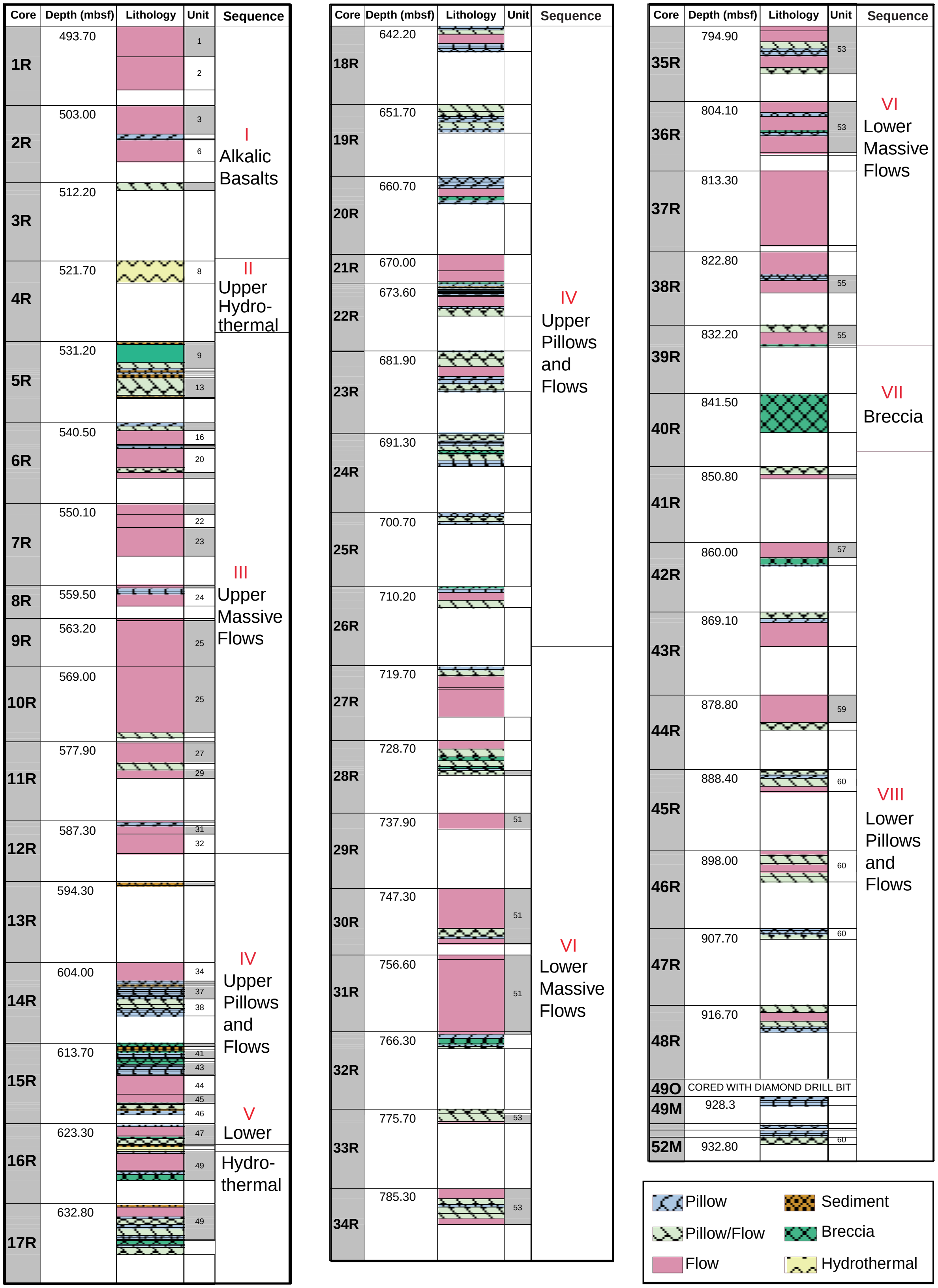

Core
Depth (mbsf)
Lithology
Unit
Sequence
1R 493.70
2R 503.00
3R 512.20
4R 521.70
5R 531.20
6R 540.50
7R 550.10
8R 559.50
9R 563.20
10R 569.00
11R 577.90
12R 587.30
13R 594.30
14R 604.00
15R 613.70
16R 623.30
17R 632.80
18R 642.20
19R 651.70
20R 660.70
21R 670.00
22R 673.60
23R 681.90
24R 691.30
25R 700.70
26R 710.20
27R 719.70
28R 728.70
29R 737.90
30R 747.30
31R 756.60
32R 766.30
33R 775.70
34R 785.30
35R 794.90
36R 804.10
37R 813.30
38R 822.80
39R 832.20
40R 841.50
41R 850.80
42R 860.00
43R 869.10
44R 878.80
45R 888.40
46R 898.00
47R 907.70
48R 916.70
49O CORED WITH DIAMOND DRILL BIT
49M 928.3
52M 932.80
I Alkalic Basalts
II Upper Hydro-thermal
III Upper Massive Flows
IV Upper Pillows and Flows
V Lower Hydro-thermal
VI Lower Massive Flows
VII Breccia
VIII Lower Pillows and Flows
Pillow
Pillow/Flow
Flow
Sediment
Breccia
Hydrothermal

Figure 10

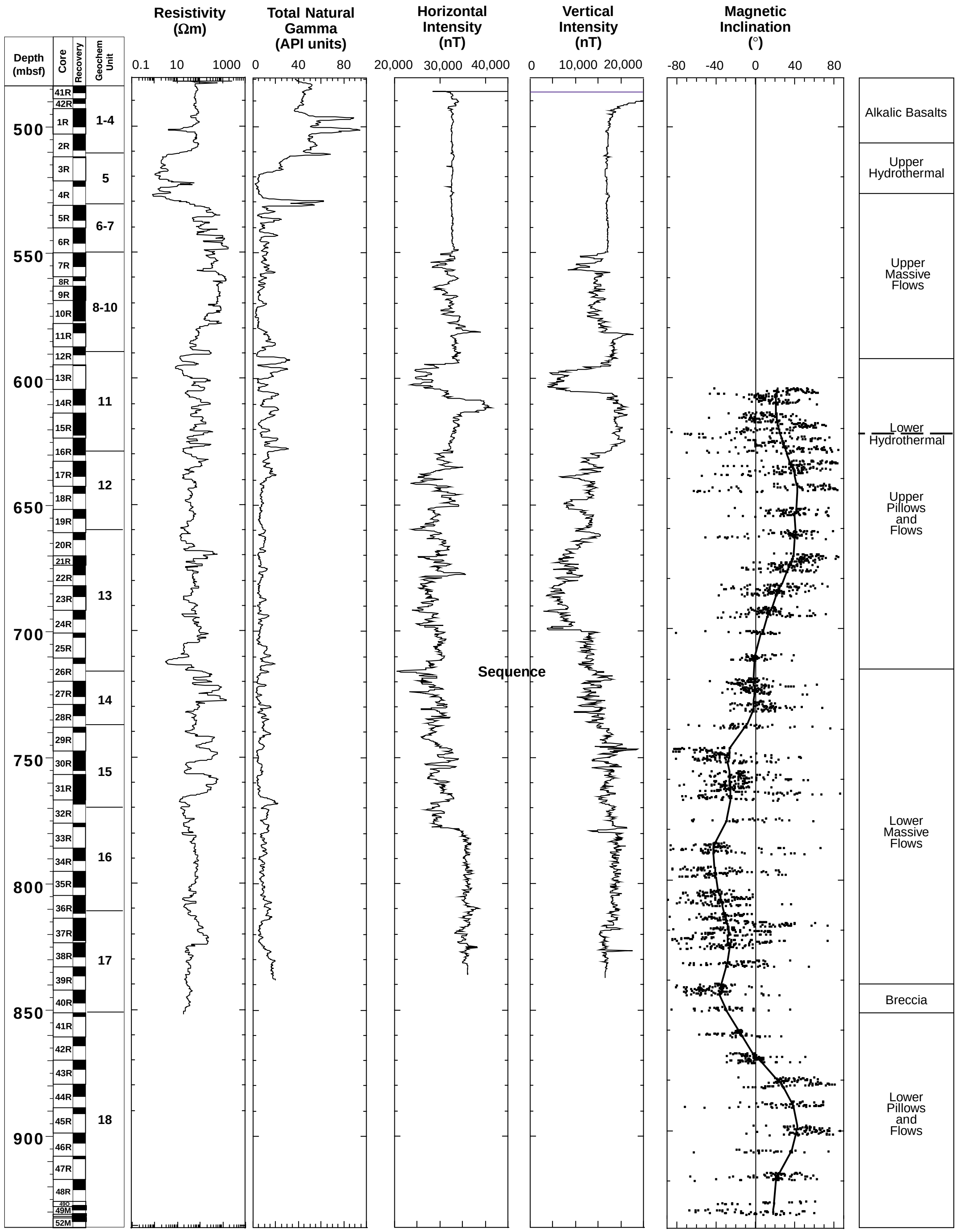

Resistivity (Ωm)
Total Natural Gamma (API units)
Horizontal Intensity (nT)
Vertical Intensity (nT)
Magnetic Inclination (°)
Depth (mbsf)
Core
Recovery
Geochem Unit
0.1 10 1000
0 40 80
20,000 30,000 40,000
0 10,000 20,000
-80 -40 0 40 80
500
550
600
650
700
750
800
850
900
1-4
5
6-7
8-10
11
12
13
14
15
16
17
18
Sequence
Alkalic Basalts
Upper Hydrothermal
Upper Massive Flows
Lower Hydrothermal
Upper Pillows and Flows
Lower Massive Flows
Breccia
Lower Pillows and Flows

Figure 11

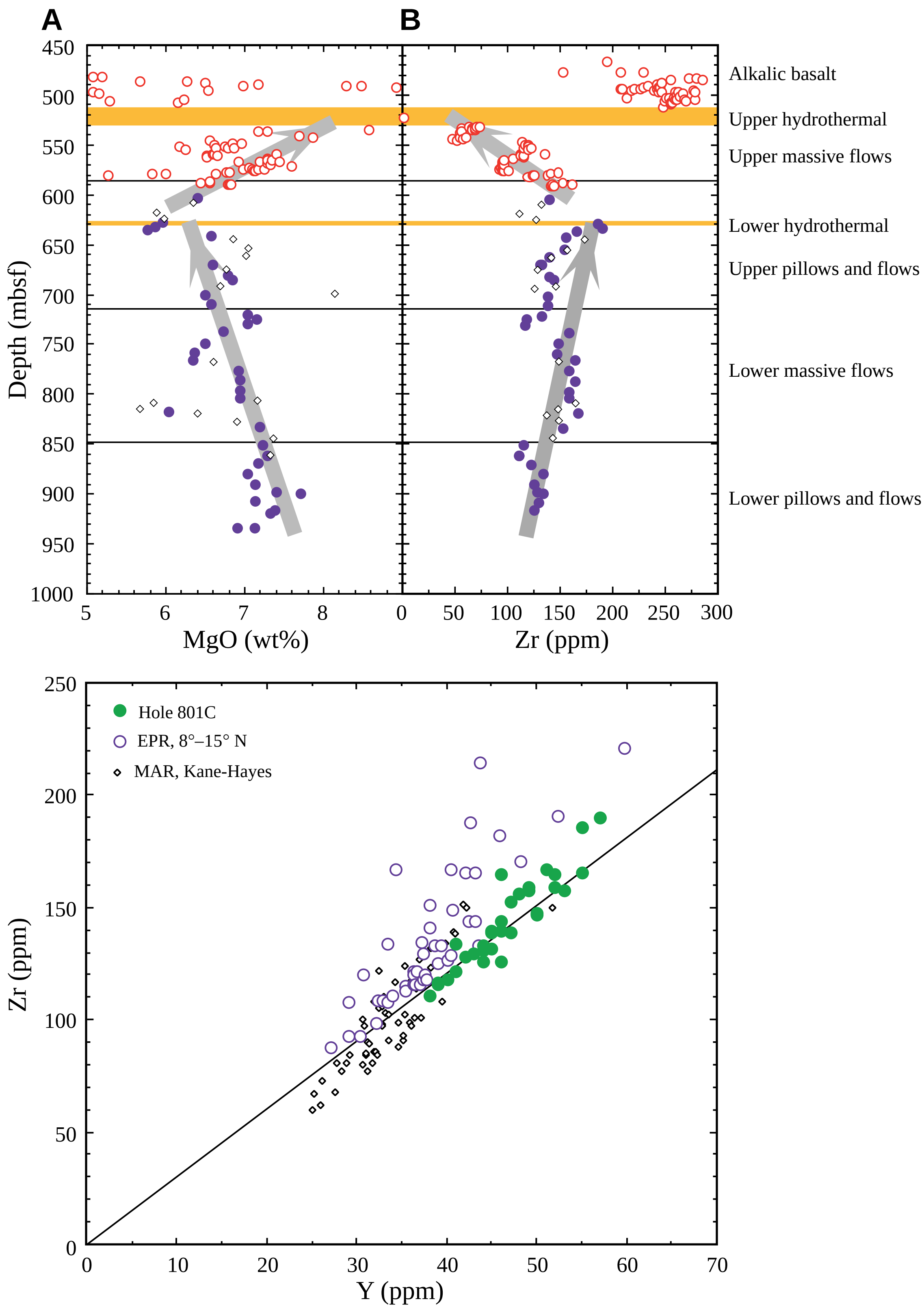

A
B
450
500
550
600
650
700
750
800
850
900
950
1000
Depth (mbsf)
5
6
7
8
MgO (wt%)
0
50
100
150
200
250
300
Zr (ppm)
Alkalic basalt
Upper hydrothermal
Upper massive flows
Lower hydrothermal
Upper pillows and flows
Lower massive flows
Lower pillows and flows
Hole 801C
EPR, 8°–15° N
MAR, Kane-Hayes
Zr (ppm)
Y (ppm)
0
10
20
30
40
50
60
70
250
200
150
100
50

Figure 12

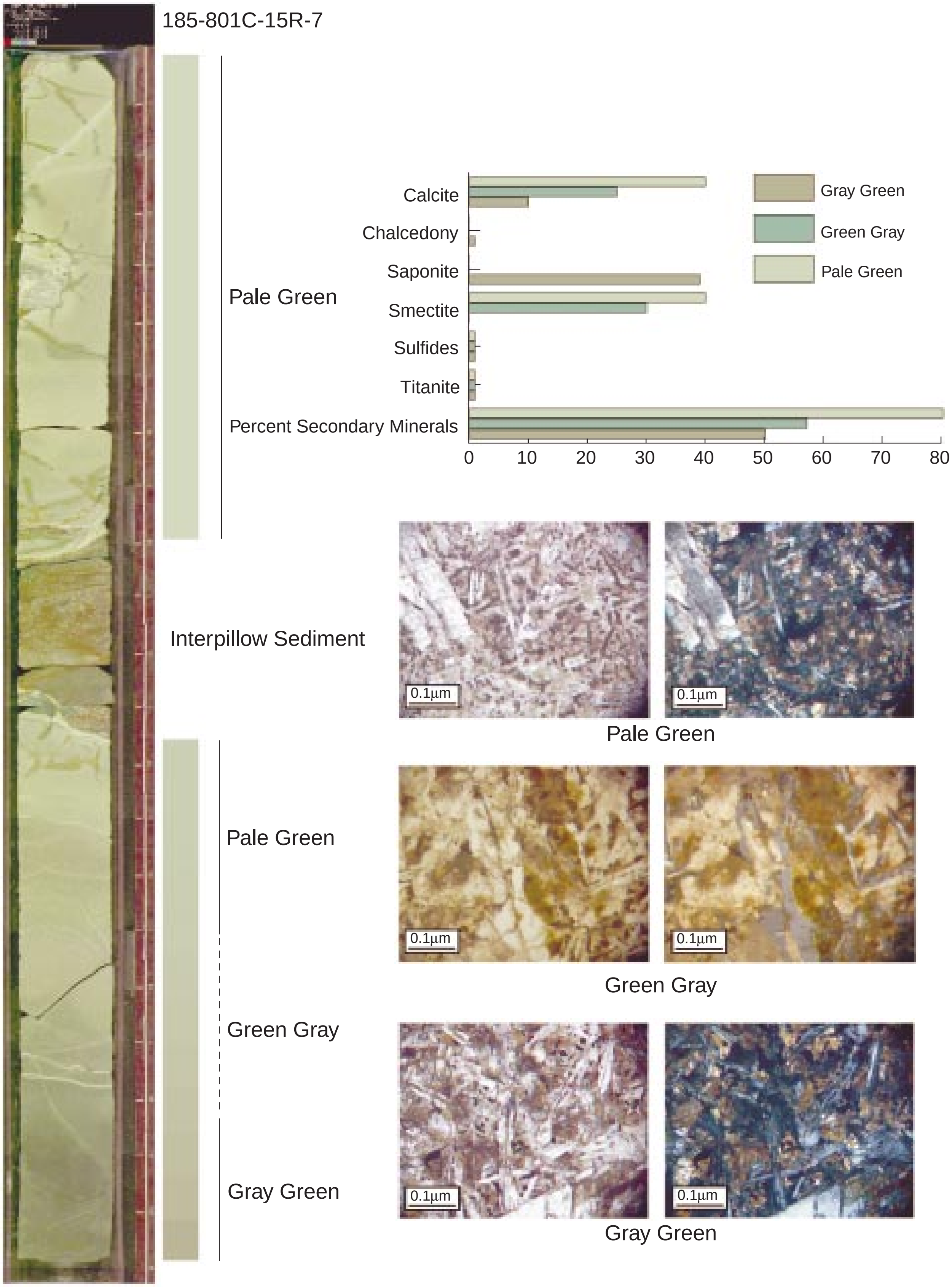

185-801C-15R-7
Pale Green
Interpillow Sediment
Pale Green
Green Gray
Gray Green
Calcite
Chalcedony
Saponite
Smectite
Sulfides
Titanite
Percent Secondary Minerals
0
10
20
30
40
50
60
70
80
Gray Green
Green Gray
Pale Green
0.1µm
Pale Green
Green Gray
Gray Green

Figure 13

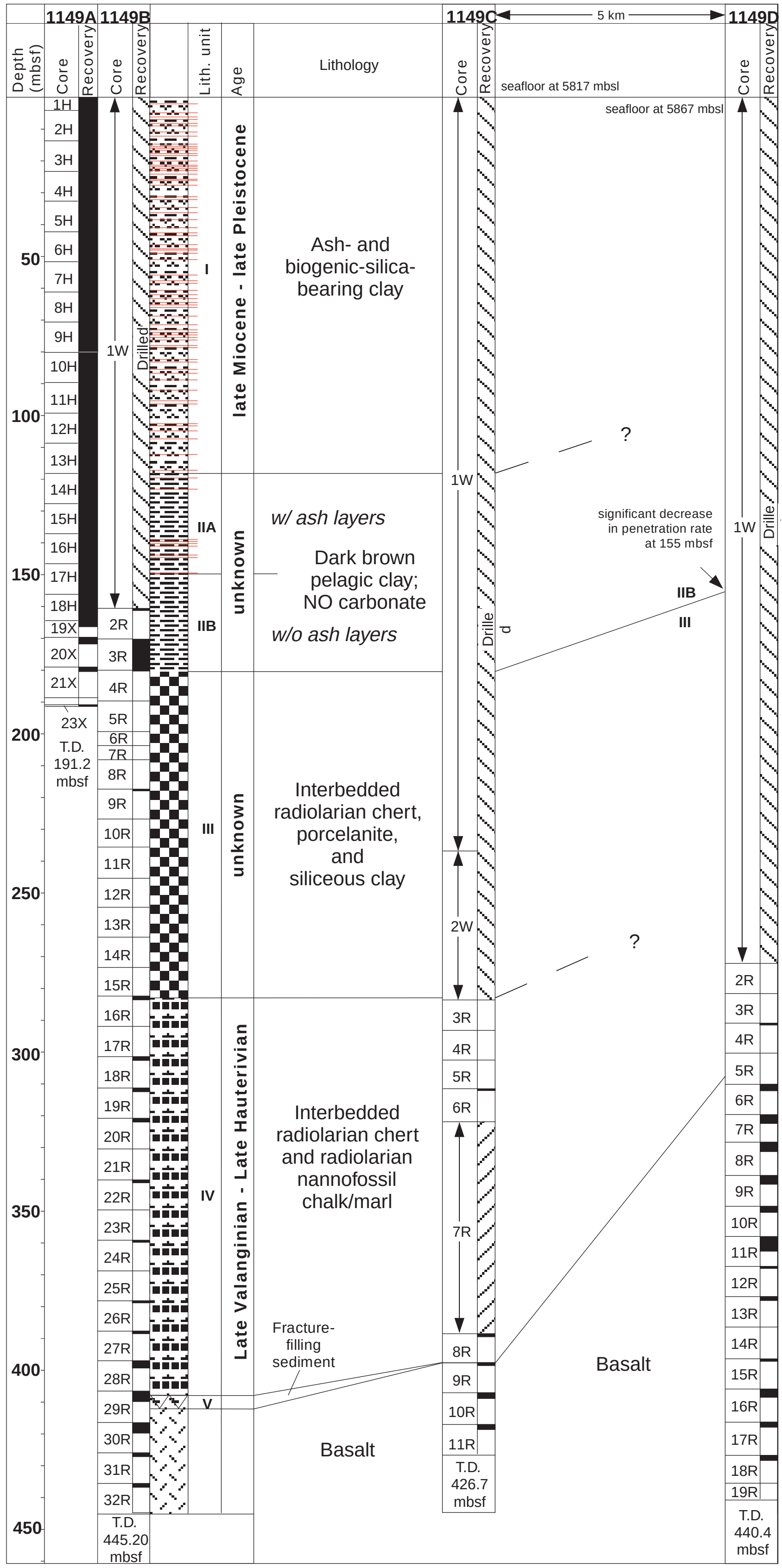

1149A
1149B
1149C
5 km
1149D
Depth (mbsf)
Core
Recovery
Lith. unit
Age
Lithology
seafloor at 5817 mbsl
seafloor at 5867 mbsl
late Miocene - late Pleistocene
Ash- and biogenic-silica-bearing clay
I
IIA
IIB
III
IV
V
unknown
w/ ash layers
Dark brown pelagic clay; NO carbonate
w/o ash layers
Interbedded radiolarian chert, porcelanite, and siliceous clay
Late Valanginian - Late Hauterivian
Interbedded radiolarian chert and radiolarian nannofossil chalk/marl
Fracture-filling sediment
Basalt
significant decrease in penetration rate at 155 mbsf
Drilled
T.D. 191.2 mbsf
T.D. 445.20 mbsf
T.D. 426.7 mbsf
T.D. 440.4 mbsf

Figure 14

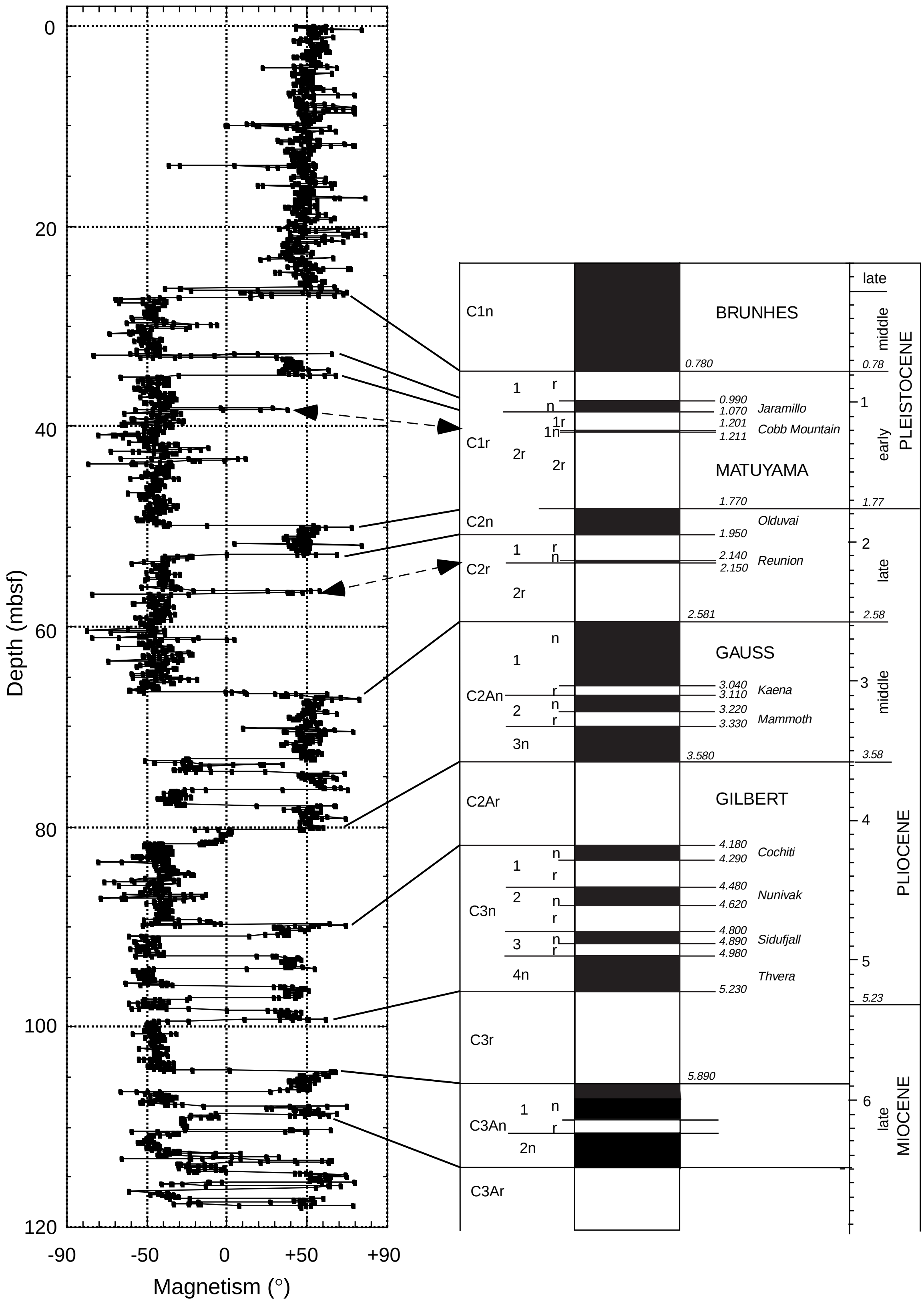

Depth (mbsf)
Magnetism (°)
0
20
40
60
80
100
120
-90
-50
0
+50
+90
C1n
C1r
C2n
C2r
C2An
C2Ar
C3n
C3r
C3An
C3Ar
BRUNHES
MATUYAMA
GAUSS
GILBERT
Jaramillo
Cobb Mountain
Olduvai
Reunion
Kaena
Mammoth
Cochiti
Nunivak
Sidufjall
Thvera
0.780
0.990
1.070
1.201
1.211
1.770
1.950
2.140
2.150
2.581
3.040
3.110
3.220
3.330
3.580
4.180
4.290
4.480
4.620
4.800
4.890
4.980
5.230
5.890
late
middle
early
PLEISTOCENE
0.78
1.77
2.58
3.58
5.23
PLIOCENE
MIOCENE

Figure 15

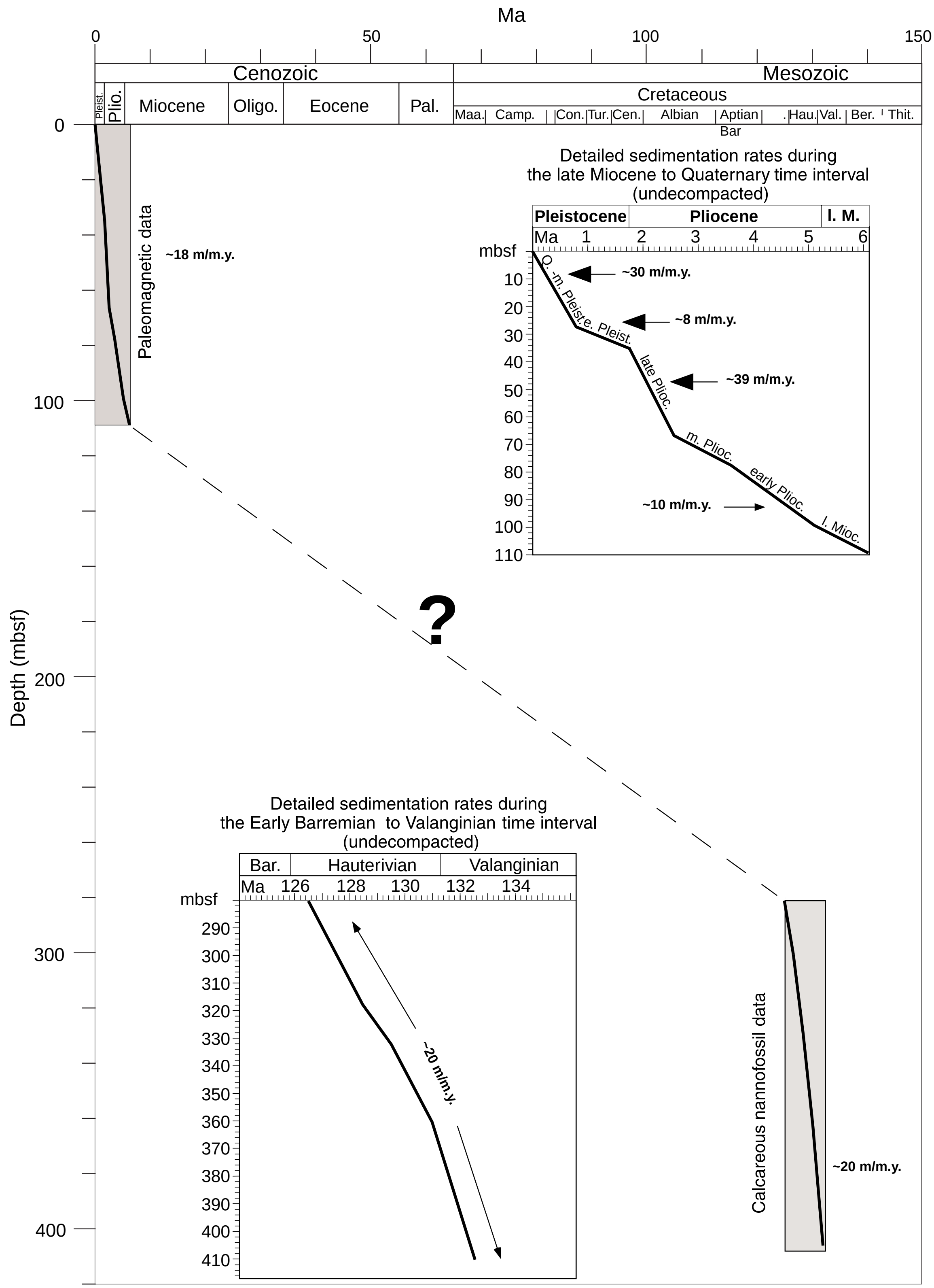

Ma
Cenozoic
Mesozoic
Pleist.
Plio.
Miocene
Oligo.
Eocene
Pal.
Cretaceous
Maa. Camp. Con. Tur. Cen. Albian Aptian Bar Hau. Val. Ber. Thit.
Depth (mbsf)
Paleomagnetic data
~18 m/m.y.
Detailed sedimentation rates during the late Miocene to Quaternary time interval (undecompacted)
Pleistocene
Pliocene
l. M.
mbsf
~30 m/m.y.
~8 m/m.y.
~39 m/m.y.
~10 m/m.y.
Q.-m. Pleist.
e. Pleist.
late Plioc.
m. Plioc.
early Plioc.
l. Mioc.
?
Detailed sedimentation rates during the Early Barremian to Valanginian time interval (undecompacted)
Bar.
Hauterivian
Valanginian
~20 m/m.y.
Calcareous nannofossil data
~20 m/m.y.

Figure 16

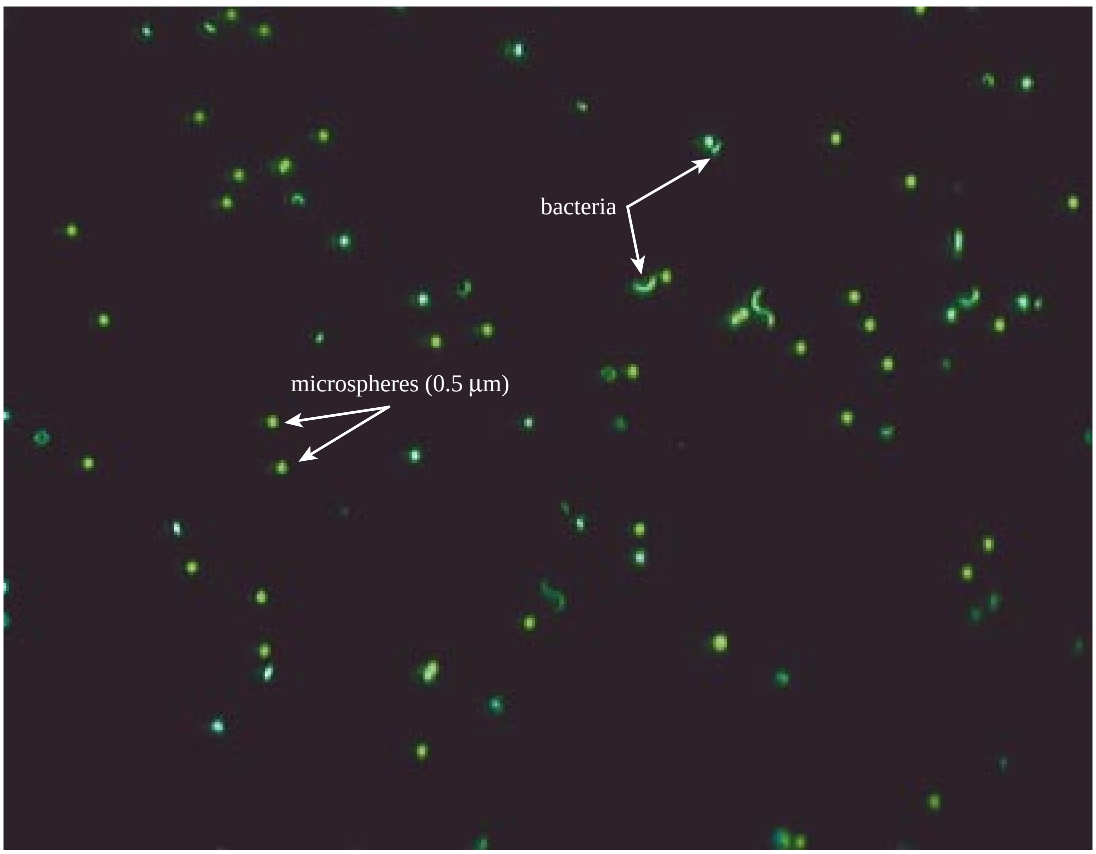
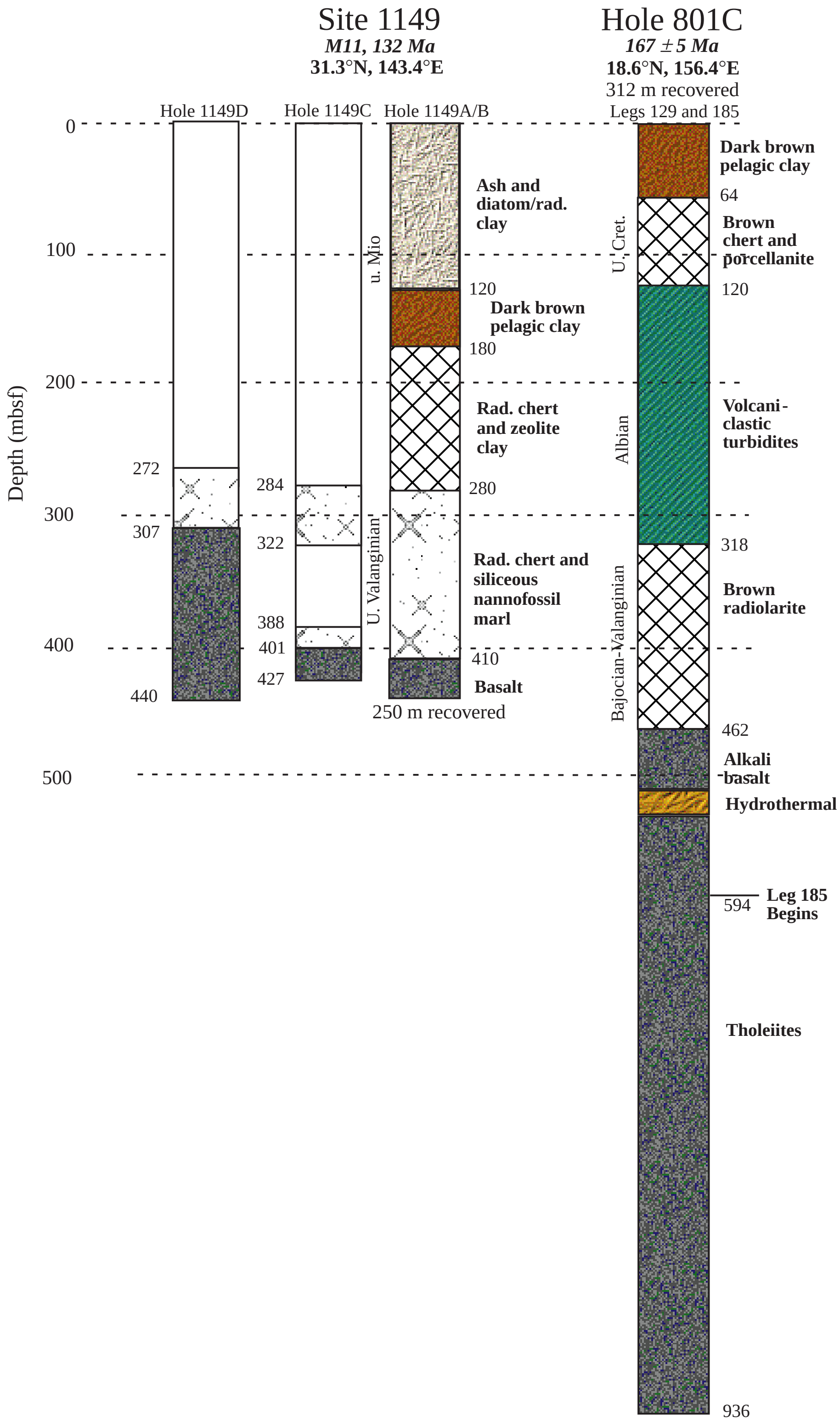


Figure 17



Site 1149
M11, 132 Ma
31.3°N, 143.4°E
Hole 801C
167 ± 5 Ma
18.6°N, 156.4°E
312 m recovered
Legs 129 and 185
Hole 1149D
Hole 1149C
Hole 1149A/B
Depth (mbsf)
0
100
200
300
400
500
272
307
440
284
322
388
401
427
120
180
280
410
Ash and diatom/rad. clay
Dark brown pelagic clay
Rad. chert and zeolite clay
Rad. chert and siliceous nannofossil marl
Basalt
250 m recovered
u. Mio
U. Valanginian
U. Cret.
Albian
Bajocian-Valanginian
Dark brown pelagic clay
64
Brown chert and porcellanite
120
Volcani-clastic turbidites
318
Brown radiolarite
462
Alkali basalt
Hydrothermal
594
Leg 185 Begins
Tholeiites
936

Figure 18

OPERATIONS SYNOPSIS[1]

SITE 801

Leg 185 began at 0835 hr on 12 April 1999 with the port call in Hong Kong. At 1005 hr on 18 April the port call ended when *JOIDES Resolution* departed the Yiu Lian terminal. The planned transit of 2400 nmi to Site 801 was accomplished in near-perfect weather and calm seas. The vessel navigated to the Global Positioning System (GPS) coordinates of Hole 801C and launched a positioning beacon at 1000 hr on 28 April. The transit had been accomplished in 235 hr (9.79 days) at an average speed of 10.5 kt.

Hole 801D

Immediately after the beacon launch, assembly of the bottom-hole assembly (BHA) began. Once the BHA and the vibration-isolated television (VIT) frame arrived at reentry depth, a quick search was made to locate the reentry cone of Hole 801C. When a strong sonar target had been determined to be the cone, the ship was positioned 100 m east of the cone in preparation for Hole 801D. A seafloor punch core had been requested for microbial studies; therefore, the top drive was picked up and water was pumped through the drill string at a high rate to clean it. A rotary core barrel (RCB) system inner core barrel then was pumped into place, and the drill string was lowered. Under TV observation, the core bit tagged the seafloor at a depth of 5685 m below driller's datum at 0710 hr on 29 April. To increase chances of recovering an adequate amount of the soft sediment, the bit was pushed as far as possible (19.3 m) into the seafloor. The bit then was pulled clear of the seafloor, and the inner core barrel was retrieved by wireline. About 9.4 m of soft mud was recovered when the core barrel was laid out, ending Hole 801D at 0830 hr. Because an interval greater than the length of a core barrel had been penetrated, the recovery was designated a "wash core" (1W).

Hole 801C

As soon as the top drive had been rigged down, the bit was repositioned for reentry. About 45 min of maneuvering were required to coax the drill string over the reentry cone. Hole 801C was reentered at 1015 hr on 29 April.

The bit then was lowered into the open hole to 468 mbsf. A water sample from the undisturbed borehole had been requested for microbial studies, and the top drive was again picked up in preparation for a sampling run with the water-sampling temperature probe (WSTP). The bit was lowered without circulation to 490 mbsf, the WSTP was landed at the bit, and time

[1]The Operations and Engineering personnel aboard the *JOIDES Resolution* during Leg 185 were ODP Operations Manager Glenn Foss and Schlumberger Engineer Steve Kittredge.

was allowed for the preset timer to open the sampling valve. Upon recovery of the WSTP, however, no sample had been collected. A second WSTP attempt then was made with the bit lowered to 540 mbsf, just below a known interval of unstable hole. A good water sample was obtained, and the pipe trip continued with the top drive deployed and a RCB inner core barrel in place.

An obstruction, or "bridge" that had stopped logging tools in this hole during Leg 144 was encountered by the drill string at 546 mbsf. The obstruction was cleared easily with rotation and circulation, but the effect of "pushing something down the hole" was noted. Rubbly fill was encountered ~3 m off the recorded total depth. The fill was washed to total depth at 594.3 mbsf, where torque and rough running indicated the presence of loose rocks on the bottom of the hole. After a few minutes, the rocks were broken up and the coring of Core 13R began.

Continuous RCB coring then proceeded under ideal weather and motion conditions for 3 days. The first two cores were cut at a rate of penetration (ROP) of ~2.0 m/hr. The ROP increased slightly on each core because of increasingly fractured rocks with an accompanying downtrend in recovery from excellent to low (i.e., from 89% in Core 15R to 32% in Core 20R). Anomalous drilling parameters on Core 21R (i.e., an abrupt decrease in ROP accompanied by increased drill string torque and slightly low circulating pressure readings), and over 36 rotating hr on the bit were considered sufficient reason to trip the drill string for a bit change. Average recovery for the 79.3 m cored with Bit No. 1 was 52%. At 2230 hr on 2 May, the core bit arrived on deck and was found to be in excellent condition, with bearing seals still effective and only a few broken tungsten carbide inserts.

Reentry scanning began at noon on 3 May after pipe tripping with Bit No. 2. Maneuvering for reentry consumed a frustrating 5 hr, primarily because of the subdued response of the long drill string to changes in the ship's position. Reentry was made at 1700 hr, and the bit was run into the hole without incident. Coring of Core 22R began at 2200 hr on 3 May. Core recovery and ROP were quite variable, but there was a trend toward more massive rock units with depth with resultant higher recovery and lower penetration rates. Weather and hole conditions remained good, and 83 m of new hole was made before the bit was tripped on the basis of its 47.7 rotating hr. Core recovery for the interval was 44%.

A third bit was installed, and the drill string was tripped back toward the seafloor. After 7 hr lost to repairs of the cable head of the VIT and subsequent problems with flooding of the short oil-filled cable that connects the coaxial cable head to the telemetry pod of the VIT, maneuvering for reentry began at 0200 hr on 8 May. Again the inhibited response of the long drill string to ship movement slowed the operation. At 0538 hr, a successful reentry stab was made. The trip into the hole was uneventful except that 14 m of soft fill was found. It was removed without difficulty, and coring recommenced at 1030 hr, 8 May. Core recovery and ROP were quite variable, with both the highest (i.e., 1–2 m/hr) and lowest (i.e., 3.3 m/hr) penetration rates to date encountered within the interval. Coring continued without incident through Core 42R at 869.1 mbsf. At that depth the bit had accrued 50 rotating hr, and the trip began for the fourth RCB bit.

Bit No. 3 cored 112.5 m at an average ROP of 2.2 m/hr and with average core recovery of 53.5%.

A fourth RCB bit was tripped to the seafloor, and the swinging of the pipe was less troublesome with reentry accomplished in only 24 min of maneuvering time. Coring resumed at 869.1 mbsf at 0100 hr on 13 May. The first four cores were in altered pillow basalt units and produced relatively low recovery at fairly high penetration rates. On the next two cores, penetration slowed in fractured flow units, but recovery did not improve correspondingly. The bit run cored 57.1 m with an average ROP of 2.1 m/hr and an average recovery rate of 34.9%. To divide the remaining site operating time between logging operations and coring with the diamond core barrel (DCB) system, coring was stopped with only 27.3 rotating hr on Bit No. 4.

Diamond Core Barrel System Test

Two additional days had been allocated to Leg 185 for testing the DCB system. A 7¼-in diamond core bit with "carbonado" stones was selected for coring basalts. The drill string and VIT were run to reentry depth, and another quick reentry of ~10 min was achieved. Because over 90 m of hole fill had been encountered by the logging operation, considerable caution was used on the return to total depth. The hole then was cleaned out to firm resistance, which was felt at 928.3 mbsf, 2.1 m deeper than the bottom of the previous core. The discrepancy was interpreted to be because of a difference in pipe stretch caused by the 40,000 lb difference in BHA weight between the two strings.

Coring with the diamond core bit deepened the hole by 7.4 m in 20.5 hr, and core recovery averaged 42% in hard, fractured basalt. Although the DCB cut slowly through the basalt, the recovered core appeared to contain more delicate features, such as complete interpillow hyaloclastites and abundant veins, than is typical for RCB core.

After the test was concluded, the drill string and the original acoustic beacon were recovered without incident. The 6¾-in drill collars were returned to the drill collar racks, the rig was secured for sea, and *JOIDES Resolution* departed Site 801 at 1330 hr on 19 May.

SITE 1149

Site 1149 (see Fig. 2), the second drill site of Leg 185 was located just east of the Bonin Trench, ~1040 nmi northwest of Site 801 and 300 nmi south-southeast of Japan's Boso Peninsula. Site 1149 was tentatively located on an east-west reference profile (*Conrad* 2005, Line 39) but a site survey was required to determine the best location for the site. *JOIDES Resolution* approached the *Conrad* reference seismic line from the southeast, slowed to 6 kt, and streamed seismic gear ~12 nmi before crossing the reference line. The survey continued until a location with favorable basement characteristics was found. After a triangular seismic survey pattern was completed, the profiling gear was recovered and the ship returned to the GPS coordinates of the site. A positioning beacon was launched at 1500 hr on 23 May. The transit from Site 801 to Site 1149, including the 7-hr seismic survey was accomplished in 4.05 days, at an average speed of 11.4 kt.

Hole 1149A

Hole 1149A was spudded with a "mudline" core at 0200 hr on 24 May. The core barrel contained 4.2 m of core, which was interpreted as the seafloor interface, fixing the seafloor depth at 5829.3 m from driller's datum. Continuous advanced piston cores (APC) cores were taken with >100% recovery to 164 mbsf, when an abrupt increase in the stiffness of the sediment resulted in an incomplete APC stroke on Core 18H.

APC cores were oriented in azimuth beginning with Core 4H. Temperature recording shoes were also run on Cores 4H, 6H, and 8H, and the Lamont-Doherty Earth Observatory (LDEO) drill string acceleration tool (DSA) was run on Cores 2H and 10H. Tracer experiments, to determine potential core contamination for microbiology studies, were carried out by fixing a bag of fluorescent microbeads into the core catchers of Cores 3H, 6H, 9H, and 12H, and by pumping perfluorocarbon tracer into the drilling fluid on Cores 6H, 9H, and 11H.

The APC system was replaced by the extended core barrel (XCB), which cored 24.3 m (i.e., Cores 19X–21X) with an average recovery of 21% in stiff clay with interbedded porcellanite. After 2.2 m penetration when cutting Core 22X, the XCB encountered a hard streak that halted penetration.

Further progress with the XCB system was highly unlikely because of the inability to penetrate the chert or porcellanite horizon. The situation had been anticipated, and the plan called for using the motor-driven core barrel (MDCB) system to attempt to core the chert layers. Although conditions were not favorable for the MDCB because of the presence of steel and tungsten carbide junk in the hole from the XCB shoe, it was nevertheless decided to attempt a MDCB core as a "last chance" to core the chert with an alternative system before tripping for the RCB system. When the MDCB was recovered, the corehead was noted to have all the diamonds worn off the crown and to show signs of junk damage. The core barrel also showed grooving from junk. When the core catcher was removed, only 30 cm of chert and clay debris from the hole was found in the split and collapsed plastic liner. There was no indication that any core had been cut or that any new hole had been made by the corer.

Coring attempts in Hole 1149A were abandoned at that point, because there appeared to be no remaining alternatives to tripping for an RCB coring assembly. The MDCB system was rigged down, the top drive was racked, and the pipe trip began. Hole 1149A ended at 0725 hr on 26 May, when the bit arrived on deck.

Hole 1149B

Hole 1149B was 30 m northwest of Hole 1149A. No seafloor core was planned, so the water depth was assumed to be the same as at Hole 1149A. The new hole was spudded at 2000 hr on

26 May and drilled ahead to core point at 161 mbsf in 3.5 hr. The "wash barrel" then was retrieved, which contained ~3.5 m of cored material and drilling rubble.

Continuous RCB coring then commenced. At ~190 mbsf, interbedded chert caused core recovery to drop sharply, and drilling conditions deteriorated. Up to 4 m of fill accumulated between cores, causing high torque, and the bit hammered on the chert ledges when the motion compensator was locked out. Only chert "rollers" were recovered in the core barrels, with traces of soft brown clay, probably representing a large portion of the unrecovered material. At ~261 mbsf, the ROP slowed considerably and hole conditions improved markedly with depth. Recovered cores contained representative quantities of calcareous interbedded material with interbedded chert. Only a small amount of fill was present by the time basaltic basement was encountered at 410 mbsf while drilling Core 29R. Average core recovery in the cherty interval from 190 to 410 mbsf was only ~6%. Although it had penetrated >200 m of cherty sediments, the core bit had accrued only 21 rotating hr when it reached basement. The condition of the cutting structure was unknown, but the plan for the hole called for running the bit to "destruction." Penetration of the highly altered basalt continued at >2 m/hr through Core 32R with a recovery rate of ~20%. At the time the core barrel for Core 33R had been dropped, however, without warning the drill string became partially stuck. Indications were that chert or basalt fragments were wedging the BHA, either at the top or at the bit. The string could be moved up or down in irregular intervals before it would torque up and bind vertically. A mud pill was circulated while the string was worked free, and the inner core barrel landed during the process. Eventually three "knobby" joints were removed from the string as the bit was pulled upward. When the bit passed the approximate depth of the sediment/basalt contact, the resistance ceased. A joint of drill pipe then was added to the drill string, but circulation was nearly plugged off when the pump was restarted. Because the inner barrel had held the float valve open while the pipe was being freed, cuttings had been able to flow back into the jets of the bit. It was then necessary to make a wireline trip to retrieve the inner barrel and regain normal circulation. A total of 4½ hr was spent on the consecutive hole problems.

Although additional basement penetration was planned, the highest remaining scientific priority of Leg 185 was a good set of logs of the sediment section at Site 1149. The onset of difficulties with the hole was a reminder that coring to bit destruction could result in loss of the hole and the opportunity for logs. Because there was ~35 m of "rathole" for the logs to record the base of the sediment section, plans were changed to terminate coring in Hole 1149B and proceed with logging operations. When logging operations were completed at 0900 hr on 2 June, the drill string was tripped, and Hole 1149B was completed when the mechanical bit release top connector arrived on deck at 2000 hr on 2 June.

Hole 1149C

Hole 1149C was spudded at 0820 hr on 3 June and was drilled without coring to 283.6 mbsf. Two "wash" core barrels were pulled at 237 and 283.6 mbsf as a precaution because of the accumulation of loose chert fragments in Hole 1149B. After the wash core barrel at 283.6 mbsf was retrieved, preparations began for retrieving four spot cores requested by the science party. A short trip back to 188 mbsf to replace the "knobby" drilling joints was slowed by the torquing and sticking of the drill string. Although a considerable amount of soft fill was found in the hole, the string was free as it returned to total depth, and coring began.

Mud was circulated while the first core (3R) was being cut, but torquing and sticking tendencies returned during the wireline trip to retrieve it. It was necessary to "work" the pipe for 3½ hr and to pull back to 245 mbsf before Core 4R could be cut to 303 mbsf and retrieved. Almost immediately after the barrel for Core 5R was dropped, the drill string began to torque and stick again. While the string was being worked up the hole with restricted circulation, the inner barrel landed, opening the float valve. When the next joint of pipe was removed from the string, backflow plugged the pipe. Rotation and vertical movement were possible, so the bit was pulled to 235 mbsf before a wireline trip was made to retrieve the inner barrel and re-establish normal circulation.

The cause of the hole cleaning problems was believed to be the interval of dark brown clay with lower porosity and shear strength between 140 and 155 mbsf that had stopped logging tools in Hole 1149B. Therefore, a "wiper trip" was made to 130 mbsf to ream out any clay restriction. No resistance was noted in either direction until the bit returned to ~235 mbsf, where a solid ledge was encountered. Several other ledges were noted as the top drive was used to clean the hole back to total depth, and ~4 m of fill were found on bottom. After the inner barrel was pumped into place, Cores 5R and 6R were cut and retrieved without incident, but the combined recovery was only 78 cm of chert and chalk core pieces.

With a wash barrel in place, the hole was drilled ahead to 388 mbsf, the next requested core point to sample the sediment/basement interface. Because of the history of hole problems, the knobby joints were laid out and a precautionary short trip was made back up to 130 mbsf, above the unstable clay zone. No resistance registered on the weight indicator, but the top drive was picked up to ream through the clay zone and to clean the hole back to total depth with circulation and rotation. The hole was clean, with only 3 m of soft fill, but an additional 50 bbl of mud were pumped to sweep out any debris. Core 8R then was cut with all parameters normal, and 1 m of chert/chalk core was recovered.

Before the inner barrel was dropped before cutting of Core 9R, the pipe began to torque and stick. Additional working of the pipe resulted in more sticking. For 4 hr, various circulation rates, amounts of overpull, and stuck-pipe techniques were tried. Success was slowly achieved by "drilling up" or backreaming with tension just short of the amount that would produce stalling of the top drive. Progress up the hole of about 1 m/hr was achieved with that technique. Circulation had been held to moderate rates to avoid excessive hole erosion, but a desperation move involving use of both mud pumps at 90 strokes per minute (spm) produced enough improvement in the backreaming progress that a joint of pipe could be removed. The pipe was set on the elevators with 80 kips overpull to break out the joint. When it was reconnected to the top drive and lifted off the elevators, it was free. The string then was pulled to ~60 m off total depth with no resistance and run back to bottom, where ~4 m of fill were found. The cause of the sticking was believed to be gravel-sized chert fragments that had settled around the BHA.

Hard basement drilling was encountered 2 m into drilling Core 9R (at 401 mbsf), allowing a higher coring circulation rate to be used for the remainder of the core. The pattern of stuck pipe following core retrieval continued after both Cores 9R and 10R, with average core recovery of only ~15%. It became apparent that chronic sticking problems were leading to excessively slow recovery of material and that continuing to operate in Hole 1149C eventually would result in loss of the hole and the BHA. While Core 11R was being cut, a decision to relocate had been made, and the trip out of the hole began as soon as the core had been recovered. The bit arrived on deck at 0215 hr on 7 June. The vessel got under way at 0300 hr, ending Hole 1149C.

Hole 1149D

The 3.5-kHz echosounder was used to refine the desired offset position on a nearby basement high. A new beacon was dropped at 0515 hr on 7 June ~3.1 nmi east-southeast of Hole 1149A, and Hole 1149D was spudded at 1530 the same day. Hole 1149D was drilled to basement without coring and without pulling the “wash barrel.”

Drilling parameters indicated chert stringers beginning at ~155 mbsf. No hole problems were encountered except for an incident of sticking during the rereaming of the interval to 263 mbsf. At 272 mbsf, a “wash” core barrel was pulled to initiate continuous coring in anticipation of encountering basement. Three consecutive cores then produced a combined total of 1.2 m of chert fragments. Basement was encountered at 307 mbsf while coring Core 5R. During coring of Hole 1149D, some problems were encountered with sticking and torquing of the pipe, which caused some delays. However, coring continued until through Core 19R, when the time allotted for coring had expired. Hole 1149D was deepened to a total depth of 6319.4 m (440.4 mbsf). Departure from Site 1149 was at 1615 hr on 13 June.